# Final Report

## Millennium Science Complex

University Park, PA


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## Executive Summary

The Millenium Science Complex is a four story, 275,600 square foot, LEED Gold Certified laboratory and office facility for the Life and Material Sciences on The Pennsylvania State University, University Park campus. Located on the eastern end of campus, the Millennium Science Complex is the focus of the Integrated Project Delivery / Building Information Modeling Thesis (IPD / BIM Thesis). The building will house research facilities for the Material Science and Life Science departments. This report includes the final design alternatives completed by Building Stimulus design team during the Spring 2011 Semester. Each alternative presented was done to utilize an integrated project delivery method and building information modeling approach as applicable.

Building Stimulus focused the design alternatives to achieve an overall team goal of improving the efficiency and performance of the building while still maintaining the architectural integrity that the architect, Raphael Vinoly intended for its contribution to the University Park Campus. In order to accomplish this overall goal, three areas of concentration were identified.

The main focus for the design team in order to improve the efficiency of the building's performance involved redesigning the façade of the Millennium Science Complex. This allowed an extensive implementation of integrated project development as this component affected each discipline. A double skin façade was designed to allow for enhanced thermal performance and daylighting control for the perimeter spaces of Millennium Science. After several iterative processes, this design was implemented on two of the building's faces. Not only were the glazing and solar louver systems reconceived, but also the panel design associated with façade. The current precast panels were redesigned to decrease the structural load on the building and to accommodate the twenty-four inch air gap provided for the double skin.

Through the use of BIM processes and Revit MEP, enhanced accuracy in terms of modeling the building's energy performance was also achieved. By modeling the mechanical and electrical components, the original energy model developed in the fall semester was revised to account for accurate plug loads designated in the laboratory spaces to obtain a more realistic energy profile. In order to facilitate the energy performance, lighting designs were created to efficiently meet IESNA design criteria and ASHRAE 90.1 lighting power densities. Lighting designs were also incorporated with the mechanical system through the implementation of chilled beams in the office spaces to reduce energy consumption.

The final area of concentration for Building Stimulus lied with the most iconic portion of the building, the large cantilever. At the cantilever is where the two wings of the building, Life Science and Material Science, join to merge the two research facilities. The truss system of the cantilever was modified by introducing an additional column to each truss, decreasing the unsupported length of the cantilever by 22 feet. The web and chord members were also redesigned to be optimized for strength and deflection, resulting in a savings of 76 tons of steel. Underneath the cantilever, a new lighting design for the existing plaza was created to enhance the iconic stature of the cantilever.

# Building Overview

## Building Statistics

### Architecture

The Millennium Science Complex is a 4-story LEED-Certified laboratory facility housing Life Sciences and Materials Sciences on The Pennsylvania State University, University Park campus. Located on the eastern end of campus at the corner of E. Pollack and Bigler Rd, the Millennium Science Complex is an L-shaped building with stepping cantilevers and expansive green roofs. Stepping green roofs allow for minimal intrusion on pedestrian areas while concentrating the heart of the building away from the street, maximizing green space. Designed by Rafael Viñoly Architects the building was designed with continuous horizontal glazing along each floor creating a plethora of natural light.

The building is composed of two wings joined with a 150-ft cantilever that stretches out over an open air public plaza. The cantilever allows for the addition of necessary isolated research laboratories to be located beneath the plaza without transferring vibrations through structural members. Over the plaza the wings of the building join at the 3rd and 4th floor to create the L-shaped research facility. The 3rd floor is composed of open meeting areas and lounge space, whereas the 4th floor is dedicated entirely as mechanical space. Rafael Viñoly Architects have created a unique state of the art facility that compliments Penn State's faculty while providing the tools for research in the field of life and materials sciences.

### Construction Background

The Millennium Science Complex is a multi-use research facility found on the Northeastern region of Penn State University's University Park campus. Located on the corner of Bigler Road and Pollock Road, the facility sits in one of the most densely populated regions of campus. The structure is also located on the direct route between East Hall dormitories and Pollock dormitories in one of the most highly trafficked pedestrian walkways on campus. Buildings directly adjacent to the Millennium Science Complex include the Penn State Medical Center, Eisenhower Parking Deck, Life Sciences Building, and Thomas Building.

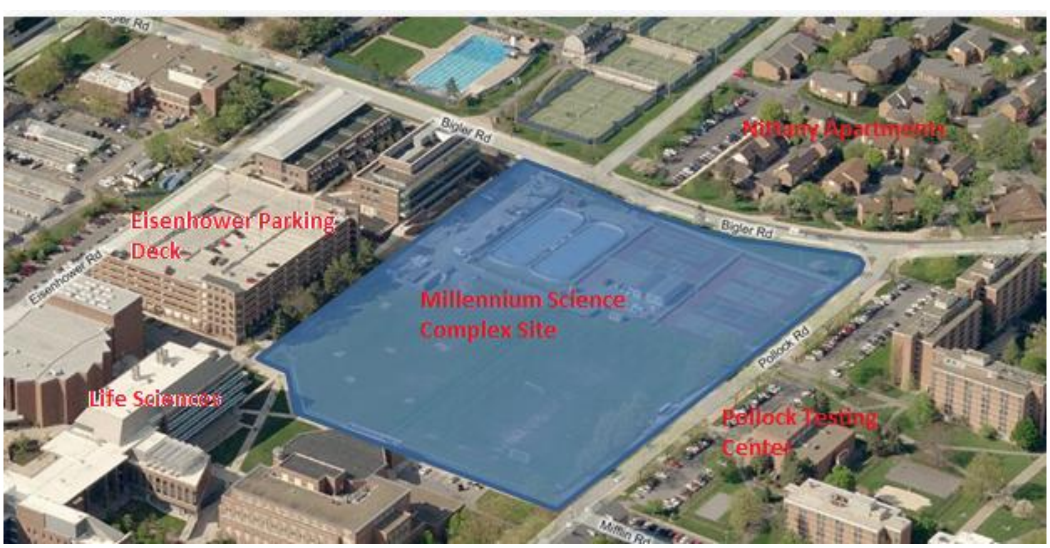



Figure 1: Site of Millennium Science Complex

As seen in Figure 1, the original site of the Millennium Science Complex was occupied by multiple tennis courts, roller hockey rinks, as well as a small parking region. The open grass region was frequently used for intramural sports and leisure activities.

Construction in such a location introduces a plethora of logistic and safety issues. Bigler Road and Pollack Road are subject to high vehicular traffic during early afternoon and evening hours, including a CATABUS Stop servicing community routes, as well as the Blue and White Campus Loops. High volume traffic caused delivery complications of large items such as structural steel, precast panels, and various pieces of equipment utilized on the project. Delivery of oversized items, such as those previously mentioned, was delivered during early morning hours via University Drive. Turning onto Hastings drive from University Drive will lead into Bigler Road and the Bigler Road site access gate.

Additional pedestrian safety concerns primarily focus on the construction of the Life Sciences wing cantilever which reaches over pedestrian walkways, as well as a portion of Pollock Road. Temporary fencing was applied to the perimeter of the site, as well as shutting down of portions of Pollock Road during crane picks and architectural precast panel installation

Whiting-Turner developed a two phase site logistics plan for the construction of the Millennium Science Complex. Phase one, seen in Figure 2, planned the use of the site from site preparation through the completion of the foundation. Phase two, seen in Figure 3, was used from steel erection through the completion of interior finishes.

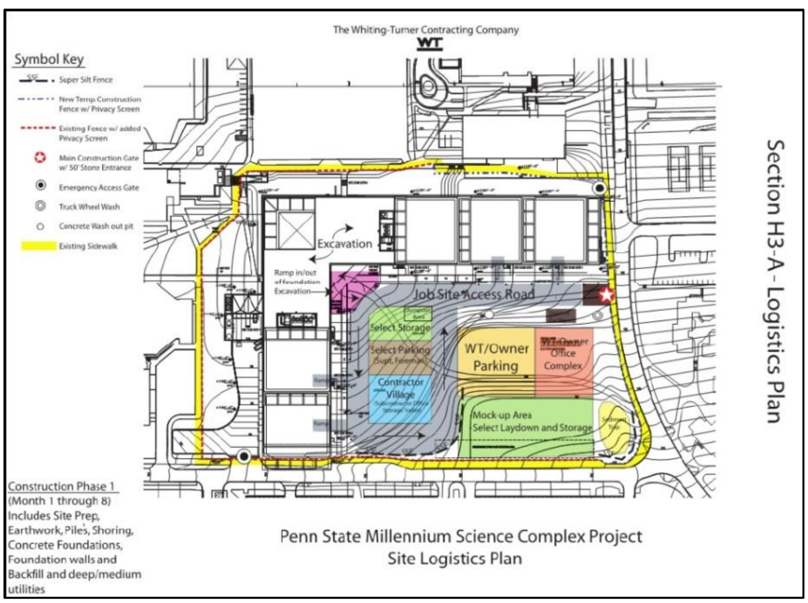



Figure 2: Phase One Site Logistics Plan.

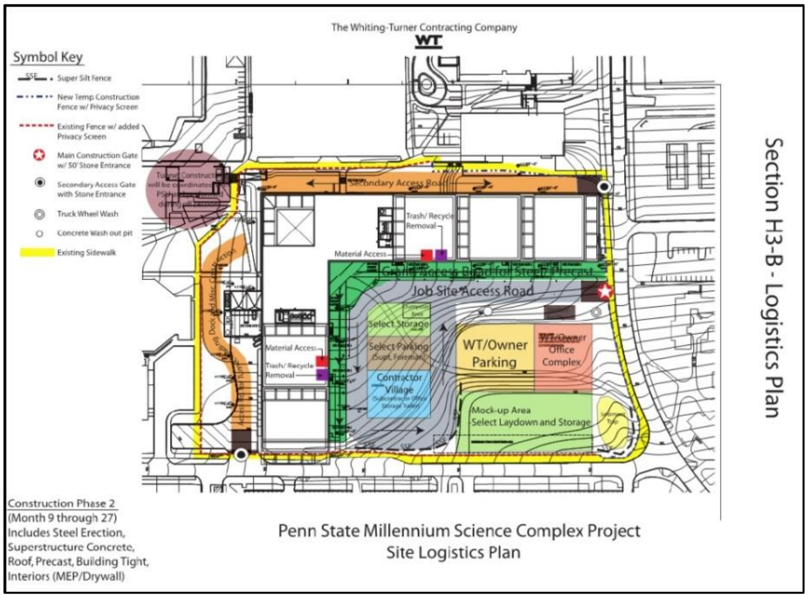



**Figure 3: Phase Two Site Logistics Plan.**

## Project Schedule

The schedule provided represents a summary of significant phases of construction for the Millennium Science Complex. The full detailed schedule of existing activities is provided in Appendix D: Construction Management. Below are the key durations and milestones to be utilized during general conditions estimates of schedule impacts from various analyses.

**Table 1: Schedule Durations and Milestones.**

| Phase | Start | Finish | Duration (Days) | Work Weeks |
|---|---|---|---|---|
| **Foundation/Substructure** | 2/16/2009 | 2/26/2010 | 270 | 54 |
| **Super Structure** | 7/7/2009 | 7/23/2010 | 274 | 54.8 |
| **Concrete** | 8/18/2009 | 5/28/2010 | 204 | 40.8 |
| **Enclosure** | 11/9/2009 | 1/5/2011 | 303 | 60.6 |
| **Mechanical** | 3/29/2010 | 11/12/2010 | 165 | 33 |
| **Electrical** | 2/12/2010 | 11/30/2010 | 208 | 41.6 |
| **Interior Finishes** | 9/9/2010 | 3/22/2011 | 139 | 27.8 |
| **Construction** | 8/12/2008 | 7/7/2011 | 758 | 151.6 |

## Project Delivery Type

As with most of Penn State University's projects, the Millennium Science Complex is primarily a Design-Bid-Build delivery type. The project also utilizes a form of Construction Management Agency and Fee with Whiting-Turner Contracting Company. Much of the funding for the Millennium Science Complex is backed by the Department of General Services (DGS). DGS funding is public funding which, by law, requires that Penn State University directly hold contracts with the construction service provider. DGS funding is typically allocated to early activities in case state budgets determine that funding be reduced or removed. Therefore, Penn State University holds the contracts to much of the early upfront activities in which Whiting-Turner Construction oversees, manages, and coordinates as a Construction management Agent to Penn State University. For the remaining work, Whiting-Turner performs work for a fee. While they do not self-perform their own work, Whiting-Turner monitors and manages the work of their subcontractors. See Appendix D: Construction Management

## Project Cost Evaluation

Actual cost estimations of the Millennium Science Complex are difficult to produce considering the complexities of the facility, namely the research technology and ever-changing finishes within the building. Below are the best estimations of Millennium Science Complex's overall cost and cost per square foot.

**Table 2: Total Building Cost.**

| Total Cost | Total Cost Per Square Foot |
|---|---|
| **$215,000,000** | $788/SF |

**Table 3: Total Construction Cost.**

| Construction Cost* | Construction Cost Per Square Foot |
|---|---|
| **$139,176,843** | $510/SF |

***Construction Cost does not include contingency, general conditions, insurance and fees.**

**Table 4: Building System Cost.**

| Building System | Percentage of Project Cost | Cost | Cost Per Square Foot |
|---|---|---|---|
| **Structure** | 17.6% | $24,559,974 | $90.06/SF |
| **Plumbing** | 4.8% | $6,731,107 | $24.68/SF |
| **Enclosure** | 11.8% | $16,459,873 | $60.36/SF |
| **Interior Finishes** | 6.8% | $9,540,237 | $34.98/SF |
| **Excavation and Foundation** | 11.9% | $16,644,502 | $61.04/SF |
| **Special Requirements** | 8.9% | $12,404,386 | $45.49/SF |
| **HVAC** | 18.1% | $25,159,105 | $92.26/SF |
| **Electrical** | 8.9% | $12,313,658 | $45.15/SF |

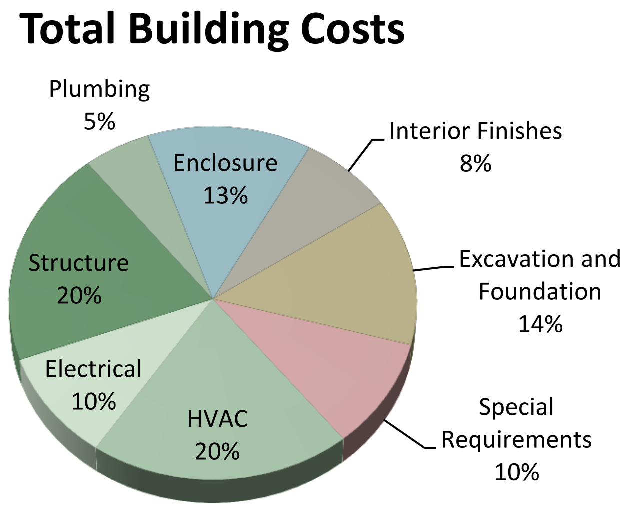



**Figure 4: Total Building Costs by Type.**

Millennium Science Complex is a state-of-the-art facility, incorporating many of the Material and Life Sciences most advanced and complex research equipment. Accompanied with the facility's complex structure and cantilever, the Millennium Science Complex is considered incomparable to any seemingly relevant building type. Due to the limitations of D4Cost Estimations as well as RS Means Square Foot Estimates, no direct estimates can be made. However, using RS Means Square Foot estimates, comparisons can be made to visualize the complexity of the Millennium Science Complex. Below are square foot estimates of similar size facilities of building types that are present in the Millennium Science Complex. Listed as well are recently constructed buildings on the University Park Campus, as well as the recently constructed New York Times building in New York City due its large scale and significant complexity.

**Table 5: Building Cost Comparisons.**

| Building Type | Cost | Cost Per Square Foot |
|---|---|---|
| Office Building | $47,772,500 | $183.74/SF |
| Hospital | $77,436,500 | $224.46/SF |
| College Laboratory | $15,325,000 | $144.85/SF |
| The New York Times Building | $1 billion | $667.00/SF |
| The New Dickinson School of Law * | $60,000,000 | $530.97/SF |
| Life Sciences Building* | $37,790,085 | $245.39/SF |
| Student Health Center* | $26,000,000 | $406.25/SF |
| (*) denotes PSU Infrastructure | | |

## Building Envelope

A complex pre-cast panel system comprises the majority of the Complex's building enclosure. Each of the 338 precast pieces were fabricated in York, PA and trucked to the site. The exterior is clad in "Penn State" brick with bands of recessed dark-fired brick adhered to 6" of concrete. This panel is backed by 4" of rigid insulation and a vapor barrier. Each 22' panel is mechanically attached to the exterior column structure by a threaded rod and gusset plate system. Between each precast section, two lites of glass are broken by an exterior shading device, meant to help control solar heat gain and glare, while adding a valuable aesthetic feature. The lower vision lite wraps around the entire building providing views to the exterior, while the upper lite is fritted and meant to improve day lighting. A system of metal panels and storefront glazing encloses the building around the landscaped exterior atrium.

The roofing system, once designed to be the largest green roof in the United States, will span 60,000 sq. ft. This extensive sedum green roof will require a shallow depth of soil and drainage, and will be waterproofed from the concrete structure below. The mechanical penthouse will not have a green roof, rather it will be built of rigid insulation covered by a black EPM waterproofing membrane.

The vibration isolated laboratories located under the exterior atrium will be enclosed in a system unique to the building. As these labs are located underground, they will be surrounded by 24" of concrete to mitigate sound and vibration transmittance, while providing moisture protection and thermal resistance.

## Structural System

### Foundations

The foundation of the Millennium Science Complex utilizes a system of micropiles, pile caps, and grade beams. Each column is supported by a pile cap composed of 6000 psi concrete on grid lines spaced 22 feet apart in a square pattern. Drilled micropiles are attached to the pile caps and descend through the soil to bear on bedrock. The variation in depth of the local bedrock leads to a large difference in pile depths throughout the building. For example, there was a peak difference of 128 feet in depth, in a single pile cap. Each of these pile caps are connected by grade beams which help to reduce differential settlement, a crucial design consideration for a laboratory building.

Forming the floor of the basement are four different slabs on grade in the occupied area of the basement, shown in Figure 5. Slabs on grade, foundation walls, footings and piers use 4000 psi concrete. The basement covers only a portion of the entire footprint of the building, the area colored in white indicates the presence of compacted fill occupying the space between the basement level and first floor level. Columns and piers extend from the pile caps at the basement level up through the compacted fill, in this area of each wing, to the first floor. This was presumably designed in the event that the University would want to expand the basement level under each wing. Further evidence of this assumption can be found in the foundation walls called out in red around the perimeter of the west wing, which enclose the compacted fill, and are in line with the exterior walls of the building. The accessible areas of the basement lie directly under the cantilever and extend to the edge of the compacted fill outlined in blue. Three isolation labs were placed at this level (highlighted in green), designed to be completely disparate of the structural elements that make up the rest of the building.

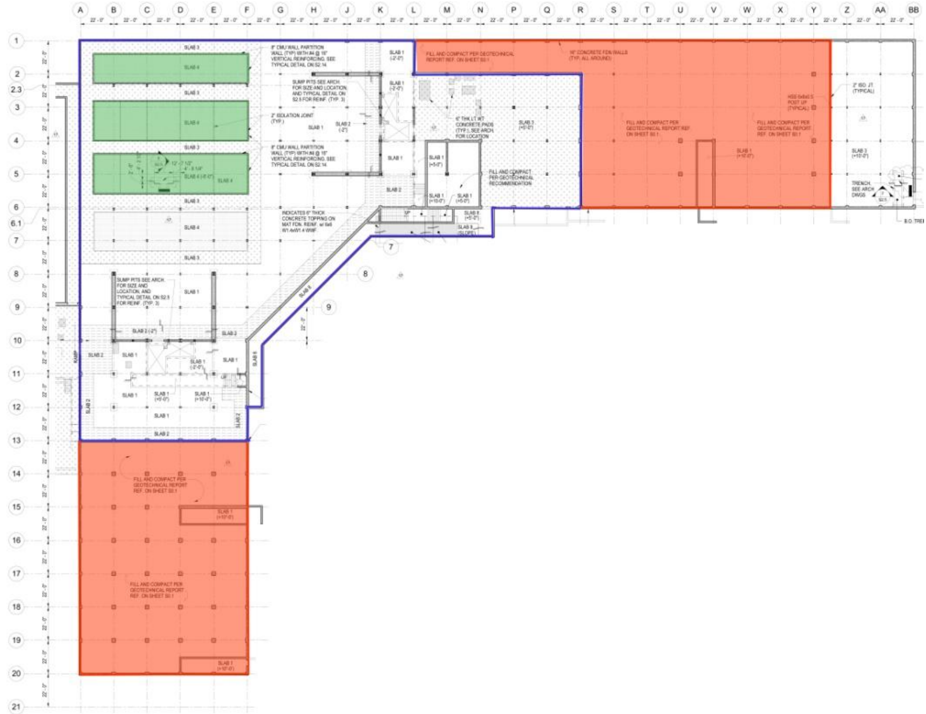


Figure 5: Foundation Plan.

## Gravity System

The gravity system of the Millennium Science Building is composed of steel framing and concrete topping on composite metal decking. The steel framing is organized in a typical 22 foot square layout with intermediate beams spaced at 11 feet and the metal decking spanning across the short direction. The typical floor layout is organized with a centralized corridor in each wing with lab and office spaces along the perimeter of the corridor. The most common floor decking configuration seen in the building is 3 inch 18 gage metal deck with 3 ¼ in light weight concrete topping. The typical steel framing configuration is made up of W21 beams and W24 girders which frame into W14 columns. Beyond the typical dead and live loads, there are specialty loads from the green roof, mechanical equipment, and the pedestrian traffic at the entrance which call for increased slab strengths. A 3 inch metal deck is used with a 7 inch normal weight concrete topping immediately below the cantilever where pedestrian traffic is heaviest as people enter and exit the building, and a 4½ inch normal weight topping is used to support each green roof.

## Lateral System

Two moment frames, several bays of braced frames, and two shear walls located at the stairwells make up the lateral system for the building. The moment frames are located at grid lines Q and 19, which are midway and at the end of their respective wings. The location of these moment frames correspond with shear walls placed in either wing several structural bays away, as shown in Figure 6:. The objective of these staggered frames and walls is to distribute the lateral forces over the entire floor diaphragm, preventing excessive torsion due to lateral loads along wing. The shear walls supporting the cantilever offer a large amount of lateral stiffness to the lateral system of the building however, lateral support must be provided along the wings to prevent torsional effects that otherwise may be experienced at the ends of the wings. State College itself does not suffer from large wind or seismic loads given building height restrictions and geographical location. Along with the large span trusses and C-shaped shear walls that support the cantilever, the lateral system more than suffices in resisting the maximum lateral loads State College has to offer.

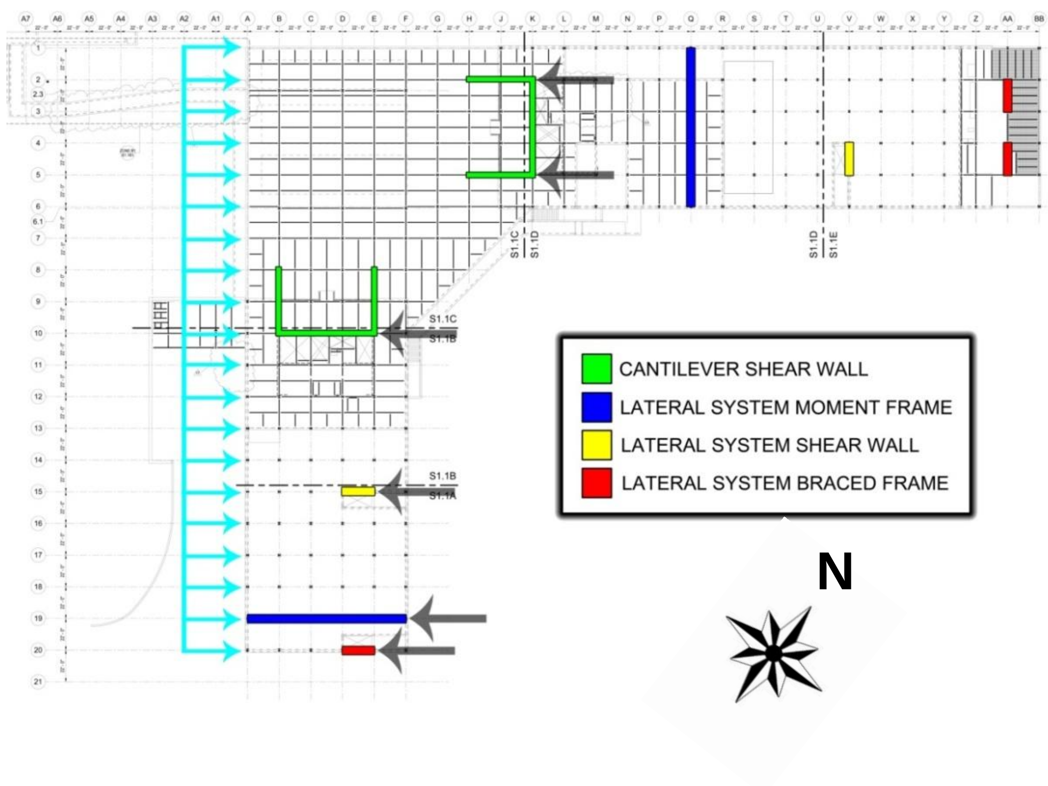



**Figure 6: Lateral Elements Diagram.**

As the wind is applied to the structure, loads are transferred from the exterior façade to the floors, acting as a diaphragm, which distribute the load to the lateral system.

## Specialty Systems

To cope with the massive stresses induced by the 150 foot cantilever a truss design was used to handle the gravity forces. Two different trusses from each wing extend to meet at the tip of the cantilever composing the structural support for this iconic building. Gravity loads are transferred into the diagonal compression members and continue along the load path as shown in the figure below. The loads are then distributed into a 30-inch thick shear wall integral with the truss frame and into the foundation. One of the two identical frames is shown in Figure 7:, indicating that the micropiles shown in blue act in compression and those in red act in tension resisting the overturning moment induced by loads applied to the cantilever structure. As revealed by a Thornton Tomasetti representative, the cantilever was originally designed to be supported solely by the steel truss system and the addition of the concrete shear wall was a necessity to dampen vibrations originating from the mechanical equipment located on the mechanical penthouse supported by the cantilever.

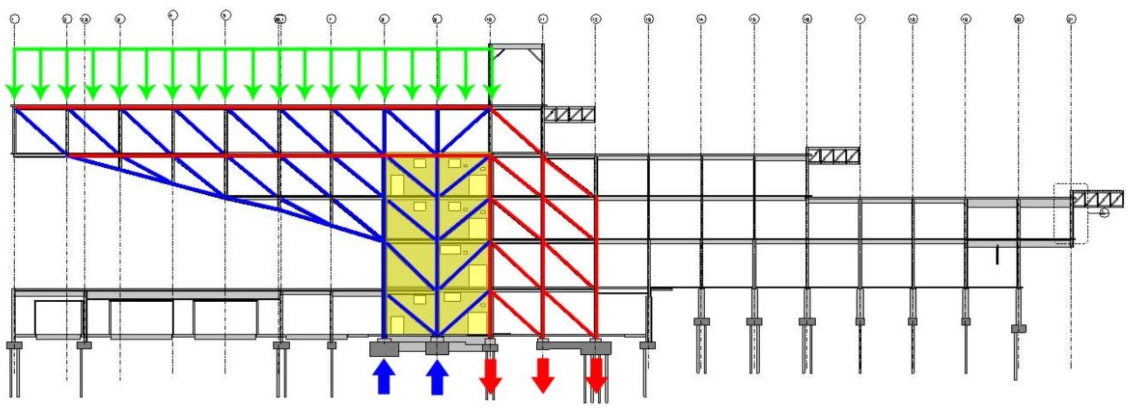


Figure 7: Truss Stress Diagram.

Shown above is one of the four truss frames dedicated to supporting the cantilever. The members highlighted in blue are under compression; the red members are under tension. The shear wall is highlighted in yellow and provides added stiffness to the frame where foundational reactions change from positive to negative directions. The green distributed load represents gravity loads on the frame. This frame is located at grid line B.

## Mechanical Systems

The Millennium Science Complex combines both Materials Science and Life Sciences functions and spaces into one building. Each of these spaces contains offices, laboratories, and unique rooms such as a vivarium and a clean room. Different HVAC strategies are required to handle the varying requirements of this unique building.

The Millennium Science Complex connects into the existing campus steam lines and chilled water lines. Steam enters the building at high pressure, 140 psi, but requires two pressure reducing stations to reduce the steam pressure to medium and low pressures of 60 psi and 15 psi respectively. Medium pressure steam is utilized for sterilization, heat exchangers, and other equipment loads. Low pressure steam is used for the steam coils within the AHUs and in heat exchangers that produce hot water for a finned tubed perimeter heating systems as well as reheat-coils at terminals devices. All steam condensate is pumped to heat exchangers to preheat incoming domestic water.

Chilled water is pumped throughout the building using three (3) variable speed split case pumps, with one reserved as a standby. An auxiliary low flow pump is utilized for part load conditions. The AHUs that serve the animal care facility and main lab are connected to standby power to allow for cooling of these spaces during the loss of power.
The laboratory areas of the building are served by five (5) 50,000 CFM VAV AHUs. Each of these AHUs contains a supply fan, cooling coils, heating coils, humidification equipment, and MERV-14 filters. All laboratory AHUs deliver 100% outside air. In an effort to save operating cost and energy in the 100% outdoor air systems, general laboratory exhaust air enters an enthalpy wheel with the incoming supply air. The laboratory fume hood exhaust is not included in the enthalpy wheel due to the potential contaminants within the exhausted fume hood air.
The office, lobbies, and common areas are served by three (3) 40,000 CFM VAV AHUs. These AHUs do not provide 100% outdoor air and instead contain a mixing box with CO2 sensors in the outdoor air, return air, and all conference rooms to ensure that the CO2 concentrations in these areas are maintained at appropriate levels by supplying enough outdoor air.

More specifically, the animal care facility is served by two (2) 25,000 CFM 100% outdoor air units. Each unit is sized to handle the full load of the space. The redundancy is needed to allow for continual service to the animal holding rooms and the rest of the animal facility should one unit fail. The clean room also has its own AHU that is designed to maintain the room's humidity levels at 45% RH. The animal care facility AHUs, quiet lab AHU, and clean room AHU all utilize run around heat recovery coils in an effort to reduce energy usage.

In addition to the main AHUs, cabinet unit heaters, electric heaters, fan coil units, supplemental air conditioning units, and other local equipment are used to address areas of the building where the main HVAC equipment cannot feasibly serve the area. It is necessary to have all of the previously mentioned components in order to effectively keep the building operating under optimum conditions for the various building occupants.

# Electrical Systems

## Power Distribution

The electrical system for the Millennium Science Complex is a 12.47kV service feeding a set of dual 4000A, 480Y/277V switchgears (main-tie-main) through two pad mounted transformers. Distribution begins with 480Y/277V for lighting and other systems, and then stepped down at further locations to 208Y/120V for receptacle and equipment power. Emergency power is fed from two separate switchgears which feed multiple ATS's with both normal and emergency power. To limit the EMF from interfering with sensitive equipment, electrical closets are encased with aluminum shielding and in certain areas rigid conduit is used in place of standard conduit.

## Lighting:

All lighting is on 277V service. All building perimeter offices and laboratories are controlled by both occupancy and daylighting sensors with appropriate dimming ballasts. Typical internal laboratory and office rooms are controlled by the occupancy sensor. Three general types of ballasts are used. Class B quiet dimming ballasts are used in the quiet labs. Lutron's Hilume dimming ballasts are installed for rooms requiring less than 10% dimming from full power. Advance Mark7 dimming ballast is used in rooms with regular dimming conditions. A system of addressable ballasts is used in accordance with Lutron's GRAKIF Eye system.

## Lightning Protection:

The Millennium Science Complex is protected by Cooper Air Terminals in coordination with NFPA 780. Air terminals located in spaces within the bounds of roof walls are mounted on bases provided by Cooper. Cooper provides the grounding conductor, which is fastened by clips to the top of the perimeter walls. Down conductors penetrate the roof and route behind the concrete panels of the façade in PVC conduit where they ultimately terminate at a ten foot ground rod.

## Telecommunications:

The telecom system consists of only a few major components – combination voice and data outlets, telephone outlets, and paging speakers. The majority of spaces contain combination voice and data outlets prewired into furniture components. Several voice/data outlets are located along all corridors and several locations have above-ceiling mounted telecom outlets for wireless access points. All offices contain at least one quad outlet and one duplex telecom outlet, while conference rooms contain one wall-mounted duplex outlet and a floor-mounted quad outlet. Computation/study areas and conference rooms also contain floor poke-through routing capability. Basket-type, twelve inch by four inch, cable trays route telecom wiring throughout corridors. Each floor is fed by several IDFs – two for the basement, four each for the first and second floors, and two for the third floor. The telecom backbone consists of one 24-strand multimode, one 24-strand single mode fiber optic cable, one 50-pair CAT-3 UTP cable, and one RG-11 coaxial cable between the MDF and each IDF. The telecom system is grounded through the telecommunications main grounding bus bar back to the building electrical ground.

## Fire Alarm

The Millennium Science Complex fire alarm system was designed in accordance with NFPA 72. The fire alarm system consists of audio, visual, and combination audio/visual notification devices. Activation devices consist of smoke detectors, heat detectors, and fire alarm pull stations. The system also contains tamper and water flow switches in the stair wells. The systems Fire Alarm Control Panel is located in Receiving N-041.

## Security System

The security system was designed in accordance with NFPA 70, NFPA101, and NEC. The system consists of magnetic swipe card access with electronic strike, door contacts, and request to exit. Exterior doors, and egress stairwells have local audible alarms. Access control panels, along with class “E” fire alarm relays are located in the security/telecom closets. Millennium Science Complex also has a CCTV system consisting of fixed type cameras. All data recorded are stored on a Digital Video Recorder in LS/MS Server Room N-020.

## Fire Protection System

The Millennium Complex will be protected on all floors by an automatic fire alarm notification system. Manual pull stations will not be required where the alarm notification appliances activate upon sprinkler water flow in this fully sprinklered building. The First Floor Outdoor Plaza must also be fully sprinklered as there is potential for combustible materials to be handled under the canopy. The laboratories will be designed to meet Ordinary Hazard Group 1 or 2, while storage rooms with dispensing capabilities must be designed to Extra Hazard Group 2.

An automatic standpipe system will be required throughout the building, and hose connections will be required on each floor at an intermediate landing level in stairways. A minimal residual pressure of 100 psi is required at the outlet of the hydraulically most remote 2 ½ inch hose connection.

## Sustainability

The Millennium Science Complex is designed to achieve LEED© Gold Certification by employing several sustainable features. One of the most unique features is the extensive green roof located on both wings of the building. It serves not only as a storm water control strategy, but also to reduce the building energy loads by acting as an insulator, extend the life of the roof, and filter pollutants and greenhouse gases from the air. Storm water collected will be diverted to underground cistern and used for the site’s landscaping. The Millennium Science Complex will be the third building on Penn State’s University Park campus to utilize a green roof system. The remainder of the roof consists of white elastomeric sheet roofing which has a high reflectance and high emissivity to help reduce the thermal gradient.

During construction of the complex, almost 90% of the construction waste was diverted from disposal and at least 10% of the materials used were from recycled content, including the steel-frame, concrete, and precast concrete. In addition to the recycled content, sustainably harvested wood was used for carpentry and 10% of the materials were regionally sourced.
Throughout the interior, stringent criteria for low-emitting materials for adhesives, sealants, paints, coatings, and carpet systems were strictly enforced to promote indoor air quality. Independent exhaust is provided for each laboratory, vivarium, and other rooms where hazardous gases and chemicals may be present to help ensure indoor air quality as well. Carbon dioxide monitors are provided in all densely occupied spaces.

Natural daylight is provided extensively throughout the building, including the offices and laboratories. The interior architecture also allows the daylight to reach the hallways from the offices and laboratories. Semitransparent glass, solar shades, and louvers are found throughout the entire façade to encourage daylight without heat gain or glare. Individual lighting controls is provided for 90% of the building occupants as well as lighting controllability for shared spaces. Advanced control systems are also designed for the management of the HVAC systems to emphasize energy efficiency.

## Building Orientation

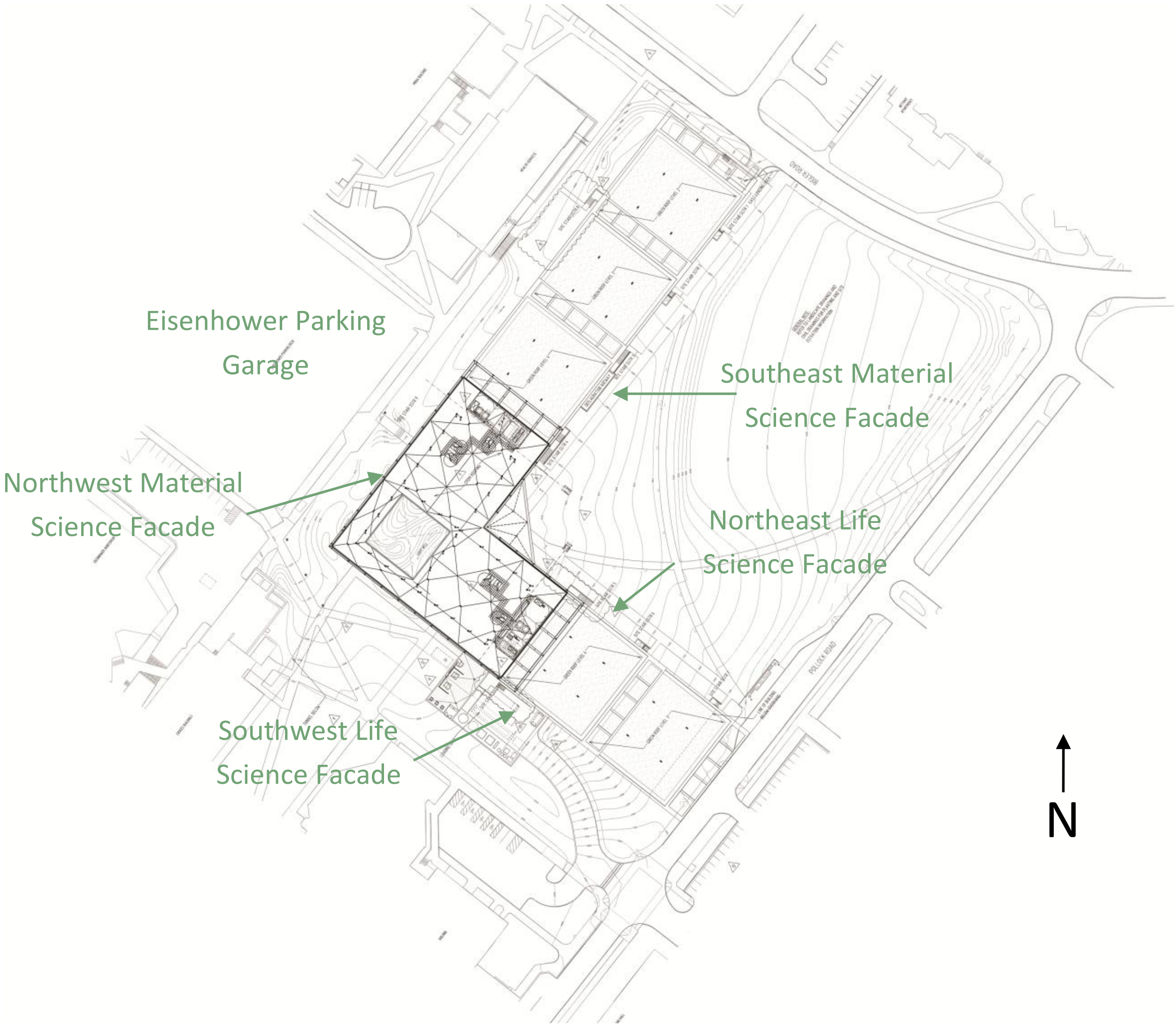



**Figure 8: MSC Site Plan View - Solar North Orientation.**

# Facade

## Summary & Goals

### Background

According to the architect Rafael Viñoly, the intended design inspiration for the Millennium Science Complex was to give the appearance of a floating building. To accomplish this, the façade's original design intent was to enhance the linearity of the building by placing continuous horizontal glazing on all floors and stacked "Penn State" brick with bands of recessed dark-fired brick adhered to eight inch thick pre-cast concrete panels along each face of the building. As a team, this element of the building was determined to be a great opportunity for redesign due to its impact on each discipline.

The existing façade system is an eight inch thick pre-cast concrete panel, each spanning 22 feet (1 bay) horizontally. The glazing configuration consists of a 1 inch thick insulated glass unit supported by an aluminum mullion system bearing on the pre-cast panel below. Solar shading is incorporated into this façade system through three techniques: an 18 inch louver placed at the midpoint of each exterior glazing, a 2'3" setback of the glazing off the face of the precast brick façade, and a fritted glass on the upper half of the glazing. Refer to Appendix E: Daylighting Results & Information for detailed drawings and assemblies.

### Redesign Goals and Methods

As stated previously the façade was chosen as an area of interest for redesign because it provided a unique opportunity for the group to utilize BIM/IPD principles. It was also theorized early in the decision making process that the façade could have the potential for increased thermal efficiency and daylighting integration. A double-skin façade system with integrated horizontal louvers was chosen to achieve this potential. The design of the façade relied heavily on coordination among team members to ensure the result was an efficient design. The goals for this redesign were as follows:

1. Increase the thermal efficiency of the façade panel and overall system
2. Decrease the weight of the precast panel to reduce the façade loads on the structural system
3. Increase the daylighting efficiency and improve user comfort
4. Determine the most efficient method of construction

# Façade Design

## Preliminary Designs

Before the specific dimensions of the precast panels were redesigned, Building Stimulus underwent a preliminary investigation of alternative panel materials. The primary focus of the investigation was lightweight material that still provided the structural stability, as well as the aesthetic quality of the existing architectural precast panels. Materials researched included the following:

- Architectural Metal Panels
- Precast Concrete with Carbon Fiber Reinforcing
- Glass Curtain Wall

Architectural metal panels, as well as a glass curtain wall, provide significant benefits including ease of installation, reduction in cost, and reduction in weight; however, the use of this type of building envelope proved to severely alter the architectural intent of the building and was thus discarded.

Precast Concrete Panels with Carbon Fiber Reinforcing uses carbon fiber sheets to increase the structural integrity of the panel while allowing a reduction in total concrete, creating a significantly lighter panel. After consulting manufacturers, however, it was concluded that carbon fiber reinforced panels could not be designed to the required dimensions for the Millennium Science Complex without creating serious moisture permeability, as well as structural stability issues, both of which were unacceptable on a double-skin façade. Therefore, the remaining alternative materials were deemed impractical for use.

## Single Skin Facade

The existing envelope consists of a single skin façade, described previously in report. During the redesign process of the façade, it was Building Stimulus' initial intention to implement a double skin façade along the entire perimeter of the building. However, upon further review, it was concluded that specific facades were unable to produce the same benefits and energy savings needed to justify the costs of the double skin façade. Therefore, the existing single skin façade system remains on the facades indicated below, with the new precast panel design.

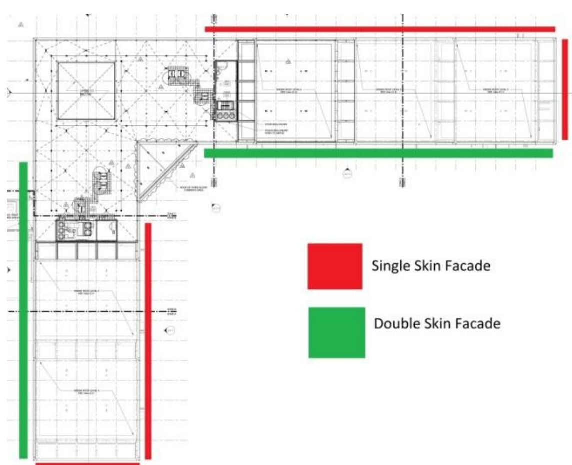



Figure 9: Facade Placement

## Double Skin Façade

A double skin façade is a unique enclosure design in which two building skins envelope the building. The composition of the two skins complicates the building envelope immensely on numerous fronts, including but not limited to the constructability, accurate thermal modeling, and overall enclosure design. Enclosure design is the process by which the building envelope is designed to be functional and efficient. Complete and functional building envelope design was out of the scope of this thesis report. However, initial design processes and potential issues were researched and considered during the design phase of the façade.

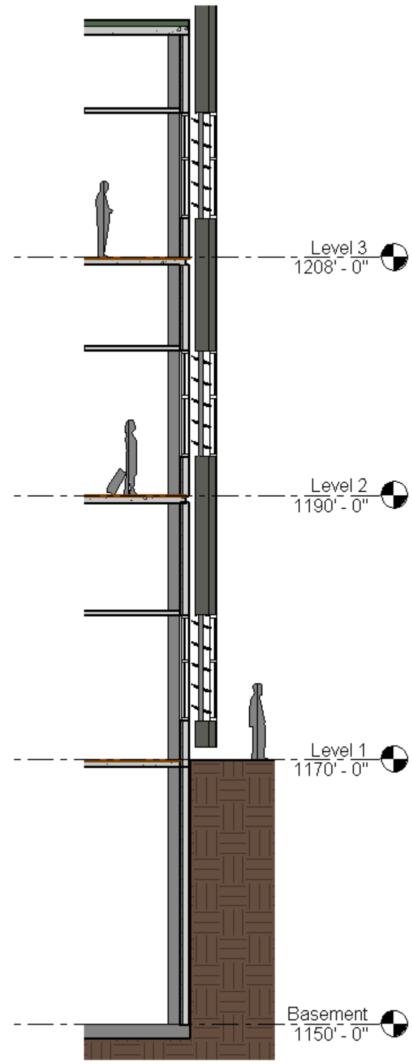


Figure 10: Double Skin Facade Section.

The double-skin façade proposed by Building Stimulus for this system is comprised of two glazing configurations which consist of an interior glazing system and an outer single pane glazing. The redesigned glazing and mullion design consists of a 10 mm annealed PVB laminated outer glazing connected via T5 5mm thick 100 mm x 150 mm mullions and transoms. A sample calculation of this design can be found in Appendix B: Enclosure Analysis. Laminated glass was chosen for the exterior enclosure due to the building's operation as a sensitive laboratory environment and due to the potential for the building to experience high wind loading. The glazing and mullion system was designed for the local components and cladding wind pressure of 32psf using ASTM standard 1300 – 04 and ASCE7-05.

The two glazing configurations for the double skin are separated by a 24 inch air gap. The two foot interstitial space acts as a thermal buffer between the outdoor environmental conditions and the interior perimeter spaces of the building. For the interior glazing, the high performance glass used in Millennium Science's current design was selected, Viracon VE-12M. This selection was maintained due to the current glazing's excellent U-value rating of 0.29 and visible transmittance of 70% for daylighting purposes. The low-emittance coatings on the interior glass provided reduced solar heat gains to the interior and serves as the insulating layer.

Several iterations were performed to select the exterior glazing for the second skin of the façade. Initially other high performance glazing types were selected, such as Viracon VE6-2M and VNE1-63, (see results in Appendix C: Energy Analysis). However, after consultation with John Jackson, an associate from HOK engineering and design firm, the design was reconfigured to consist of a hardened single glazing for the exterior skin. By specifying a glass with lower performance capabilities, it allowed the air gap to perform similar to a greenhouse, allowing the solar heat to collect in the space to create a lower temperature difference between the perimeter spaces and the outside air during the heating period for the winter. The resulting U-value for the new configuration of the double skin façade was determined to be 0.126 BTU/hr ft$^2$ $^o$F.

Table 6: Glazing Properties.

| | | Transmittance | | | Reflectance | | | U-Value | | SHGC | LSG |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | Product | Visible | Solar | U-V | Vis-out | Vis-in | Solar | Winter | Summer | | |
| **Exterior Glazing** | Clear | 79% | 61% | 46% | 14% | 14% | 11% | 0.47 | 0.49 | 0.7 | 1.12 |
| **Interior Glazing** | VE1-2M | 70% | 32% | 10% | 11% | 12% | 31% | 0.29 | 0.26 | 0.38 | 1.84 |

Within the air gap, adjustable frosted glass louvers were placed to provide a shading system for the interior perimeter spaces. This allows for more dynamic control of the daylighting and solar heat gain within the perimeter spaces of the Millennium Science Complex. The design of the double-skin façade is a continuous system that allows air to flow from the ground floor to the roof to serve as preheat for the air handling units during the winter. The relative heat gain for this configuration, on a center of glass basis was determined to be 50.8 BTU/hr ft$^2$ for the winter and 81.2 BTU/hr ft$^2$ for the summer conditions. In the summer time the air flow in the interstitial space is naturally exhausted at each floor by opening dampers located at each floor to prevent excess heat gain for the perimeter spaces since the solar heat gain is much greater.

One significant issue arouse with the double skin façade in terms of determining the cleaning and maintenance for its lifespan. The inner clearance between the two envelopes, as previously mentioned, is 24 inches, which can possibly provide enough space for a maintenance worker. However, the presence of the stationary louver system occupies much of this space and therefore access to the space is not an option. The compromise Building Stimulus arrived at was to have all maintenance and cleaning be performed via a hinged outer glazing system that is accessible by means of a scissor lift. It is estimated that all double skin façades will have to be cleaned once per year. In addition, for this method of operation the glazing panel must be sealed to outer enclosure via a dry gasket and latching system. This gasket provides a potential for failure over long term exposure to the elements. Therefore, in addition to yearly cleaning, it is recommended that this dry gasket on each glazing system (1 bay, 22ft x 8ft section) must be replaced every five to ten years based on yearly inspection. The design of this building envelope system proved to be an educational experience, however, due to the extreme costs and complexity of the system it would be advised to not continue with this design.

## Precast Panels

The focus of the façade, structurally, was concentrated mainly on the design of the precast panel. A number of iterations were produced before the final solution was reached, including a thicker slab without returns, a one-way joist system, carbon fiber reinforced slab, etc. Figure 11 below shows a number of different panel configurations that were analyzed for strength and deflection under dead and wind loading, in and out-of-plane. Once the group determined that the mechanical efficiency would benefit from having a continuous air gap rather than a non-continuous air gap, the challenge was to design a panel without returns running laterally across the panel which would inhibit the flow of air vertically up the double skin façade. Once this was realized, the design of the pre-cast panel proved to be mostly dictated by providing adequate clearance between the inner faces of the interior and exterior enclosures. This clearance was determined early in the design process to be 24 inches. This would ensure that a continuous air gap was achieved for thermal efficiency and the louvers used to optimize daylighting efficiency would have enough space to operate.

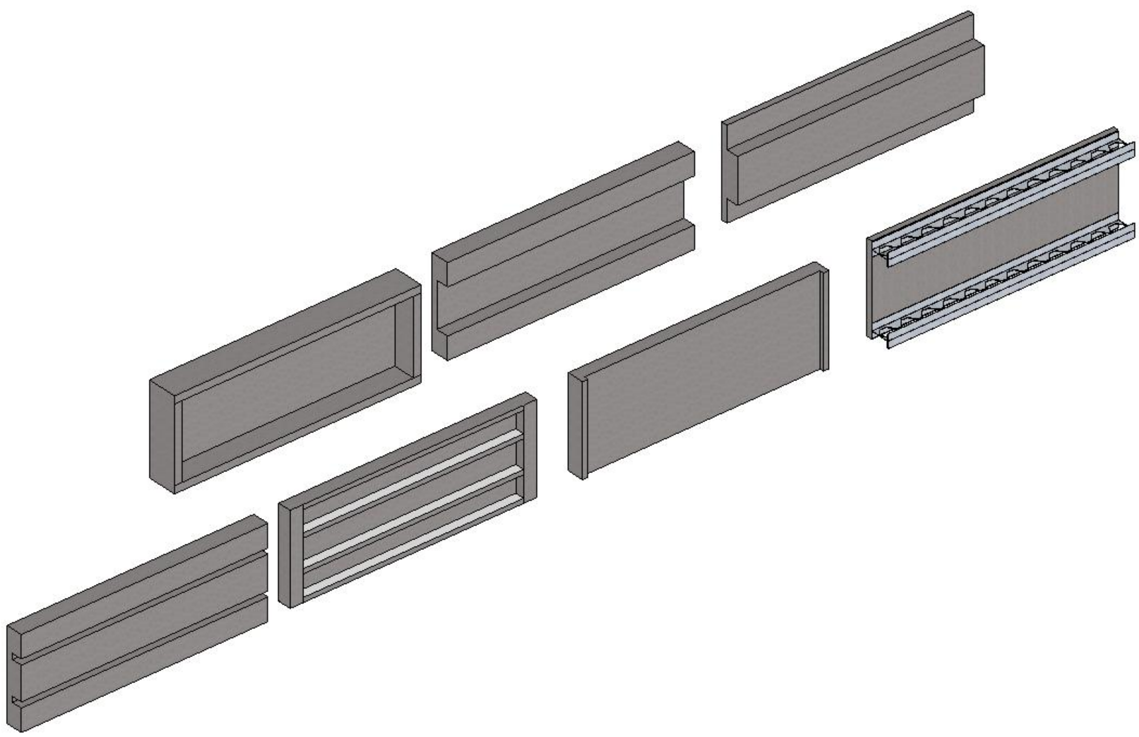


**Figure 11: Precast Panel Iterations**

The redesigned system (Figure 12) features a flat slab of 6 inches thick and 3 beams 8 in x 12 in placed at the ends and middle of the panel, running vertically up the panel. The beams were necessary to prevent the panel from cracking under its own self-weight during storage and construction and to provide extra lateral support under wind loading (calculations can be found in Appendix B: Enclosure Analysis). The existing panel-to-structure connections were used in the redesigned system with the addition of one lateral resisting connection on the middle beam of the panel which is connected to the structure at the midpoint of the steel beam of the gravity system. In addition to adding flexural strength to resist the lateral loads the panel would experience after installation, the center beam also prevents the panel from cracking under its own self weight during storage, transportation, and erection. It should be noted that the panel must be stored and transported with the beams facing down to ensure cracking and chipping does not occur on the face brick.

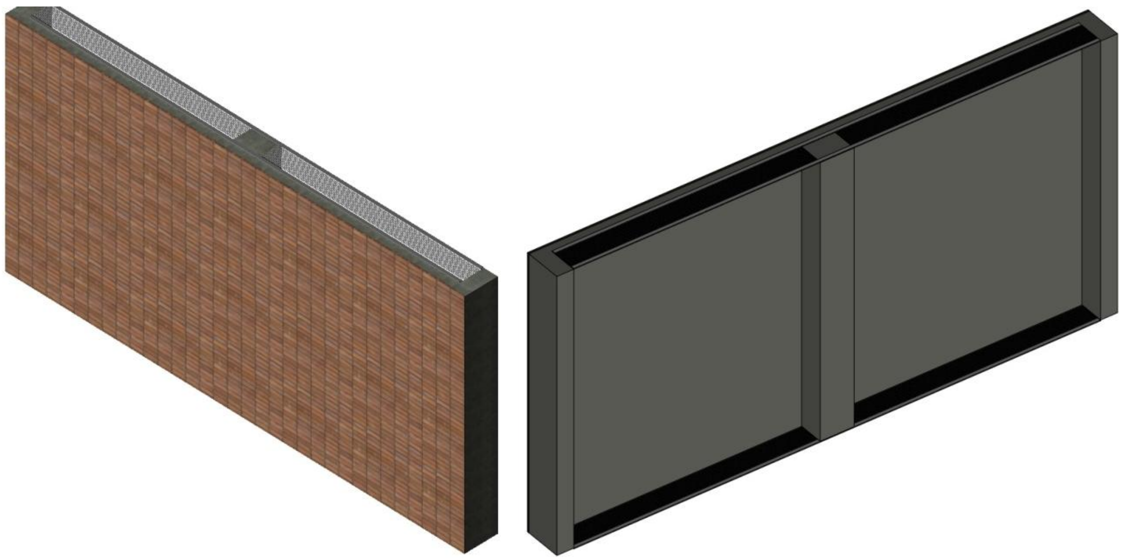


**Figure 12: Redesigned Precast Panel (black indicates location of non-structural horizontal grating)**

## Sequence of Panel Installation

The construction of the double-skin façade requires significant adjustment to the original schedule. The original sequence of precast panel installation can be seen in the diagram below:

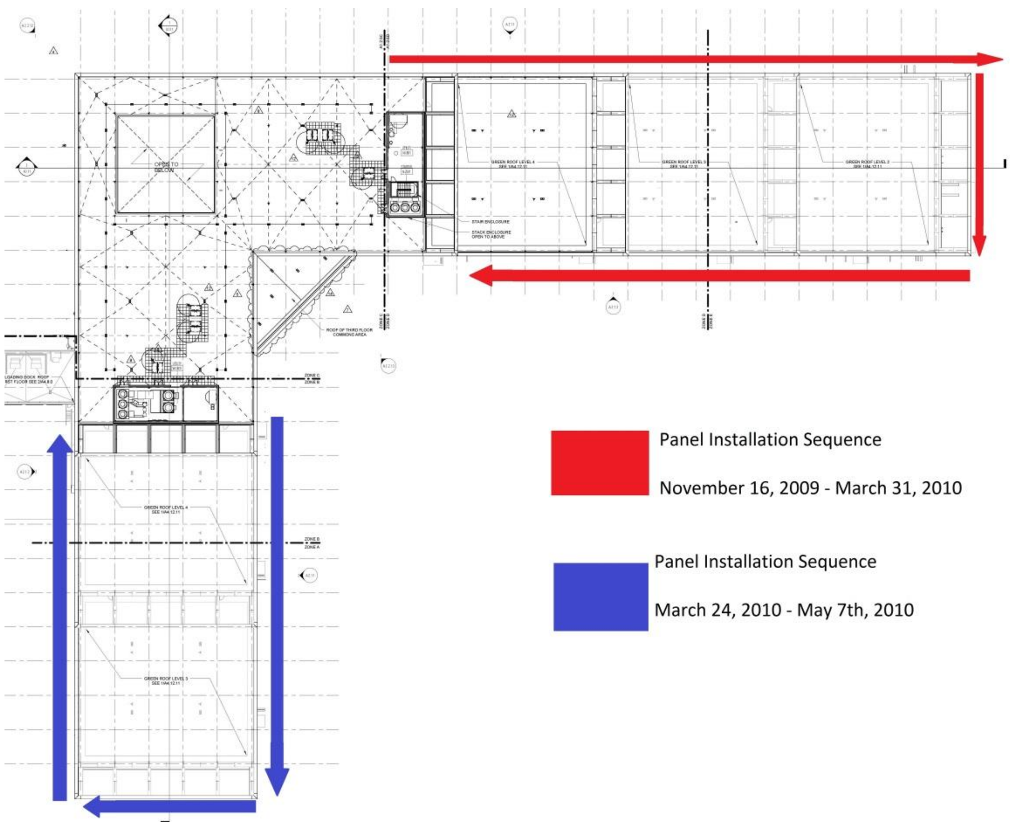



**Figure 13: Panel Erection Sequence.**

Panel erection began on the North elevation of the Material Sciences wing on November 16th, 2009 and continued clockwise until the Material Sciences wing was completed on March 31st, 2010. The East elevation of the Life Sciences wing began on March 24th, 2010, continued clockwise around the Life Sciences wing until the west elevation was completed on May 7th, 2010. The full schedule of activities can be found in Appendix D: Construction Management.

To implement a double-skin façade, the sequence of precast panel erection must be rescheduled to create an efficient process. The construction of a double-skin façade demands that specific activities be completed by the time precast panel installation occurs, namely the completion of perimeter studs along the facades utilizing the double-skin. Refer to the Double-Skin Façade Construction section for more discussion on sequence of double-skin construction. Originally, the first area to have perimeter wall studs installed was Material Sciences wing, Level 2, on March 29th, 2010. However, interior walls are laid out much earlier, with the first instance being December 14th, 2009 in the lab space on Level 1. Therefore, with the installation of perimeter wall studs dictating the time that double-skin façade panels can be erected, it is logical to move perimeter wall studs to an earlier date, and move interior stud construction to a later date to ensure that there is no crowding amongst trades. An updated double-skin erection schedule can be found in Appendix D: Construction Management. While the double-skin façade requires perimeter stud construction to be completed, the single-skin façade does not. Therefore, the sequence of panel erection has been revised, completing all single-skin façades first, before beginning double-skin facades. Doing so allows perimeter studs of Life Science West elevation and Material Science South elevation, the double-skin façades, to be constructed, while single-skin precast panels are being erected concurrently. The revised direction of panel erection can be seen below:

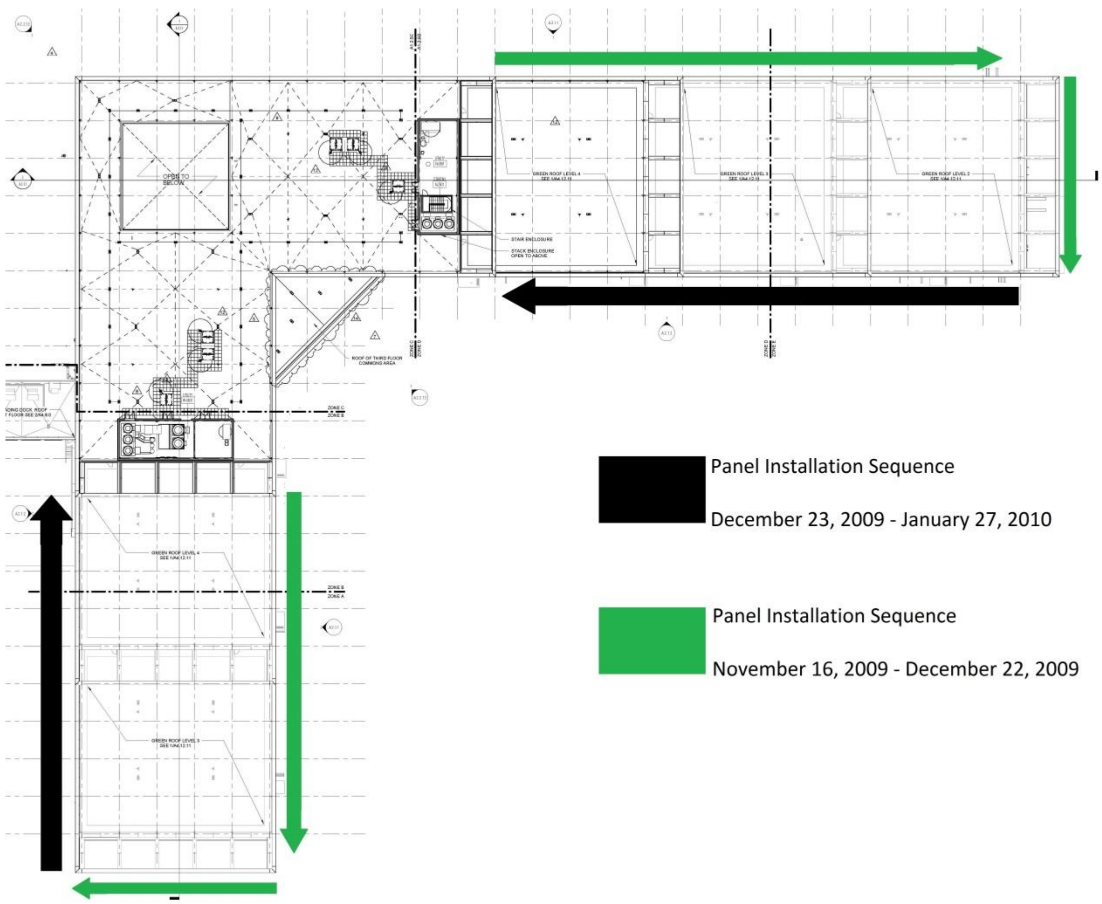



**Figure 14: Panel Erection Sequence.**

According to Whiting-Turner, architectural precast panels can be erected at a conservative estimate of 7 panels per day, making the North elevation the longest duration at 90 panels erected over 13 days, and the shortest duration being east elevation of Life Sciences at 9 days. Whiting-Turner took 83 days to complete the south elevation of Material Sciences wing, and 40 days to complete the west elevation of Life Sciences wing. These lengthy durations were intentional as these elevations were left incomplete to allow the distribution of large materials into the facility easily. This concept will continue, however, the south elevation of the Material Sciences wing cannot be used due to interior studs completed early for double-skin construction. Therefore, the north elevation of Material Sciences wing will remain incomplete to allow the distribution of materials instead of the south elevation.

## Double-Skin Façade Construction

The double-skin façade is a specialized system that requires a unique approach to construction, and is only complicated by its use with precast panels. Double-skin facades are predominantly fully glazed systems with two layers of glass. Using brick panels with a double-skin façade requires careful considerations for construction, including:

- Ensuring interior wall is protected from moisture
- Applying thermal and/or vapor barriers on interior wall
- Installing interior glazing without damaging materials
- Ensuring interior wall is complete prior to installation of precast panels

The double-skin façade is designed to allow outside air to flow through the cavity. In the winter months this air will be very cold. In the summer months, this air may have high moisture content. Therefore, appropriate thermal and moisture barriers must be present. Building Stimulus has redesigned the insulation on double-skin facades to be placed on the exterior-most side of the interior walls as compared to directly behind the precast panels on the original façade. A polyethylene vapor barrier will be applied on the interior wall as well to prevent moist summer air or inclement weather from entering the interior wall.

Applying the thermal insulation and vapor barrier properly requires that the precast panel not be installed yet. The existing schedule of activities has been altered to have the perimeter wall studs of the double-skin façade to be completed before panels are installed. The panels are then welded into place and lateral connections are fastened.

This method of construction presents several issues. As the thermal barrier is applied, an opening must be created for the bearing support of the panel. This creates an opportunity for the building envelope to fail. These openings are vulnerable to moisture penetration and extra care must be taken when the vapor barrier is installed. Additionally, protective material must be applied to nearby vapor barriers and insulation, as welding poses a threat to the integrity of the aforementioned materials.

## Daylight Integration

Integrating shading devices into the façade designs of the Millennium Science Complex provides various advantages for building occupants, owners, and designers. The opportunity exists to lower solar heat gain, lower electrical lighting power consumption, and increase overall user comfort in perimeter spaces.

There are generally three types of spaces that can be classified as perimeter rooms that which daylight integration directly affects. These spaces are offices, student study areas and open lab work areas labeled as "Neurophys-Invitro." These perimeter spaces are intensive work areas, where occupants will be using computers and doing lab research.

Daylighting summaries can be found on page 308 in Appendix E: Daylighting Results & Information. Extensive hourly illumination contours of all façade orientations on design dates can be found at:

*http://www.engr.psu.edu/ae/thesis/BIMTeam22010/Final/Daylighting%20Contours.pdf*

## Shading Devices

While the Millennium Science Complex Currently uses a continuous static shading lover along the buildings' façade, the redesign incorporated façade orientation based dynamic shading systems. American Warming and Ventilating (AWV) provide a slim, self-adjusting system that can be integrated within the proposed double skin façade.

The system is comprised of five 20' long by 19" frosted glass louvers. AWV provides their systems with "Shadoglass," which are glass blades with a vast array of material and color choices. The advantage of choosing frosted glass versus alternatives, such as perforated metal shades, is the ambient glow produced by the shades while simultaneously reducing glare into the space. View to the exterior is important to maintain when shading devices are utilized. With proper use, the system can maximize user comfort while retaining a view to the exterior.

Solar shading device cutsheets and information can be found in Appendix E: Daylighting Results & Information.

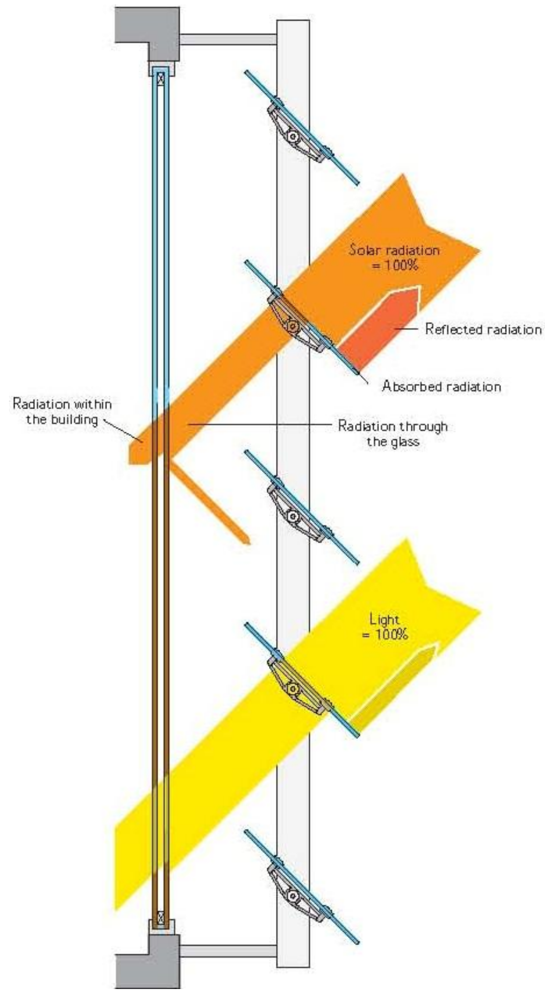



Figure 15: AWV Solar Shading Device Section.

## Daylighting Controls

### Shading Device Controls

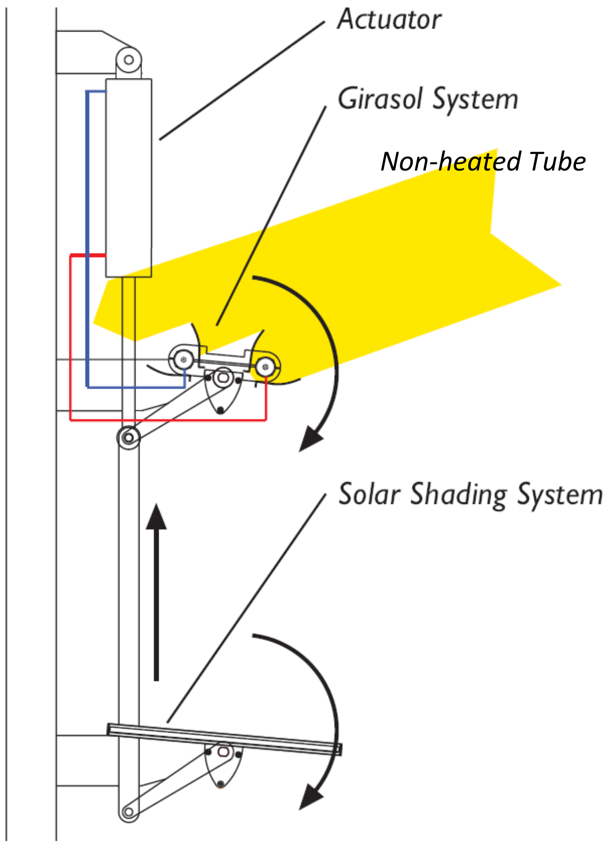



Figure 16: Girasol Shading Control.

AWV provides three different control systems for their shading systems. There are two electronic options and a single non-electronic control system.

SolTronic is a small electronic control system that can control ten actuators and responds to external weather conditions.

ICS-4-LINK is a large electronic system that can integrate HVAC controls, smoke control, as well as the control for the shading systems.

The non-electrical control system (shown to the right) is AWV's "Girasol." This control system is unique in the fact that it does not use electrical solar tracking or control devices. The system instead uses two absorber tubes filled with a hydraulic fluid. One tube is allowed to absorb solar radiation, while the other is not. When the exterior tube is heated by direct solar radiation, the pressure balance between the two tubes creates an imbalance. This imbalance of pressure causes the glass blades to open or close as desired.

The Girasol system was chosen for the Millennium Science Complex's facade shading control. This system will not burden the electrical system, and will require no programming. The Girasol system will allow the shading devices to operate differently from one facade orientation to another. Control systems such as this will allow for maximizing the functionality of the system, benefiting user comfort, electrical light energy, and lowering mechanical loads.

### Electric Light Controls

Use of occupancy sensors has been incorporated into student study areas and perimeter public spaces to maximize energy savings from the use of dynamic shading devices within the double skin façade. The student study area has also been equipped with occupancy sensors due to the absence of nearby manual lighting controls, as this is a public space. Typical private offices that line the perimeter of the building will incorporate an integrated chilled beam luminaire that has two manual switching options that will be further discussed in the Luminaire Integration section on page 56.

# Daylighting Overview by Façade Orientation

## Southeast Facing Material Science Façade (Plan South)

The facades on plan west face a more southeasterly direction than that of what the plans show. This facade orientation faces more east than south as it is 52 degrees counterclockwise from facing solar south.

This particular facade orientation benefits greatly from the addition of dynamic shading devices. The perimeter spaces on this orientation will receive direct daylight penetration from early morning and into the early afternoon. Solar shading devices have been incorporated into the interstitial space of the double skin facade used on this orientation.

## Southwest Facing Life Science Façade (Plan West)

The facades on plan west face a more southwesterly direction than that of what the plans show. This facade orientation faces more south than west as it is 52 degrees counterclockwise from facing solar west. The Southwest facing Life Science façade has used the double skin façade with the automatically adjusting louvers.

## Northeast Facing Life Science Façade (Plan North)

The facades on plan east face a more northeasterly direction than that of what the plans show. This facade orientation faces more north than east as it is 52 degrees counterclockwise from facing solar east.

The northeast facing Life Science facade has not incorporated dynamic louvered solar shading devices. The facade will only receive early morning daylight penetration without shading, and does not seem productive to add shading louver devices for functionality and cost reasons.  The northeast facing Life Science façade is not utilizing the double skin facade system and has retained the use of the existing fabric roller shades. Analysis of daylight contribution in perimeter spaces without the use of either double skin facades or fabric shades has shown that direct sunlight penetration will create significant visual issues with source/task luminance ratios.

## Northwest Facing Material Science Façade (Plan West)

The facades on plan north face a more northwesterly direction than that of what the plans show. This facade orientation faces more west than north as it is 52 degrees counterclockwise from facing solar north.

The northwest facing Material Science facade shall not incorporate dynamic louvered solar shading devices. The Eisenhower Parking Garage to the northeast of this facade casts a substantial shadow on the Millennium Science Complex. There will be some minor inconvenient times when direct sunlight penetrates the space, though limited.

The northwest facing Material Science façade is not utilizing the double skin facade system and has retained the use of the existing fabric roller shades. Analysis of daylight contribution in perimeter spaces without the use of either double skin facades or fabric shades has shown that direct sunlight penetration will create significant visual issues with source/task luminance ratios.

## Building Enclosure Analysis

A brief thermal/condensation analysis was performed for the redesigned precast façade system. The thermal analysis software H.A.M. Toolbox was used to determine the R-value and the potential for condensation in the interstitial cavity of the double skin façade. Both analysis procedures were performed a series of three times: 1) 4 in cavity, 2) 24 in cavity using 6 – 4 in cavity spaces, and 3) a 4 in cavity with adjusted permeance to act as 1 – 24 in cavity. The first analysis was used to provide comparison between a standard 4 in cavity and a 24 in cavity, and the third analysis was used to prove that 6 – 4 in cavities would perform the same as 1 – 24 in cavity.

As noted in the H.A.M. output found in Appendix B: Enclosure Analysis, no condensation should occur in the double skin façade cavity. This however, is higly idealized and assumes static air flow in the cavity. Any air gap or venting of the air space would influence these results greatly and possibly cause moisture to develop and condense within the cavity.

## Mechanical Design

Using the program Win 6, created by Lawrence Berkeley National Laboratory, as recommended by several literatures and articles for analyzing double-skin facades, the energy performance of the double-skin façade was analyzed. This program allows the development of different glazing systems to be analyzed for energy and optical performance, and it also includes the option to model louvers within the glazing system, just as needed for the double skin façade. These calculations were based on ISO 15099 thermal performance for windows and shading device which is a simplified radiation and conduction model and the Waterloo Model, which is a convective model for integral shading devices.

It is well known that modeling the energy performance of double-skin facades is a very arduous task which does not always render completely accurate results since the façade is so dynamic based on external temperatures, solar radiation, and wind speed. Convection within the intermediate cavity occurs through thermal buoyancy and is also wind driven. The basis for this particular analysis made several assumptions to yield approximate results for the façade’s performance. The thermal performance modeled in this analysis does not take into consideration completely the convective effects the airflow within the air gap has on the heat transfer ability of the façade. The performance was based solely on radiative and conductive performance of the glazing system by using an average u-value as calculated in the Win 6 program. The U-value for the system was reduced from 0.29 BTU/hr ft$^2$ F to 0.126 BTU/hr ft$^2$ F. Since it did not take into consideration the convective effects of the air gap, it should be noted that performance values determined slightly overestimates the actual performance of the double skin façade. This information was then input into the TRACE model previously developed during the fall semester for the third floor of the building to replace the existing façade.

Initially, the double-skin was evaluated for its performance on all faces of the building. From an energy perspective with respect to solar loads on the perimeter spaces, this yielded considerable savings for both the cooling and heating seasons. However, due to the cost and difficulty of construction versus daylighting and energy performance, the double skin was limited to just the southern and western facades of Millennium Science. According the daylighting analysis performed, these two facades experience the greatest solar exposure due to their orientation to the sun and also surrounding buildings. For instance, the north façade did not experience as great of energy improvement since it is almost constantly shaded by the student health services building, which is directly adjacent to Millennium Science and runs parallel to the north façade. (Throughout the remainder of the report the double skin façade used on only two facades will be referred to as “partial double skin.”)

Figure 17 below illustrates a significant reduction for the solar heat gain for the façade during the summer for both double skin configurations. The partial double skin façade was able to save approximately 150,000 BTU/hr.

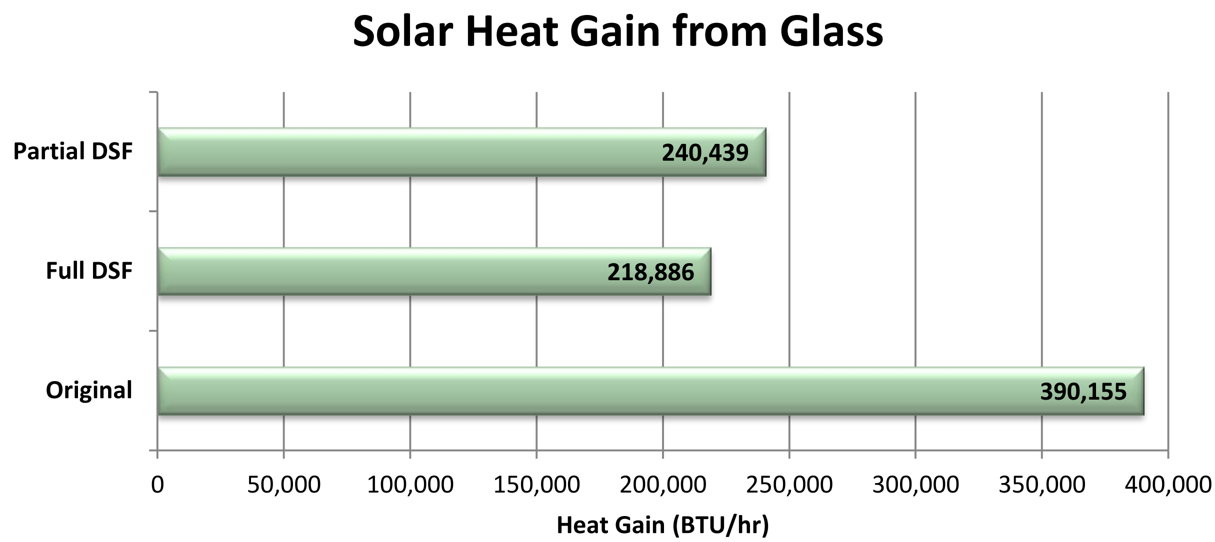



Figure 17: Glazing Solar Heat Gain on Third Floor for Summer Months.

The design criterion for the energy calculations was selected from OPP's interior design conditions and ASHRAE's 0.4% and 99.6% external conditions as seen in the tables below.

Table 7: ASHRAE Weather Data for University Park, PA.

| ASHRAE Altoona, PA | Summer Design Condition: Cooling 0.4% | Winter Design Condition: Heating 99.6% |
|---|---|---|
| Outside Air Dry Bulb (ºF) | 4.7 | 88.5 |
| Outside Air Wet Bulb ( ºF) | - | 72.0 |

**Table 8: Office of Physical Plant Interior Design Conditions.**

| Area | Season | Indoor | Outdoor |
|---|---|---|---|
| Comfort Areas | Summer | 75°F DB, 50% RH | 90°F DB, 74°F WB |
| | Winter | 75°F DB, 50% RH | 0°F DB |
| Labs | Summer | Lab specific | 92°F DB, 74°F WB |
| | Winter | | 0°F DB |
| Animal Holding | Summer | 64-79°F DB[1] | 95°F DB, 75°F WB |
| | Winter | 30-70% RH[1] | -10°F DB |

Based on these design criteria, the total energy consumption for the third floor of the Millennium Science Complex was calculated using Trane TRACE software. The building energy model created from the fall semester's analysis was used as the building base for comparison. Figure 18 below illustrates the partial double skin façade configuration's ability to reduce the building's energy consumption by 676 MBtu per year for the 45,000 square feet (third floor's area). When extrapolated for 276,000 square feet for the entire building, this results in a savings of approximately 4,150 MBtu per year. All of the extrapolations made throughout the redesign analyses for the entire building can be used as an approximation for how the whole building would perform under the new designs. However, it should be noted that do to the increased amount of perimeter spaces on the lower floors and a slightly increased proportion of lab to office spaces would change the energy consumption of the building.

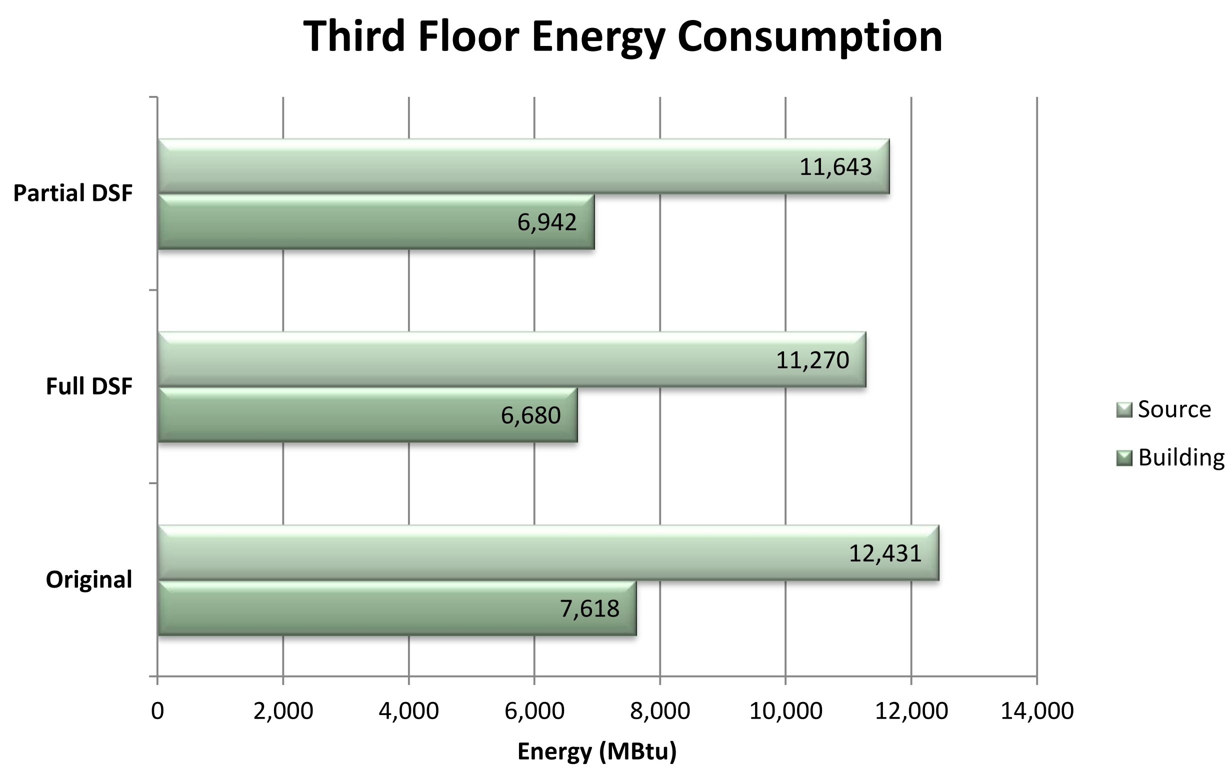



**Figure 18: Third Floor Energy Consumption.**

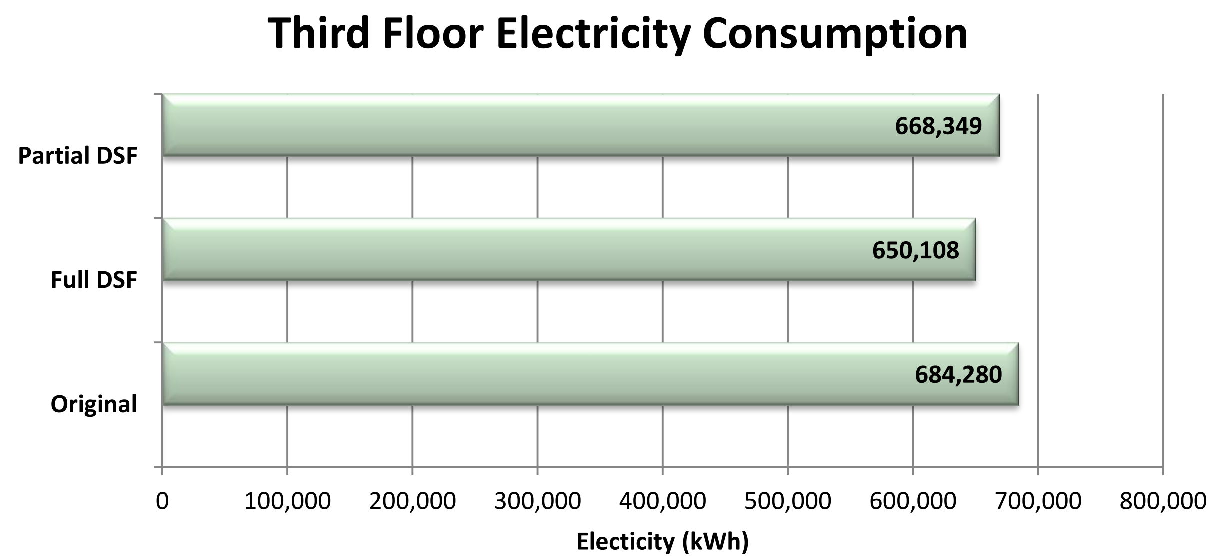



Figure 19: Third floor electricity consumption.

As shown in Figure 19 above, the new façade allows for the third floor to save 15,931 kWh in electricity consumption, which translates into a yearly building savings of 97,710 kWh.

## Energy Cost Analysis

In order to determine the yearly operating costs for the building, the total energy consumption for each design alternative was applied to the Penn State Utility Fact Sheet. Table 9 details the utility cost information and it was assumed that all utilities will be purchased from Penn State at the prescribed rates.

Table 9: Penn State Utility Information.

| Name of Utility | Cost ($)/Unit |
|---|---|
| Purchased Steam | 0.82/therm |
| Purchased Chilled Water | 0.22/ton-hr (1.83/therm) |
| Electric Consumption | 0.07517/kWh |

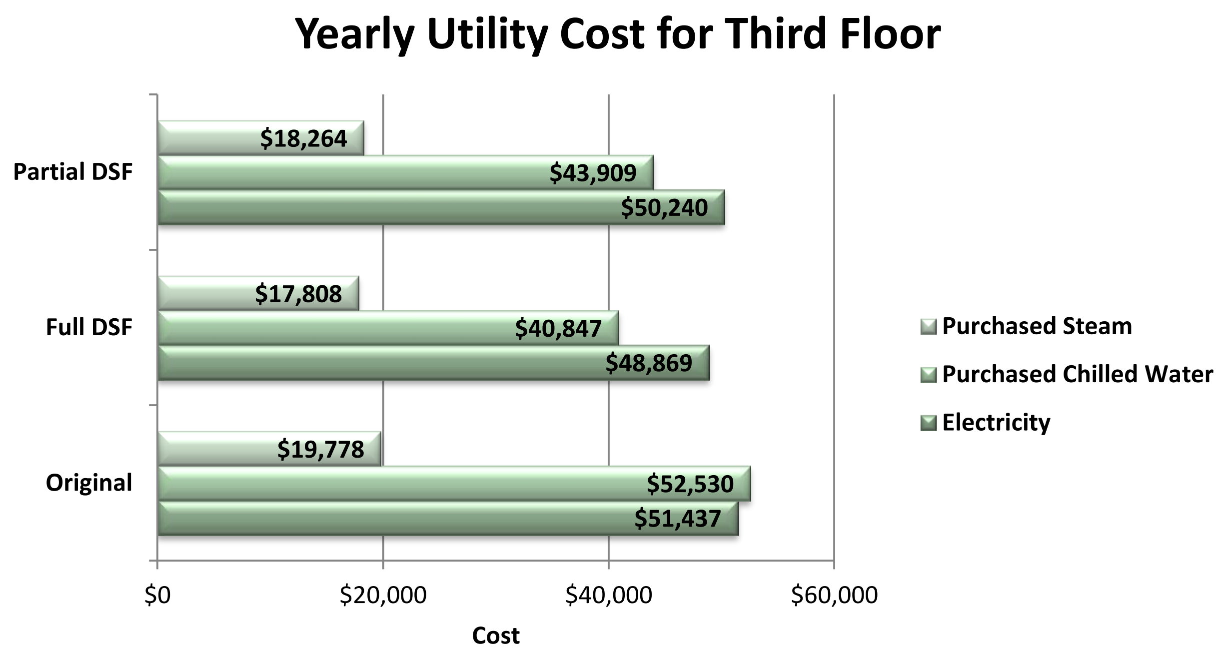



Figure 20: Third Floor Yearly Utility Cost.

The total utility cost for the third floor redesign using the double skin façade on only two faces of the building resulted in a savings of $11,332, which is a yearly savings of $69,503 for the entire building.

## Source Energy Associated Emissions Analysis

The building emissions footprint of MSC was analyzed using the total source energy consumption data calculated from Trane Trace. In continual accordance with Building Stimulus' design goal of improved efficiency, reduction of source energy associated emissions was also pursued in the redesign. The emissions analysis was based on equivalent pounds of carbon dioxide, nitrous oxide, and sulfurous oxide pollutants. As previously mentioned, the model simulated was based on the third floor of the Millennium Science Complex. Figure 21 and Figure 22 show a decrease of 8.86% of equivalent carbon dioxide and nitrous sulfurous oxide for the third floor alone with the partial double skin façade. This is equivalent to a savings of 240,649 pounds of $CO_{2e}$ for the third floor and extrapolated for the entire building, the savings is increased to 1,475,981 pounds of $CO_{2e}$.

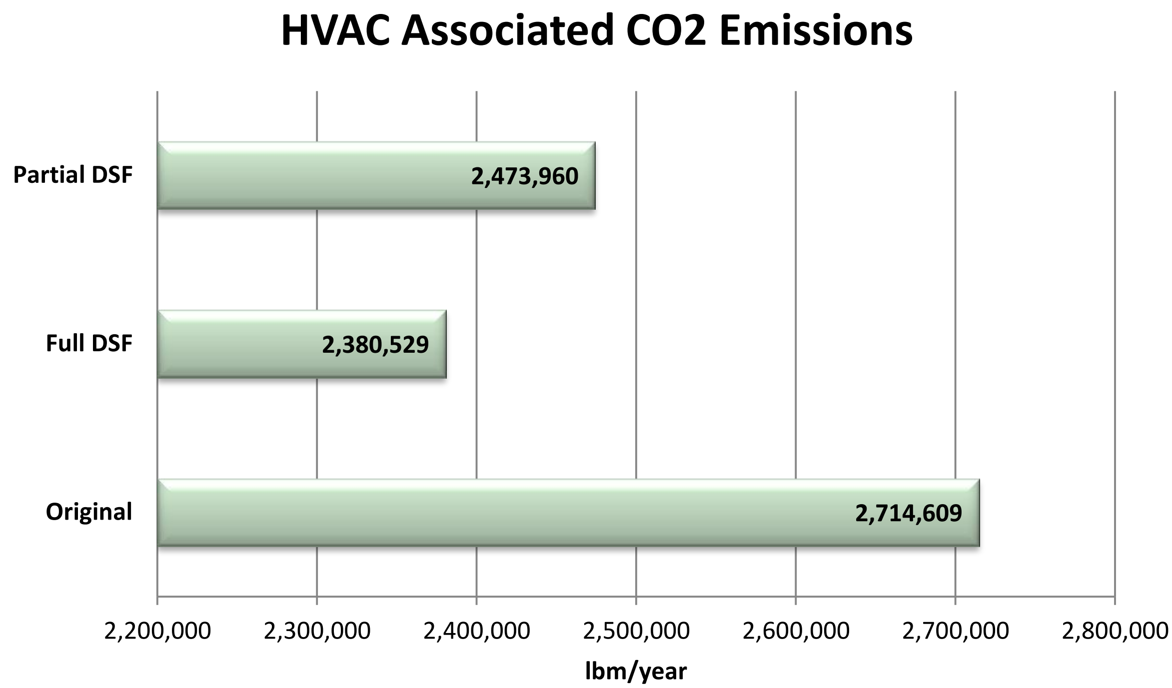



Figure 21: HVAC Associated $CO_2$ Emissions for the 3rd Floor.

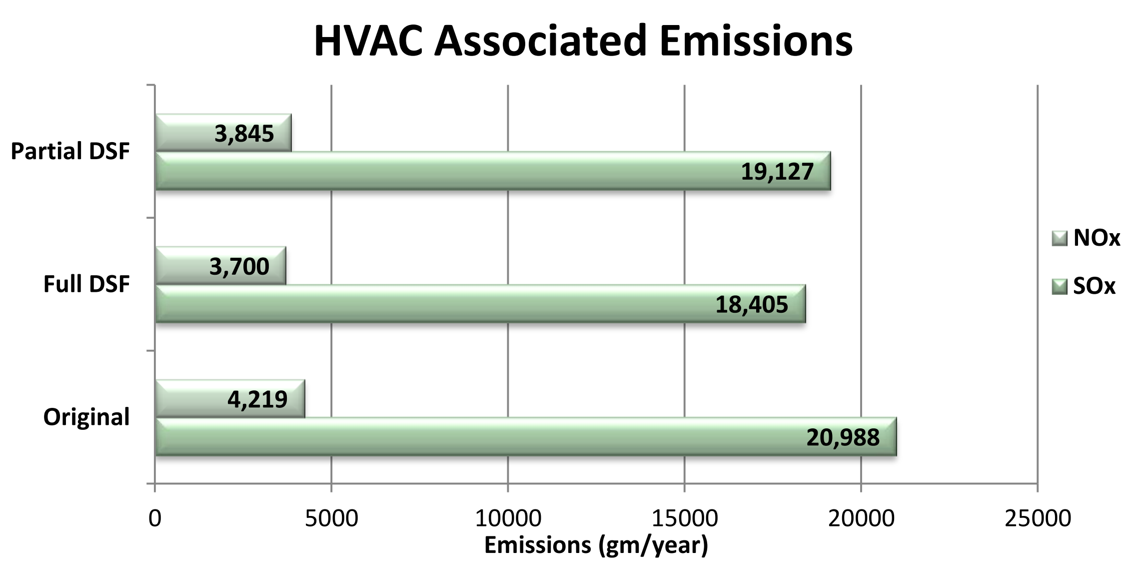



Figure 22: HVAC Associated Emissions for the 3rd Floor.

## Student Study Area Lighting Design

## Spatial Summary

The Student Study Areas throughout the Millennium Science Complex are located periodically along the perimeter of the building. Daylight integration with electrical lighting in these spaces is a focus of the design, and has been coordinated with other disciplines to ensure the most efficient overall design of the system on all fronts. Electric light in this space has been designed to complement the daylight integration and work in tandem to create a visually uniform and appealing workspace.

Since the Student Study Areas are open to the corridor, this lighting design has included a redesign of the corridor as well. The student study area and corridor designs have be transposed over the entire building.

### Drawings & Layout

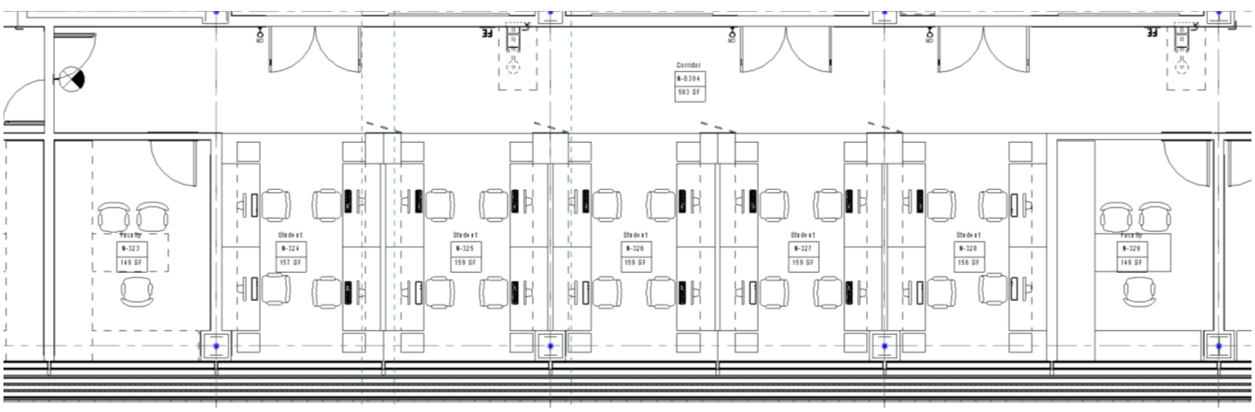


Figure 23: Student Study Area Plan.

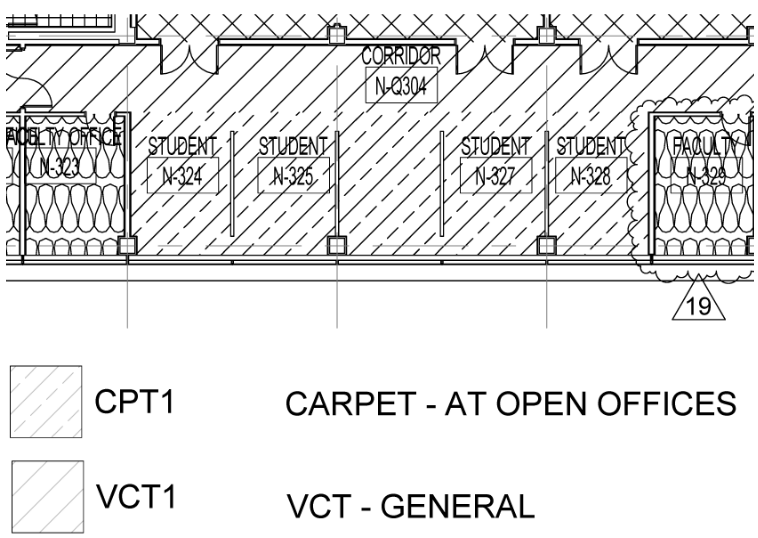



Figure 24: Corridor/Study Area Finish Floor Plan.

## Tasks & Activities

This area of the Millennium Science Complex was a challenging space to design due to the Student Study Area's layout being open to the corridor. Therefore, tasks in this area are dual natured. At any given time, an occupant may be working at a computer station transferring notes from his or her laboratory report to a word processing engine while researchers are walking by in the corridor. The corridor is used primarily for transportation throughout the building.

## Materials

**Table 10: Conference Room Materials List.**

| Surface | Reflectance | Transmittance |
|---|---|---|
| *Gypsum Ceiling* | *0.80* | |
| *Mullions* | *0.60* | |
| Interior Glazing | | 0.60 |
| *Exterior Glazing* | | *0.85* |
| *Gypsum Walls* | *0.60* | |
| *Corridor Floor* | *0.62* | |
| *Study Area Floor*** | *0.12* | |
| *Desk Surface* | *0.25* | |

**Values from AGi32 swatches for similar materials

## Design Considerations

- Study Area:
  - Considerations (IESNA Handbook)
    - Appearance of Space & Luminaires
    - Daylighting Integration & Control
    - Luminance's of Room Surfaces
    - Reflected Glare
    - Shadows
    - Source/Task Eye Geometry
    - System Control and Flexibility
    - Modeling of Faces
  - Design Criteria
    - Horizontal 30-50fc (IESNA Handbook)
    - Vertical 3fc (IESNA Handbook)
    - Power Density 1.2 W/SF (ASHRAE 90.1, Table 9.6.1)
- Corridor:
  - Considerations (IESNA Handbook)
    - Even Light Distribution
    - Direct Glare Avoidance
    - Modeling of Faces
  - Design Criteria
    - Horizontal 10fc (IESNA Handbook)
    - Power Density 0.5W/SF (ASHRAE 90.1, Table 9.6.1)

## Luminaire Schedule

**Table 11: Student Study Area & Corridor Luminaire Schedule.**

| Mark | Manuf. | Catalog Number | Description | Lamp | Ballast | Input Watts | Voltage |
|---|---|---|---|---|---|---|---|
| COR-D | Lightolier | CFS1GHP132277SO | High Performance Recessed Fluorescent Direct/Indirect 1' x 4' with Perforated Basket. | Philips: F32T8 ADV835 Alto II | Philips - Centium: ICN-2P32-SC | 34.00 | 277V |
| STD-D | Lightolier | VPS1G12PR132277SO | 1'x4' Recessed Fluorescent, 3" Deep, 12 Cell Parabolic Louvered Lens designed for intensive VDT use. | Philips: F32T8 ADV835 Alto II | Advance Mark 7: IZT-332-SC | 34-6.7W 34.16VA | 277V |

Note: Comprehensive Luminaire Schedule can be found in Appendix F: Comprehensive Luminaire Schedule.

**Table 12: Conference Room Light Loss Factors.**

| Fixture Type | LDD | LLD | RSDD | BF | Total LLF |
|---|---|---|---|---|---|
| COR-D | 0.940 | 0.968 | 0.970 | 1.00 | 0.882 |
| STD-D | 0.940 | 0.968 | 0.970 | 1.05 | 0.927 |

*LDD calculated from new IESNA guidelines for Clean Environment based on 12 month cleaning interval.

## Lighting Layout

The Student Study Ares of the Millennium Science Complex have been furnished with 20 computer stations that are setup perpendicular to the facade. The computer stations have been divided into 5 stalls, as shown in the plan detail in Figure 23. The lighting layout of the Student Study Areas use (3)-4' parabolic luminaires per computer stall. The luminaires that have been selected are designed specifically for computer spaces.

The corridor lighting design has been laid out with luminaires spaced 11' center to center while running parallel to the length of the corridor. Every third corridor luminaire has been connected to the emergency lighting system to comply with minimum pathway lighting levels exit pathways in the event of an outage. The corridor luminaires are laid out perpendicular to the Student Study Areas which provides a visual distinction between the two spaces.

## Renderings & Color Images

Figure 25: Student Study Area - Perspective View.

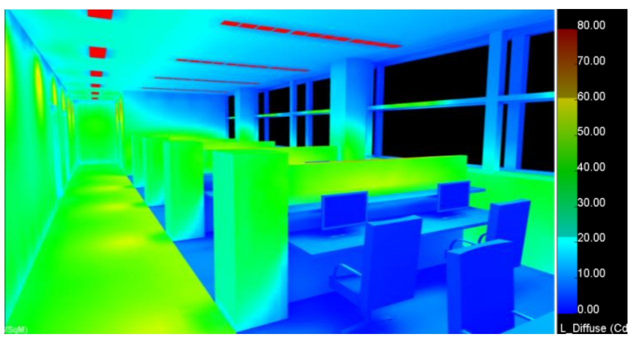



Figure 26: Student Study Area –Illuminance Pseudo Color.

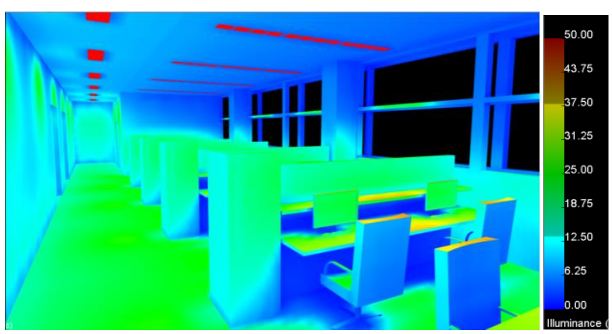
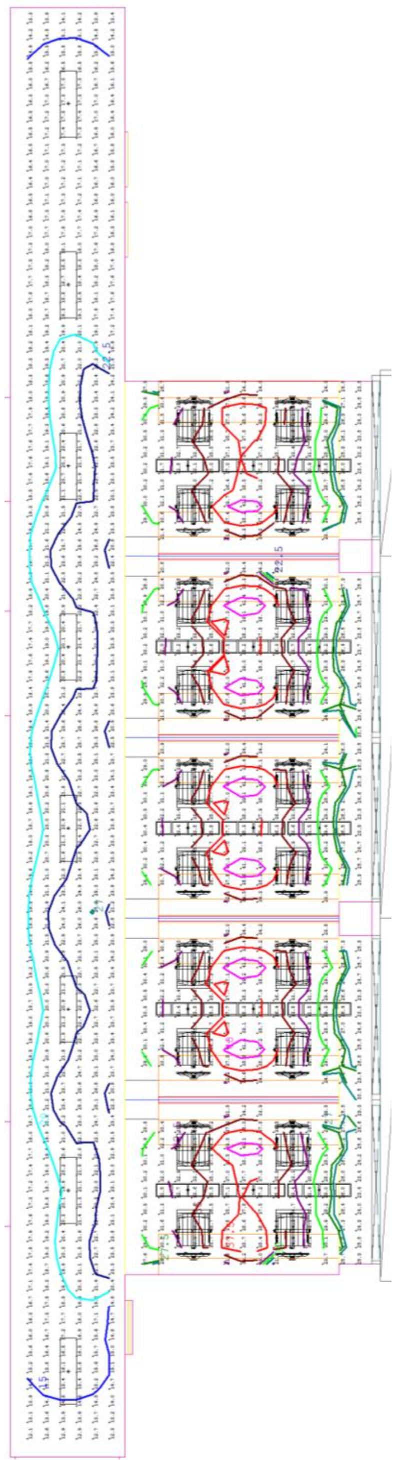



Figure 27: Student Study Area –Luminance Pseudo Color.

## Performance Summary



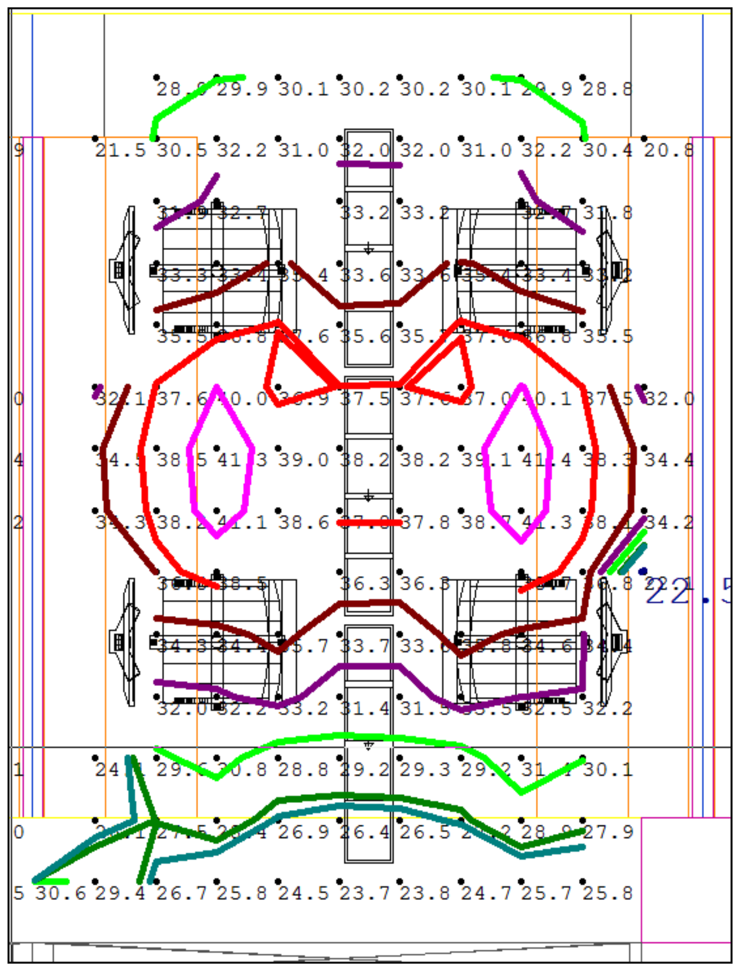


Figure 28: Student Study Area Illumination Contours - Cubical Detail,

15fc-20fc-22.5fc -25fc - 27.5fc - 30fc -32.5fc -37.5fc - 40fc

Figure 29: Student Study Area and Corridor Illumination Contours.

Table 13: Corridor & Student Study Area Lighting Performance.

| Student Study Area & Corridor Performance Data | Corridor (Stand Alone) | Corridor (By Student Area) | Study Area |
|---|---|---|---|
| Avg. Illuminance (FC) | 18.10 | 19.89 | 32.27 |
| Max. Illuminance (FC) | 20.30 | 27.20 | 40.90 |
| Minimum Illuminance (FC) | 14.00 | 12.10 | 22.20 |
| Avg/Min | 1.29 | 1.64 | 1.45 |
| Max/Min | 1.45 | 2.25 | 1.84 |
| Max/Avg | 1.12 | 1.37 | 1.27 |
| Coefficient of Variation | 0.07 | 0.16 | 0.14 |
| Uniform Gradient | 1.12 | 1.38 | 1.57 |
| Power Density (W/SF) | 0.45 | 0.45 | 0.68 |

## Electrical Lighting Controls

The corridor is a life safety transportation path, and luminaires will remain on at all times. The doors of the lab spaces actually open up into the corridor due to the nature of the lab work being completed in the lab spaces. This feature of the lab space shows the need of a speedy exit in the event of a mishap in the midst of experiments. With this in mind, it has been determined that the best option would be to have the corridor luminaires remain on at all times for safety reasons.

The student study area is unique to this project, as it is the only design space that will incorporate photosensors for dimming with regards to daylight contributions. The LRF2-DCRB-WH photosensor will dim all Student Study Area luminaires.

Occupancy sensor locations, orientation and coverage have been shown below in Figure 30. Both LOS-CUS-500 and LOS-CUS-1000 will be used. The 1000SF coverage occupancy sensor lies on both ends of the Student Study Area, covering the first and last two stalls. The 500SF occupancy sensor is positioned in the center of the Student Study Area, covering the middle stall. This layout and orientation provides maximum coverage of motion in the Student Study Area while minimizing unwanted switching of luminaires when an occupant passes by in the nearby hallway. Switching and wiring diagrams showing both photosensors and occupancy sensors are available in Appendix I: Lighting Control Cutsheets.

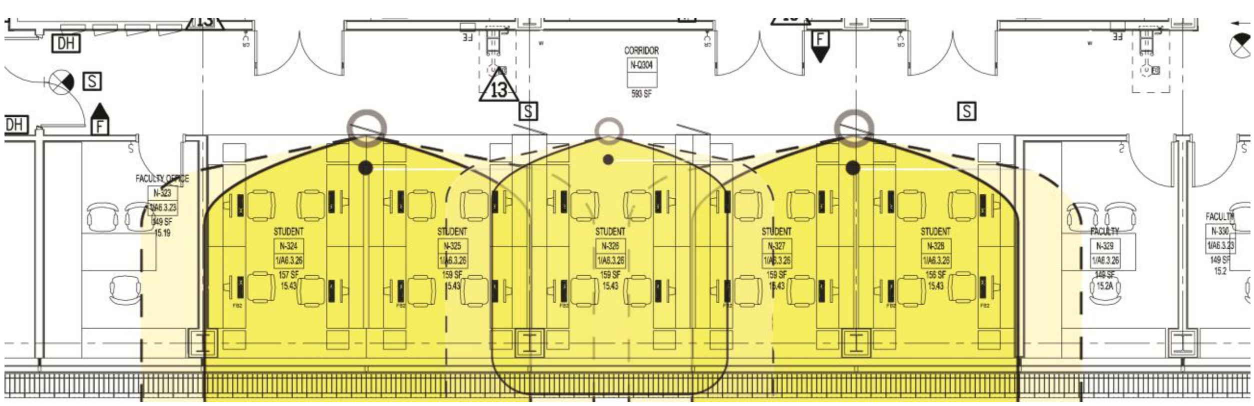



Figure 30: Student Study Area Occupancy Layout & Coverage Area.

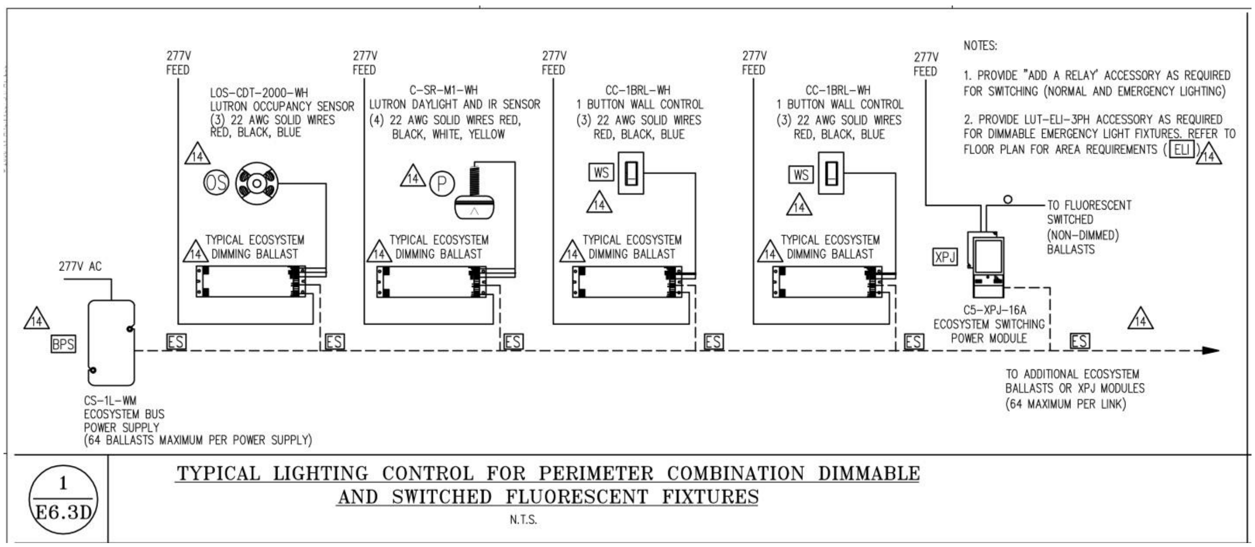



**Figure 31: Existing Dimming Wiring Diagram.**

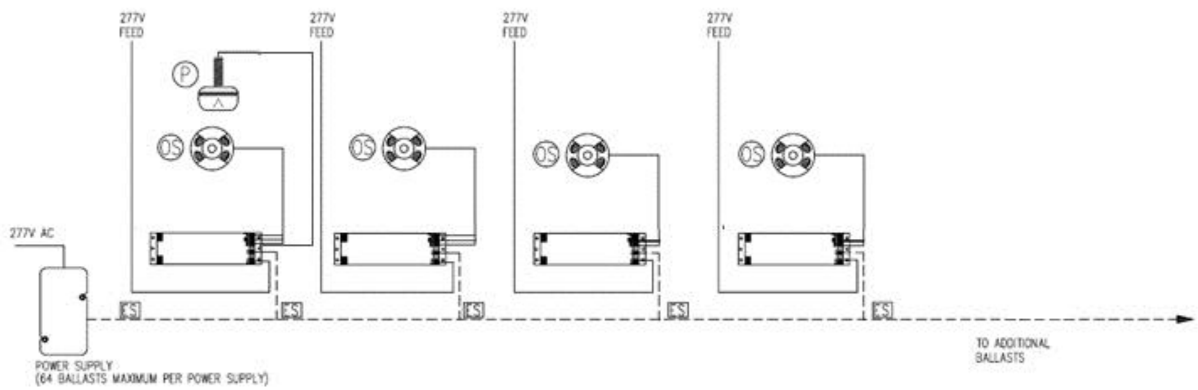



**Figure 32: Redesign of Dimming System.**

## Cost Analysis

In the process of designing the double-skin façade to be used for the Millennium Science complex, simplicity was the primary focus with hopes to minimize costs. After a full detailed estimate, the Building Stimulus estimates that the use of a double-skin façade will increase construction costs by only $71,686. The full estimate of existing facades and the full estimate of the façade redesign can be found in Appendix D: Construction Management. A summary of façade costs are shown below, Table 14: Summary of Facade Costs.

**Table 14: Summary of Facade Costs.**

| | Precast Panels | Insulation | Caulking | Metal Panels | Metal Framing | Louvers | Windows | Total |
|---|---|---|---|---|---|---|---|---|
| **Existing Façade** | $ 6,007,802 | $ 741,949 | $ 168,917 | $ 4,276,244 | $ 1,076,772 | $ 366,600 | $ 2,719,570 | $ 15,357,853 |
| **Double-Skin Façade** | $ 5,629,241 | $ 842,792 | $ 204,082 | $ 4,276,244 | $ 1,076,772 | $ 123,200 | $ 3,277,210 | $ 15,429,539 |
| | | | | | | | Cost | $ (71,686.34) |

The Building Stimulus precast panel resulted in an estimate cost savings of $5.00 SF by reducing the quantity of concrete by approximately 30%, or 2 C.Y. for every 22’ x 11’ panel. By definition, the double-skin façade will require two ‘skins’ of glazing. The majority of costs incurred due to the double-skin façade resulted from installing a second glazing system. However, Building Stimulus was able to save a significant amount of costs by removing the existing static louver system across the entire Millennium Science Complex.

## Conclusion

### IPD

Throughout the design process to create an efficient façade system between four different design disciplines, issues were inevitable due to the differing goals of each member of Building Stimulus. Primary focuses generally revolved around cost savings and system efficiency. At first Building Stimulus had set individual goals for their respective aspects of the building enclosure. Once the individual goals were established, as a team Building Stimulus met and discussed a method that allowed for the best design approach to satisfy the majority of criteria set by designers. The implementation of a double skin façade was agreed upon by all team members as the most complete building enclosure for meeting design criteria of the Building Stimulus team.

Several originally unforeseen issues arose throughout the course of the design process. One of the more pressing issues was accurately modeling the airflow within the double-skin façade, as it is a dynamic system that is constantly dependent upon temperature, wind speed, and solar heat gain. To further complicate modeling of the airflow for the dynamic system between the interior and exterior glazing, the frosted glass louvers incorporated also significantly affect the airflow. In a non-vertical position, as shown in the figure below for the images with blue and yellow arrows, the louvers greatly constrict the area between the louver edge and glazing for air to flow through, thus increasing the velocity at these instances. At the same time, this reduction in area allows an accumulation of air to build up just before the openings since the louvers create compress and release areas throughout the façade for the air flow. The airflow is not altered as much in the angled position. Therefore, the greatest concern with airflow restriction arises when the shades are in a horizontal position, as they cover 19 in of the 24 in air gap between glazings.

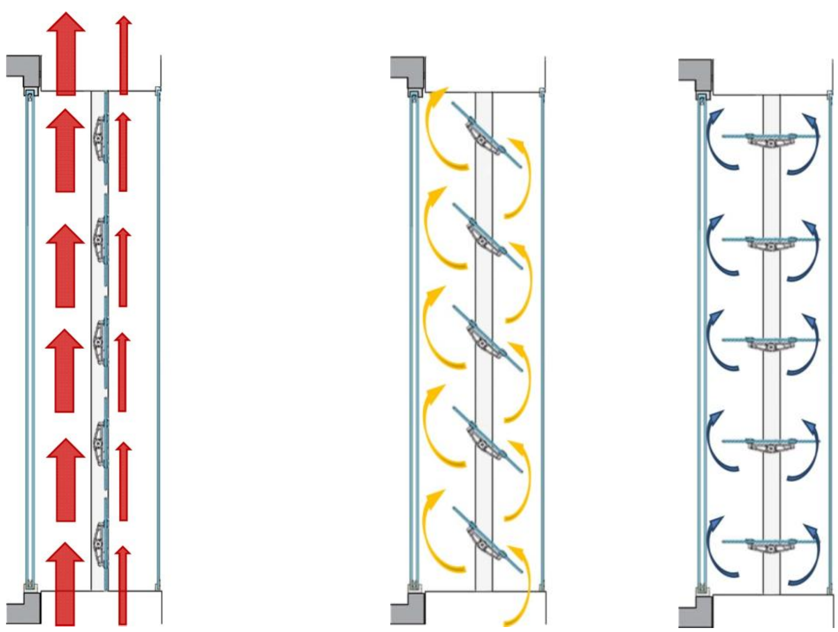


Figure 33: Windflow Around Solar Shades.

The Girasol automatic adjustment system for the louvers uses pressurized gases to rotate shades. The system uses two gas containers to push and/or pull actuators. One container is exposed to direct sunlight, while the other is shielded from the suns direct rays. The louvers will move to a more vertical position when exposed to direct solar radiation to help minimize both heat gain, and high illuminance levels in perimeter spaces. In this situation, the air in the double skin façade will be at its warmest and fastest velocity. The position of the louvers will allow for the hot air to rise in a virtually unobstructed path.

In contrast, when there is little to no direct solar gain, the louvers will move to a more horizontal position to allow more daylight illuminance into the space to maximize benefits from dimming electrical lighting. With little solar gain on the façade in this situation, the temperatures are not as high as when in direct sunlight. A lower temperature differential between the air gap and the exterior environment, allows air to move slower, and in turn creates less of a hindrance than what was originally thought.

The design of the precast panel proved to be highly dictated by providing adequate clearance between the inner faces of the interior and exterior enclosures to ensure that a continuous air gap would be achieved for thermal efficiency and the louvers used to optimize daylighting efficiency would have enough space to operate.

In terms of constructability, the double skin façade design presents several issues that must be acknowledged. The estimated cost to build the double skin façade does not place a significant financial burden on the owner, yet the constructability issues of the system demands significant monitoring of the construction process to avoid serious safety and scheduling issues. On double skin façade elevations, it is imperative to properly install a vapor barrier within the double skin plenum. As welding occurs to secure the panel to the structure, precautions must be taken to ensure vapor or thermal barriers are not damaged. Extra safety precautions must be taken as well during the installation of precast panels. With steel workers potentially working in the spaces between large precast panels and steel members, the panels must be safely secured before anyone enters those spaces.

## Daylighting Analysis

Daylighting analysis program, DAYSIM (Penn State Release), has been utilized to determine the effectiveness of using both shading devices and photosensors to dim luminaires in terms of annual energy savings.

Table 15: Cost Savings from Dimming Luminaires.

| | SEMS | NWMS | SWLS | NELS | Total |
|---|---|---|---|---|---|
| Annual Savings (kWh) | 788.86 | 776.12 | 703.38 | 861.05 | 3718.4 |
| Annual Savings ($) | $63.11 | $62.09 | $56.27 | $68.88 | $297.50 |
| Modeled Facade Length | 55’ | 55’ | 55’ | 55’ | N/A |
| Dimmable Rooms Facade Length (3rd Floor) | 66’ | 66’ | 99’ | 99’ | 330’ |
| Dimmable Rooms Facade Length (2nd Floor) | 121’ | 121’ | 209’ | 209’ | 660’ |
| Dimmable Rooms Facade Length (1st Floor) | 0’ | 0’ | 0’ | 176’ | 176’ |
| Annual Savings | $277.68 | $273.19 | $371.38 | $675.06 | N/A |
| Grand Total Building Annual Savings | $1597.36/yr | | | | |

Though the overall cost savings from dimming electrical lighting can be considered low in comparison to the cost of the system, there are other benefits to integrating daylighting.

Occupant comfort is virtually unquantifiable in terms of money. Occupants of the perimeter spaces will see an increase in productivity and overall satisfaction of their workspaces with daylight integration. Daylight provides excellent color rendering, and provides an impression of brightness to the space. These two factors are essential for increase the appearance of a space, the overall visual environment.

Shading blades made of frosted glass allowed daylight to enter the space by diffusing it and spreading it out throughout the space. Frosted glass blades helped limit direct sunlight penetration while maintaining a view to the exterior. This exterior view is very important to achieve user comfort and overall satisfaction.

The solar shading devices used in this design lower the solar heat gain for the perimeter spaces on the Southeast Materials Science and Southwest Life Science facades.

## Energy Modeling

The Millennium Science Complex is an intensive research lab with extensive electrical plug loads and research equipment throughout. Therefore, the use of ASHRAE suggested electrical design load watts/SF according to the type of room in question would be an underestimation for mechanical equipment sizing. The use of Revit MEP when designing an electrical system can allow the designer to provide each room with an actual connected load and power density for the mechanical design.

The use of an in depth program such as Revit MEP allows for quick integration between disciplines. Specifically, Mechanical and Electrical designers can exchange accurate design loads almost instantaneously. The process of setting up a Revit MEP Model can be intensive up front, yet allow for easy changes to systems and designs closer to the end of the design timeline. This was achieved during Building Stimulus' design process.

Building Stimulus took the opportunity to explore the use of Revit MEP as both an electrical design tool and a BIM/IPD design tool. Throughout the design process, electrical design loads were constantly modeled and updated in Revit MEP. Simultaneously, the redesign of the mechanical system was analyzed, using the existing building energy model created from the fall semester as a base. Once the electrical loads were completed, they were used to update the mechanical system's redesign to provide a more accurate energy profile of the building. This portion of the report illustrates the iterative process Revit MEP provides in the design process to further facilitate integration among the design team.

## Mechanical Design

The current air distribution system used in the Millennium Science Complex is handled by variable air volume boxes for all the spaces. Air is supplied to the spaces through ceiling mounted low velocity radial diffusers to maintain the room temperature set-points using a traditional overhead ducted system. The current design of the air handling system is very efficient in that it utilizes several energy recovery techniques. All of the lab and vivarium spaces are supplied by 100% outdoor air AHUs which include an enthalpy heat recovery wheel and integral exhaust fan to operate concurrently with the supply for each unit. The fume hood and vivarium exhaust fans are also equipped with run around energy recovery coils that circulate glycol with two pumps to the preheat coils in the air handling units. For the remaining non-lab spaces within Millennium Science, the AHUs utilize outdoor air economizers to save energy for the three 33,000 cfm AHUs.

After analyzing the spaces throughout the third floor of Millennium Science, the corridors and offices presented themselves as optimal candidates for placement of active chilled beams. These spaces are considered to be load heavy, so the air supply is not driven by the ventilation requirements as in the lab spaces. Active chilled beams are commonly recommended for spaces that have high solar heat gain loads compared to the total thermal load, which is the case for the perimeter office spaces since they are directly exposed to the solar heat gain from the façade. As proposed, the chilled beams were used to take care of the cooling load instead of traditional excess air change via the current VAV boxes in these spaces. Utilizing this technology helped save air handling unit sizes and ventilation loads due to the reduction in airflow required to handle the space loads. This in turn allowed optimization of the HVAC system to maintain energy efficiency and indoor air quality. To achieve this optimization, an active chilled beam system coupled with a dedicated outdoor air system was modeled to replace the current variable air volume system for the perimeter office spaces and corridors. This system was designed to work in concurrence with the lighting design to utilize the application of luminaire integrated chilled beams.

## Chilled Beam Analysis

### Chilled Beam

In order to maximize integration among the design team, multiservice active chilled beams were selected for utilization in the redesign. Multiservice chilled beams incorporate not only the airflow and temperature control to provide proper thermal comfort and indoor air quality, as per ASHRAE 62.1, but also lighting and fire protection with integrated sprinklers. Several manufacturers were reviewed by Building Stimulus to select a system that best fit Millennium Science Complex's needs. Although chilled beams are not prevalently used throughout the United States, as they are more common in Europe, several companies do manufacture these relatively new systems in the US. Selecting a manufacturer that was located within the US was an important consideration for Building Stimulus due to its impact for cost and transportation requirements. One of the first manufacturers researched by Building Stimulus was Dadanco, since it is an American based company and has a manufacturing facility in Pennsylvania. It was considered as a possible candidate due to its very close manufacturing location to the building site and also for its BIM coordination, since Revit models are provided from the manufacturer's website. However, Dadanco does not offer the multiservice beams that provide the integration Building Stimulus was looking for to greater develop coordination among the team's disciplines.

Ultimately, the manufacturers that offered the best opportunities for the design team and Millennium Science in terms of integration were Carrier, Krueger by Halton, and Semco. Not only did these manufacturers provide multiservice active chilled beams, but also Revit models of their products to help facilitate the BIM process through design. Each product enables the coordination between the thermal comfort requirements, lighting, and fire protection services. Both Carrier and Semco are American based companies, with distribution centers located throughout the US, with centers as close as Virginia to the building site. Krueger is the American division of Halton (a company based out of Finland) that is headquartered out of Texas with the closest distribution center to MSC's site located in North Carolina. See Appendix C: Energy Analysis for cut sheets and full specifications of the multiservice chilled beams, including the component diagrams, construction sequence and serviceability.

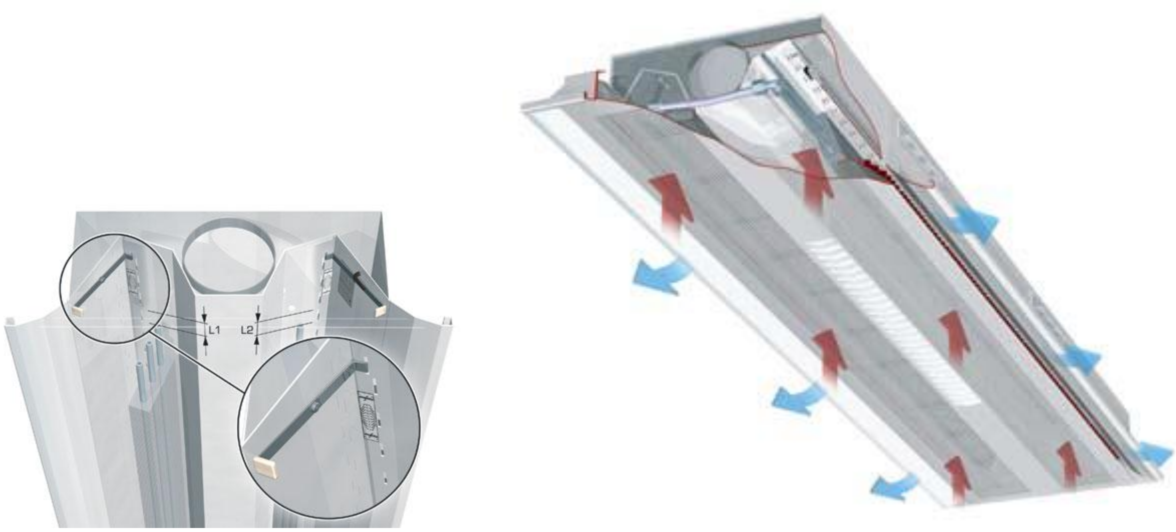



Figure 34: Semco Chilled Beam with Flow Control.

Semco's active chilled beams provide several advantages. The design of the chilled beam allows it to be equipped with Semco's patented Flow Pattern Control, to allow the beam air flow to be adjusted, just like a ceiling diffuser, which allows it to have a low water pressure drop and better compensate for heat gain through windows. This flow pattern adjustment makes equipment scheduling and installation easier because individual chilled beams do not have to be specified for each space. They can be adjusted upon installation. Semco's chilled beams also have an optional feature, "Comfort Control," that allows the amount of induction air and cooling capacity to be adjusted.

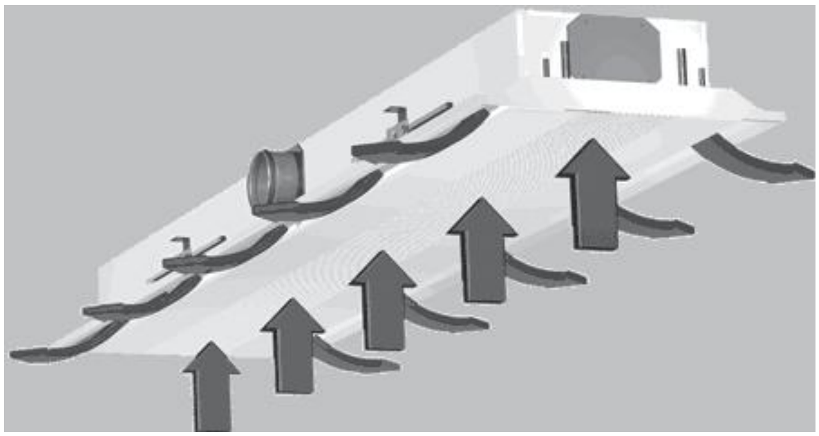


Figure 35: Krueger Chilled Beam.

Figure 36: Krueger Chilled Beam Office Application.

Chilled beams provided by Krueger also have an advantage to control air flow with their optional Halton Air Quality (HAQ) control attachment; however, it does not come standard in the beam design. For the design analysis, the Semco chilled beams, model IQID, were used as the basis for Millennium Science due to the company's availability for communication and information sharing as well as the Krueger chilled beams due to their direct lighting output profile.

## Primary Energy Use

As a way to improve the overall efficiency performance of the Millennium Science Complex with respect to energy, a four-pipe, active chilled beam system was utilized in the perimeter spaces and corridors of the building to handle the heating and cooling loads. This system required several elements to be considered during the selection process to adequately enhance the efficiency performance. Energy use, total emissions, and overall lifecycle costs associated with the system were analyzed to adequately determine the viability of this alternative. The initial energy model developed was based on the fall semester's Trane TRACE model to complete the energy and emissions analysis.

The energy model allowed a comparison to be made between the previously noted existing variable air volume system and the active chilled beam system for the perimeter spaces and corridors, for the third floor of Millennium Science. According to the results of the analysis, the active chilled beam system is expected to achieve greater performance for energy consumption, total emissions, and operating costs. Accounting for dehumidification became an issue during the design of the system since chilled beams are only able to remove the sensible load. Therefore, the central air handling system was designed to still take care of the latent load, which was done by coupling the chilled beam system designed for the perimeter office spaces and corridors with a DOAS system. The DOAS system was modeled with a total enthalpy wheel, with a prescribed effectiveness of 0.64. By decoupling the ventilation and space conditioning requirements, the DOAS AHU was able to accommodate 100% of the space latent loads and outdoor air latent loads. Figure 37 is a schematic of the energy recovery techniques used to develop the system. It was modeled with both a total energy wheel and sensible only wheel to provide optimal performance.

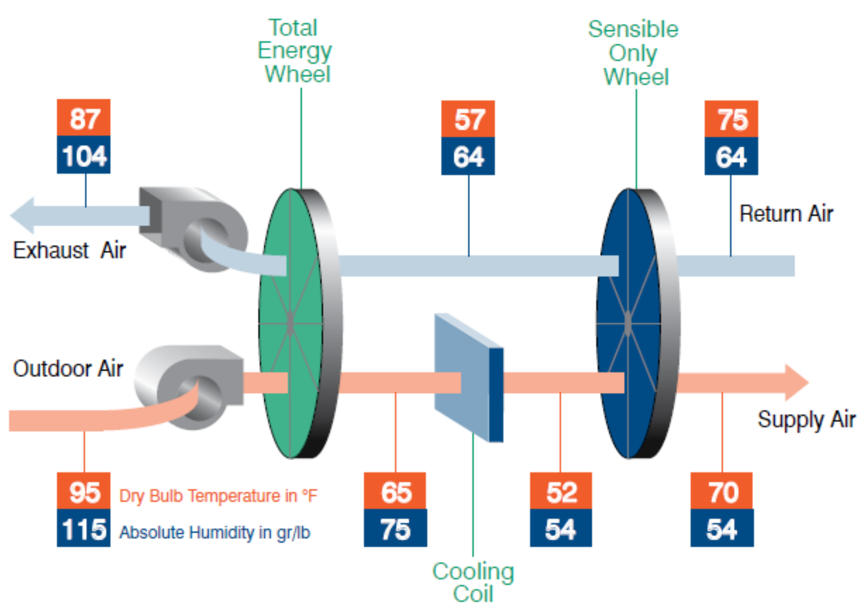



Figure 37: Dual Total Energy Wheel with Free Reheat, courtesy of Semco.

The active chilled beam system configuration, as shown in Figure 38, does provide some energy savings for the site and source energy consumption as compared to the existing VAV system by reducing the site energy use from 7,618 MBtu/yr to 7,441 MBtu/yr. This is viewed as a 2.3% savings in energy for the third floor alone.

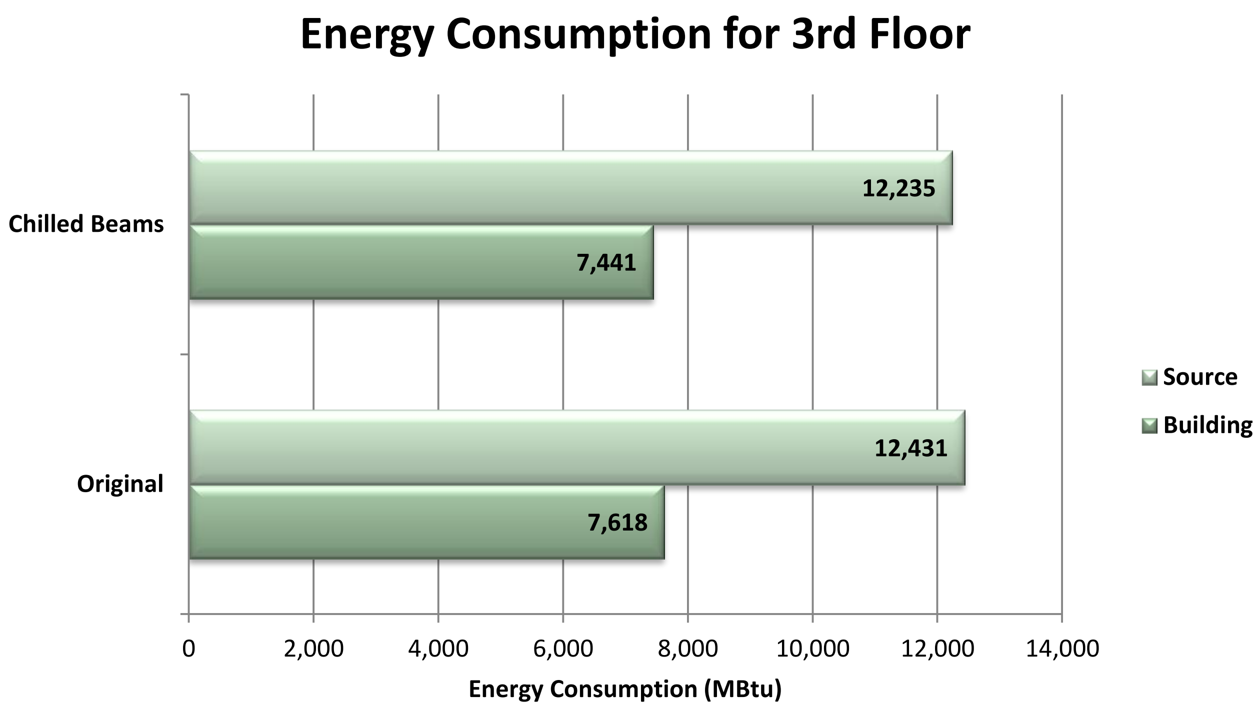



Figure 38: Third Floor Energy Consumption.

These energy savings can be accounted for due to the reduced airflow needed for the spaces. Utilizing the active chilled beam system allowed the airflow to be reduced from 29,390 cfm to 6,506 cfm for the third floor, allowing the air handling unit to be reduced for the less airflow.

## Source Energy Associated Emissions Analysis

In continual accordance with Building Stimulus' design goal of improved efficiency, reduction of source energy associated emissions was also pursued in the redesign. The emissions analysis was based on equivalent pounds of carbon dioxide, nitrous oxide, and sulfurous oxide pollutants. As previously mentioned, the model simulated was based on the third floor of the Millennium Science Complex using the base model. Figure 39 and Figure 40 show a decrease of 63,022 $lb_m$ of equivalent carbon dioxide emissions and a 487 gm/year decrease in nitrous oxide for the third floor alone.

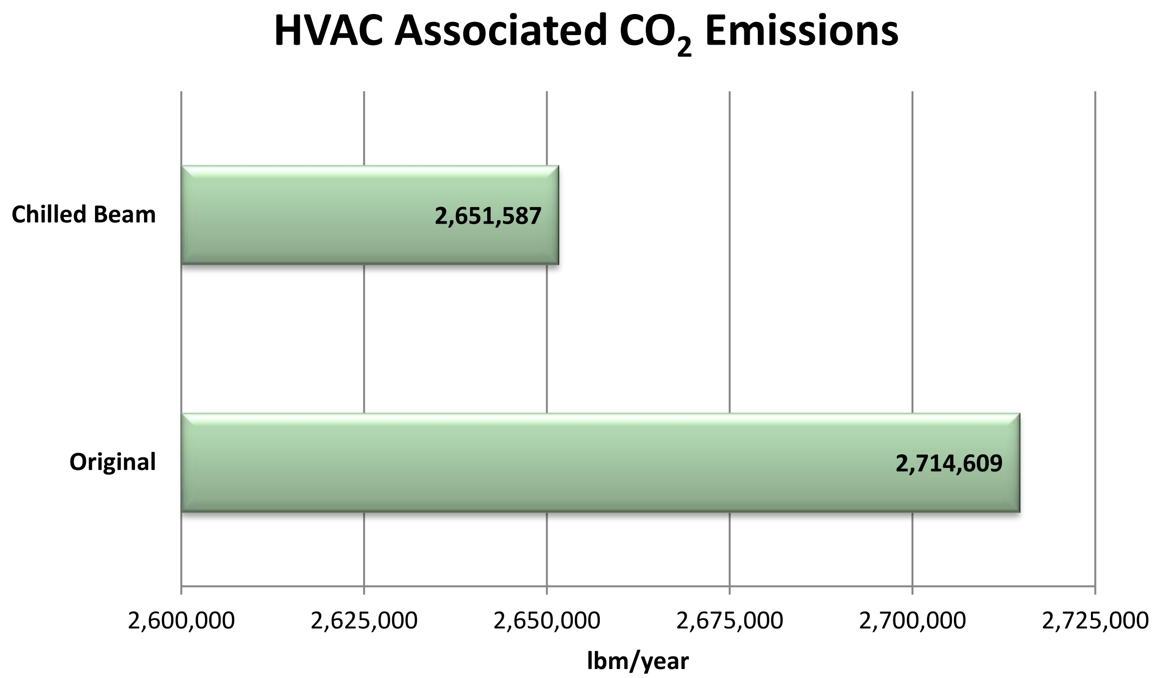



Figure 39: HVAC Associated $CO_2$ Emissions for the Third Floor.

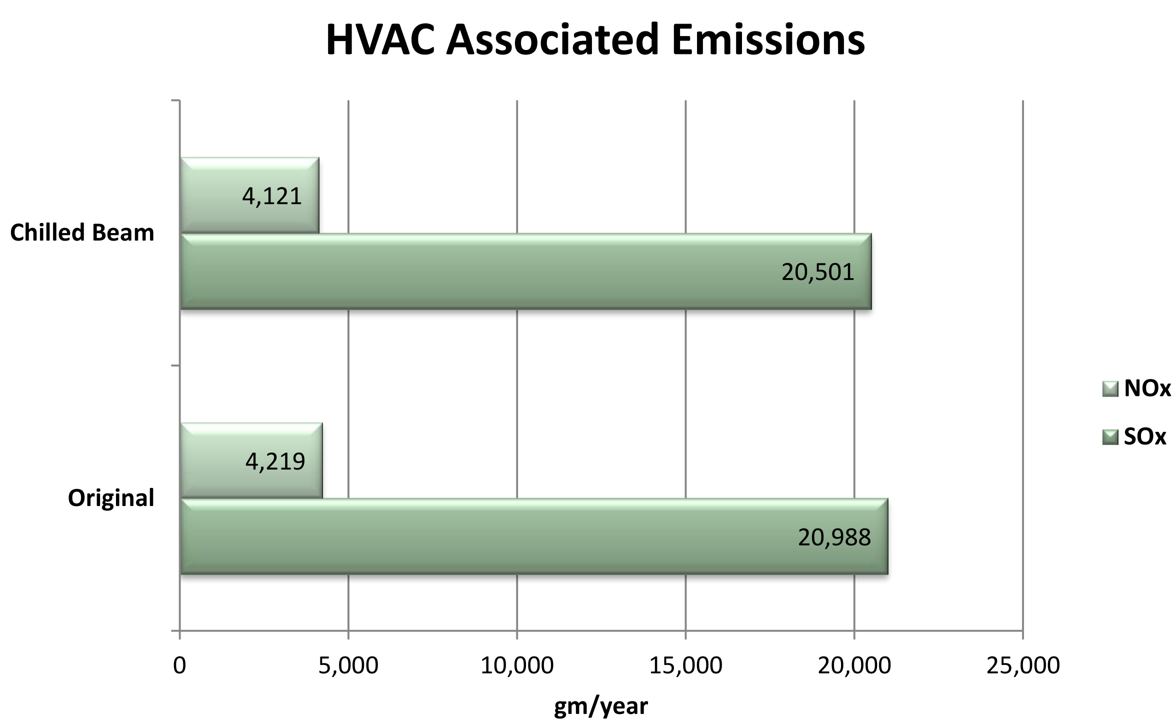



Figure 40: HVAC Associated NOx and SOx Emissions for the Third Floor.

## Indoor Air Quality Analysis

Using knowledge attained from the Master's course, AE 552: Indoor Air Quality, the air conditions of the spaces replaced with active chilled beams were analyzed on a qualitative basis. The nozzles in the active chilled beam use high pressure to provide very high velocities at the inlets to create turbulence. This turbulence flow allows the air that is re-circulated around the cooling coil to become better mixed throughout the space, which results in less stratification of the air to provide better thermal comfort for the occupants. It greatly reduces the risk of drafts and large cold air deposits due to the induction of the air flow as well, allowing it to adhere to ASHRAE Std. 55.

Due to the use of a DOAS system to handle the latent loads for the spaces, the only air now supplied to the perimeter rooms is outdoor air. This eliminated the possibility of decreasing the quantity of outdoor air supplied, as per ASHRAE Standard 62.1 minimum outdoor air requirements, to the space when the load increases, as there is a possibility for this to happen with the original VAV system. For the original VAV system, dampers are required to adjust according to space load fluctuations to properly condition the space. However, if the dampers are not correctly set, inadequate ventilation air supply may be provided to the spaces, which lowers the indoor air quality of the space and enhances the possibility to re-circulate possible contaminants, such as $CO_2$ from the occupants.

## Chilled Beam Lifecycle Cost Analysis

Figure 41 illustrates the decreased electricity consumption expected for the use of chilled beams to service the perimeter spaces. The third floor is able to consume 17,598 kWh less per year and this equates to a total building savings of 107,934 kWh per year.

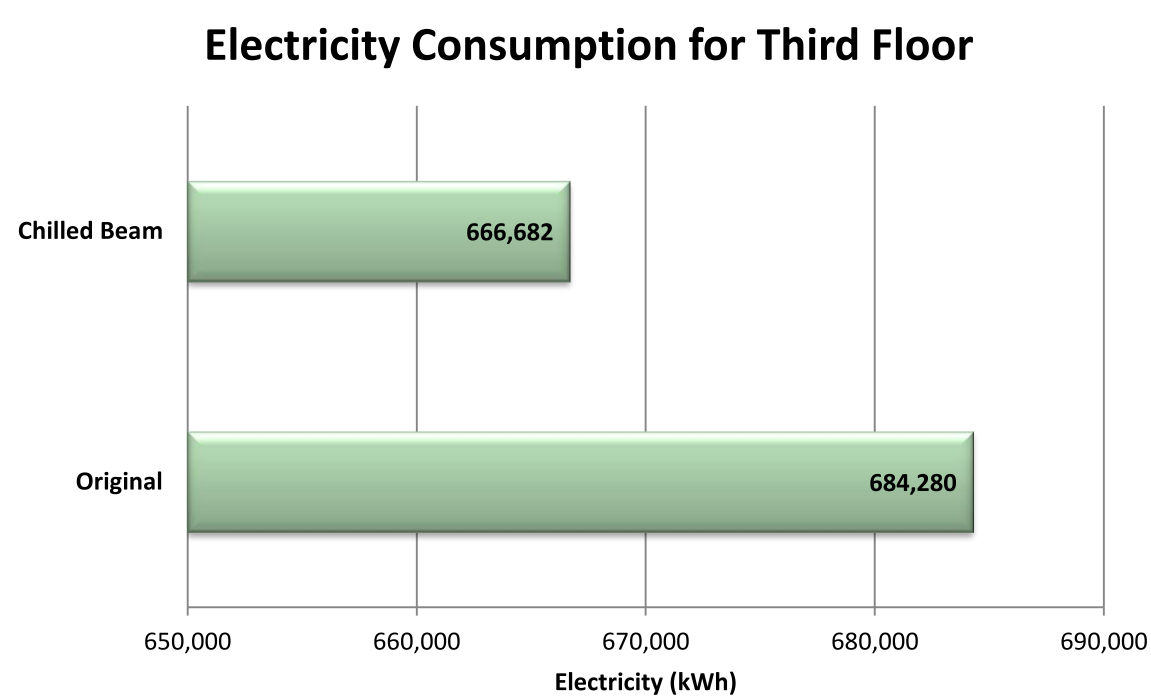



Figure 41: Third Floor Electricity Consumption.

From this savings in electricity consumption, in conjunction with the other utilities, as shown in Figure 42, a total utility cost savings of $15,720 for the third floor. This allows the entire building to decrease utility costs by $96,416 per year.

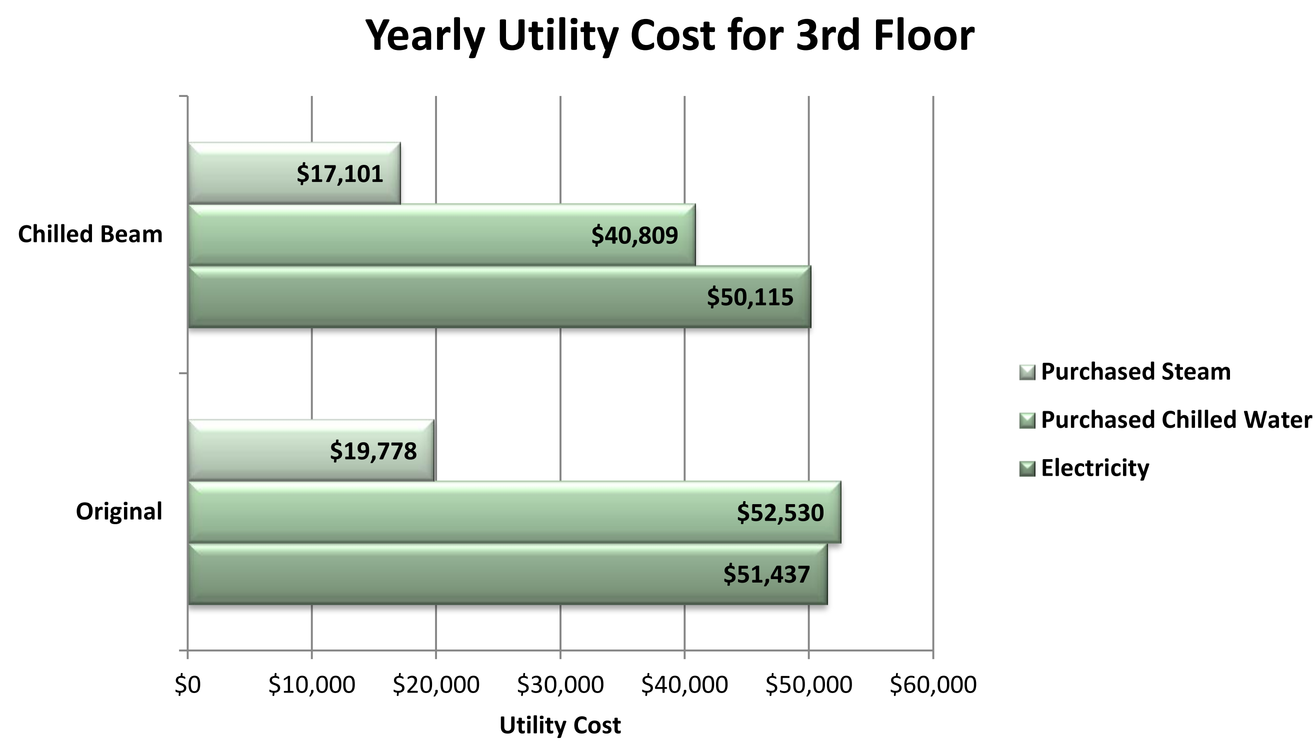



Figure 42: Utility Cost for HVAC Redesign.

## Luminaire Integration

The lighting layout in the typical office has been integrated will mechanical chilled beams. There is a single twelve foot integrated chilled beams/luminaire down the center of the room. This luminaire layout in the ceiling has been chosen to match that of the adjacent Student Study Areas. Matching layouts of perimeter spaces allowed the visual uniformity to be maximized as viewed from the exterior.

The chilled beams selected for mechanical design has a setup for either one or two lamp configurations per four foot in length. The Krueger ADC chilled beam offers only lamping for 21W, 28W and 35W T5 Luminaires. Configurations using one using the single-lamp per four foot option were not able to meet the IESNA design criteria of 30fc average on the work-plane of the office. The use of two-lamp per four foot length of chilled beam configurations with 21W T5 lamps creates an average value of 29.28fc on the work-plane. This includes a minimum of around 17fc in the corners of the room, while producing around 40fc in the center of the F-shaped desk.

Detailed electrical lighting design is discussed in detail in the following section.

## Office Lighting Design

### Spatial Summary

Staff and Faculty Offices line the exterior of the Millennium Science Complex. These spaces are on each floor of the building. There is an F- shaped desk in each office that allows for plenty of desk space. Each office is 10'4" x 14'7", for a total of 150.5SF each.

### Drawings & Layout

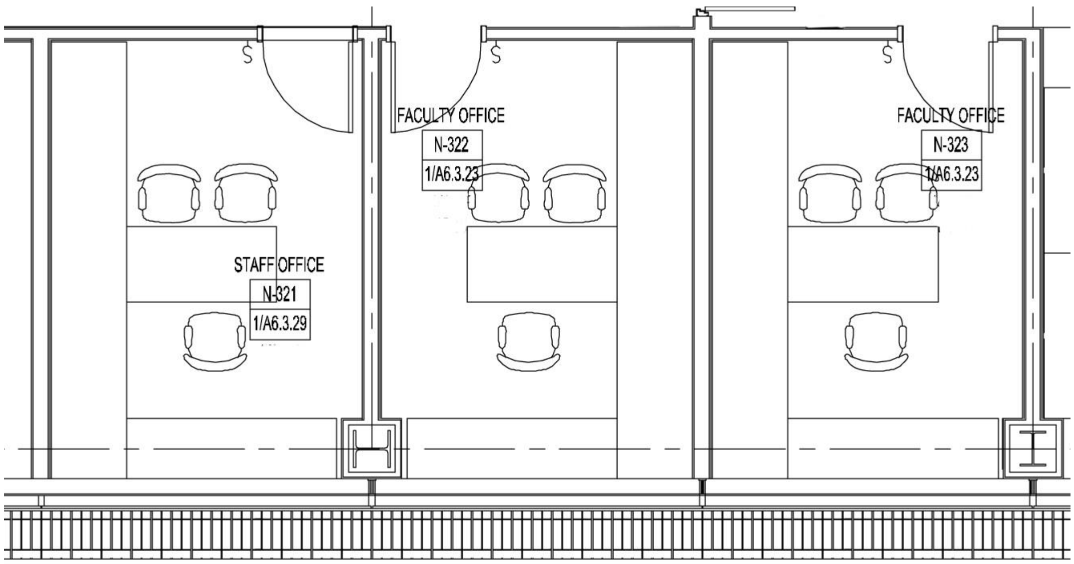



Figure 43: Typical Staff & Faculty Office - Plan View.

### Tasks & Activities

General office tasks will take place in these spaces. Tasks such as typing and computing will take place with use of a flat-screen monitor and computer. Furniture layout also indicates that this space will be able to be used for small meeting tasks involving two to three people.

### Materials

Table 16: Conference Room Materials

| Surface | Reflectance | Transmittance |
|---|---|---|
| ACT Ceiling | 0.78 | |
| Interior Glazing | | *.62* |
| Exterior Glazing | | *.85* |
| Door** | 0.50 | |
| Door Trim** | 0.50 | |
| Floor** | 0.13 | |
| Wall | 0.76 | |

**Values from AGi32 swatches for similar materials

## Design Considerations

- Private Office:
  - Considerations (IESNA Handbook)
    - Appearance of Space & Luminaires
    - Direct Glare Avoidance
    - Modeling of Faces
    - Color Rendering
    - Uniformity
    - Source/Task/Eye Geometry
    - Daylighting Integration
  - Design Criteria
    - Horizontal 30-50fc (IESNA Handbook)
    - Vertical 5fc (IESNA Handbook)
    - Power Density 1.1 W/SF (ASHRAE 90.1, Table 9.6.1)

## Luminaire Schedule

**Table 17: Typical Office Luminaire Schedule.**

| Mark | Manuf. | Catalog Number | Description | Lamp | Ballast | Input Watts | Voltage |
|---|---|---|---|---|---|---|---|
| OFF-D12 | Kruegar | Custom | 4'x12' integrated chilled beam luminaire. | (6) Philips: F21T5 835 Alto 40 PK | Philips: ICN-2S28-N | 147.0 | 277V |
| OFF-D8 | Kruegar | Custom | 4'x8' integrated chilled beam luminaire. | (4) Philips: F21T5 835 Alto 40 PK | Philips: ICN-2S28-N | 98.0 | 277V |
| OFF-D4 | Kruegar | Custom | 4'x4' integrated chilled beam luminaire. | (2) Philips: F21T5 835 Alto 40 PK | Philips: ICN-2S28-N | 49.0 | 277V |

**Table 18: Typical Office Light Loss Factors.**

| Fixture Type | LDD | LLD | RSDD | BF | Total LLF |
|---|---|---|---|---|---|
| OFF-D12 | 0.900 | 0.968 | 0.970 | 1.02 | 0.862 |
| OFF-D12 | 0.900 | 0.968 | 0.970 | 1.02 | 0.862 |
| OFF-D12 | 0.900 | 0.968 | 0.970 | 1.02 | 0.862 |

*LDD calculated from new IESNA guidelines for Clean Environment based on 12 month cleaning interval.

## Renderings &Color Images

Figure 44: Typical Office - Perspective Side View (All Luminaires On).

Figure 45: Typical Office - Perspective Side View (Half Luminaires On).

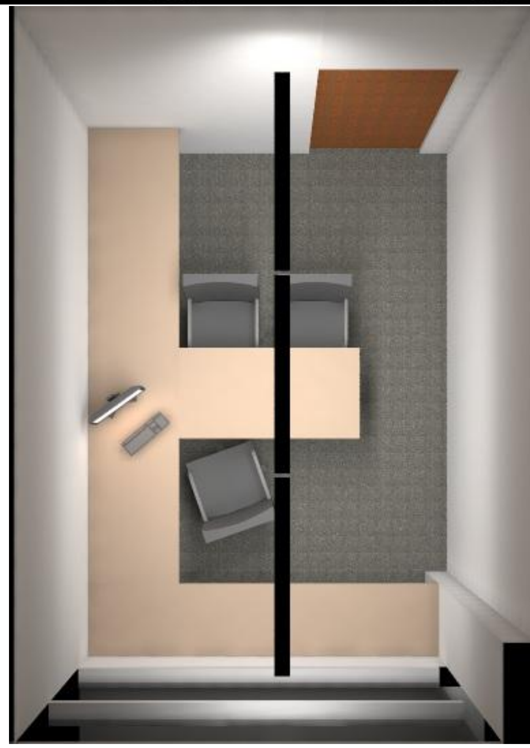


Figure 46: Typical Office - Perspective Top View (All Luminaires On).

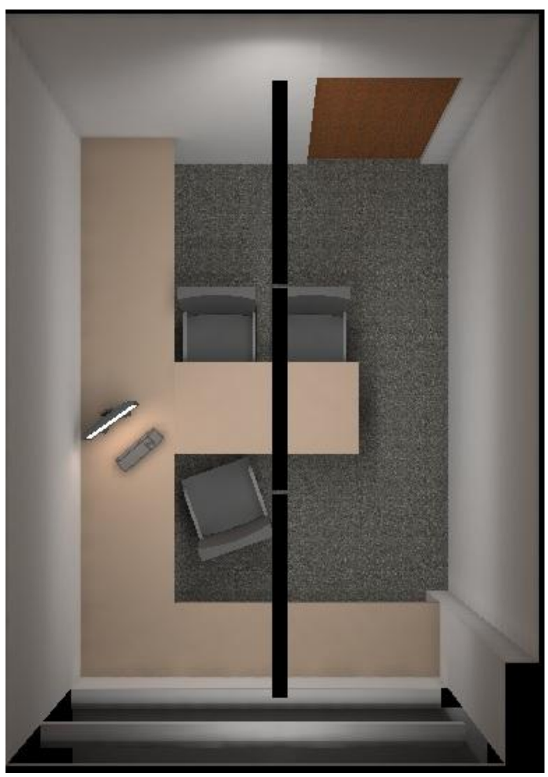


Figure 47: Typical Office - Perspective Top View (Half Luminaires On).

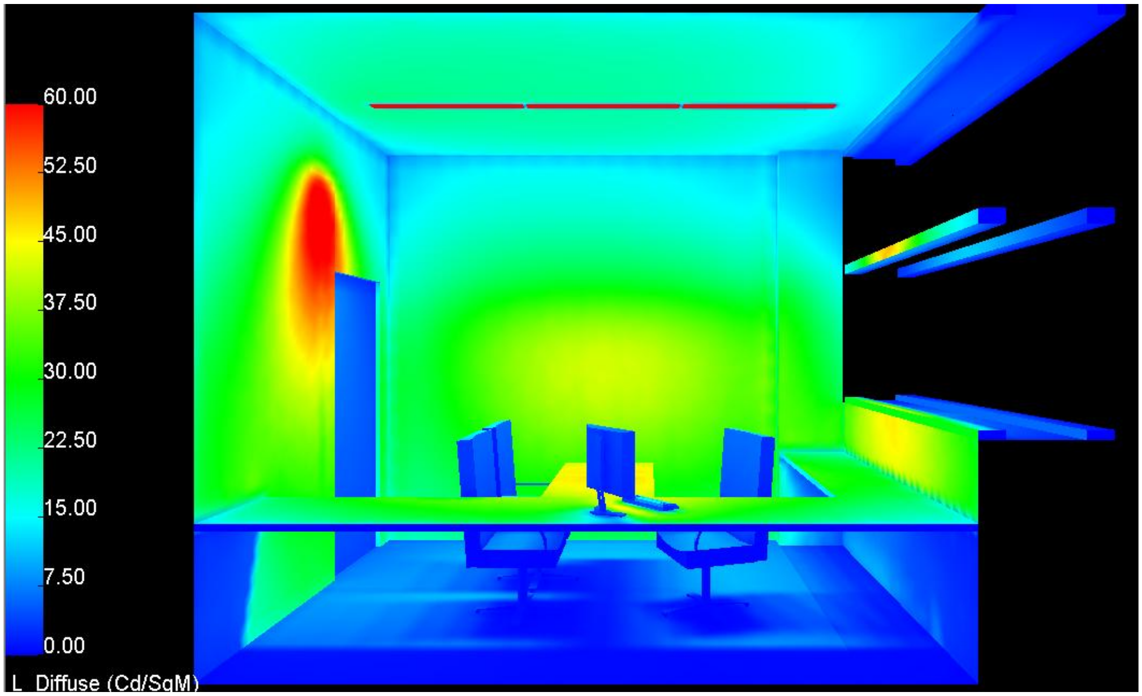



Figure 48: Typical Office - Luminance Color (All Luminaires On).

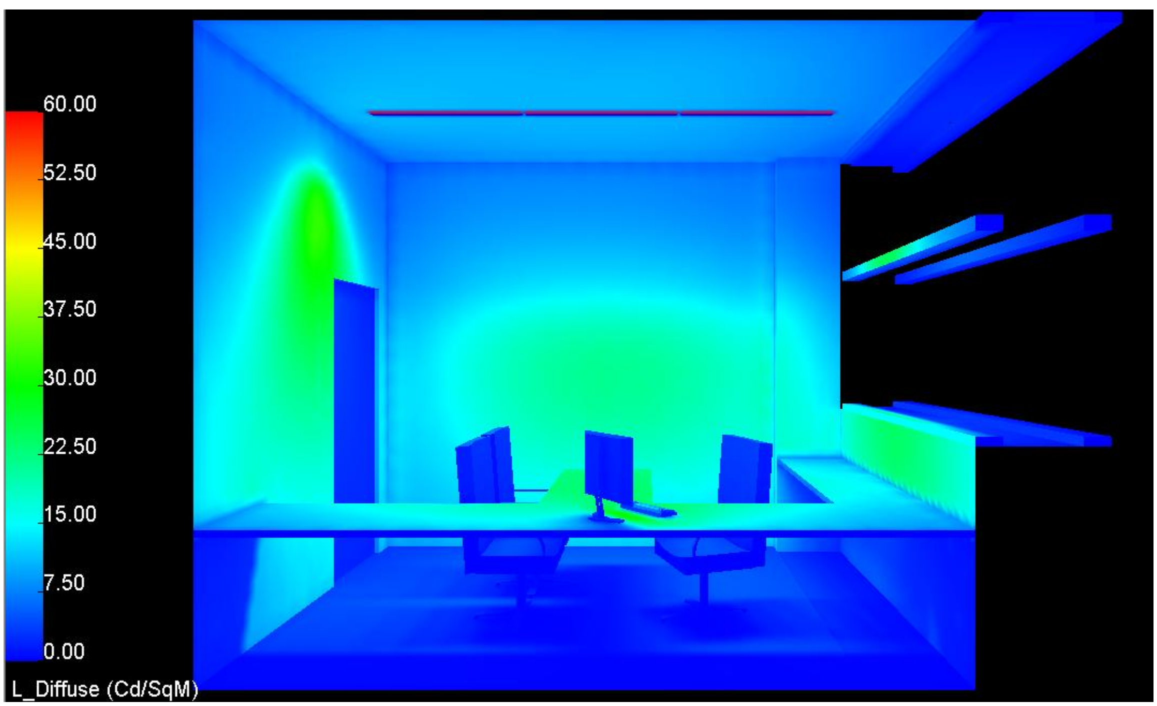



Figure 49: Typical Office - Luminance Color (Half Luminaires On).

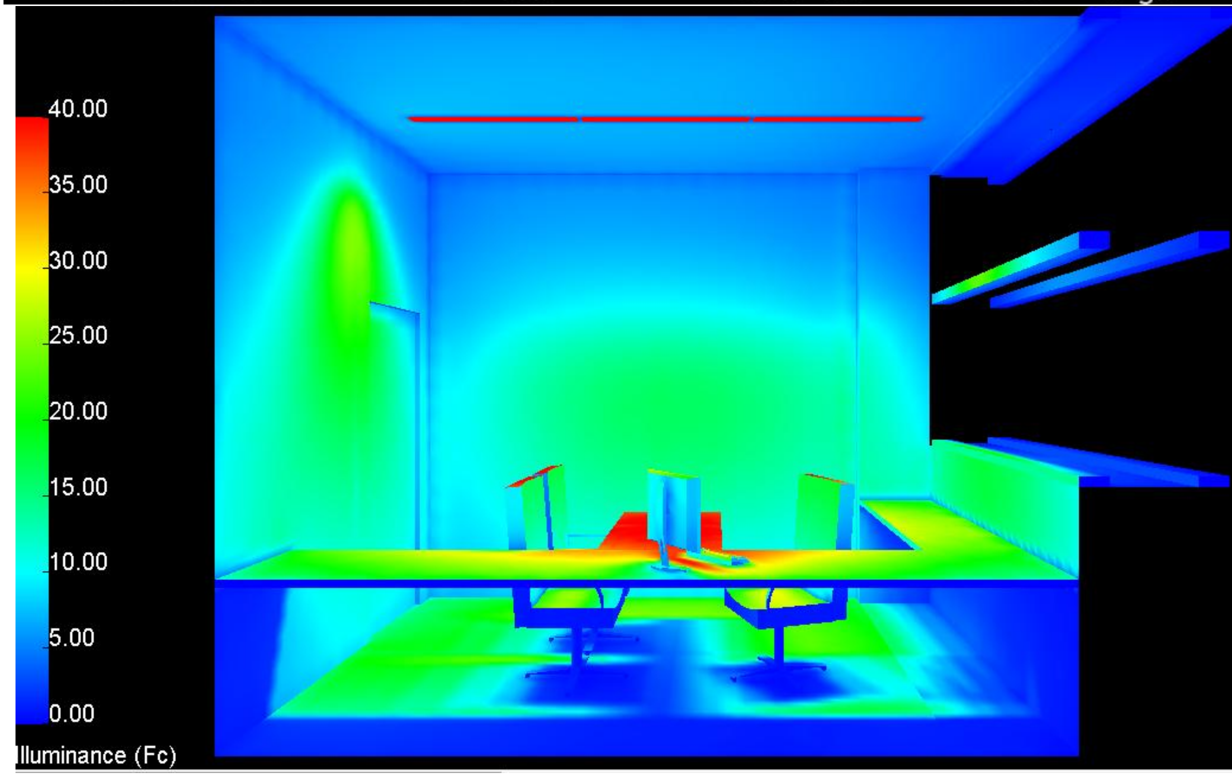



Figure 50: Typical Office - Illuminance Color (All Luminaires On).

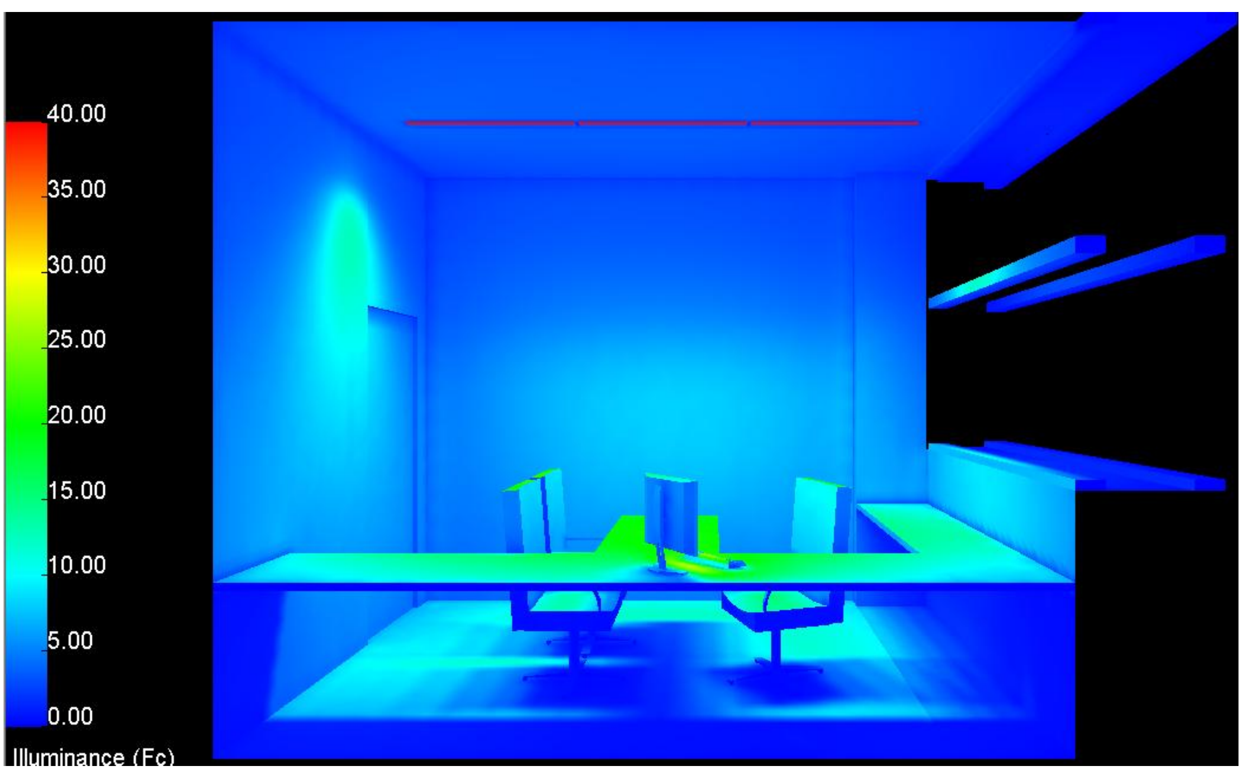



Figure 51: Typical Office - Illuminance Color (Half Luminaires On).

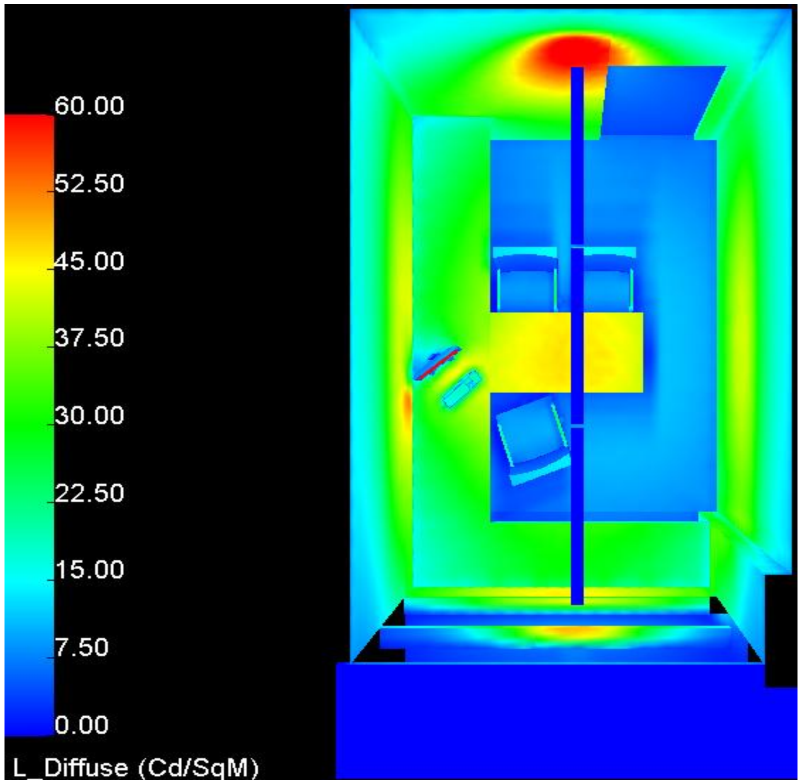



Figure 52: Typical Office - Luminance Color (All Luminaires On).

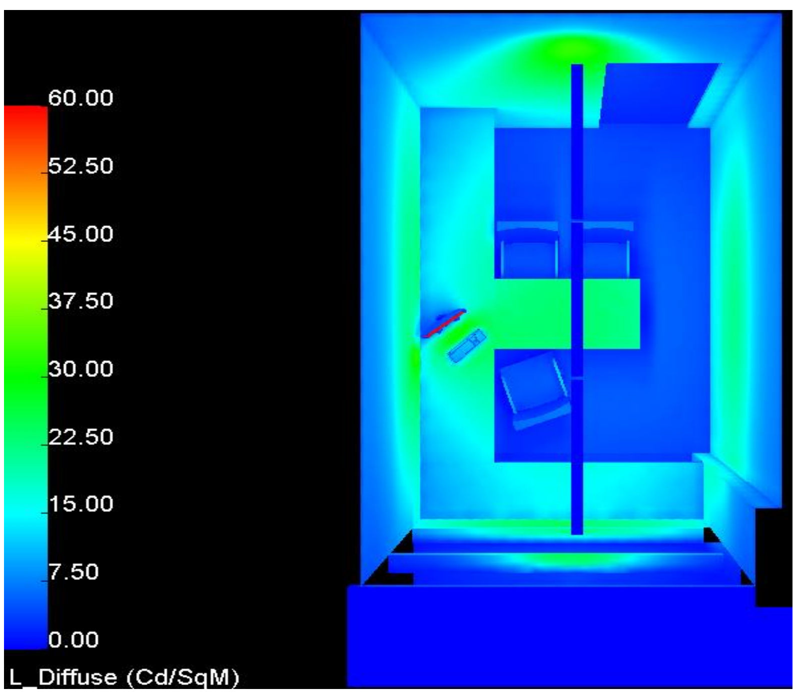



Figure 53: Typical Office - Luminance Color (Half Luminaires On).

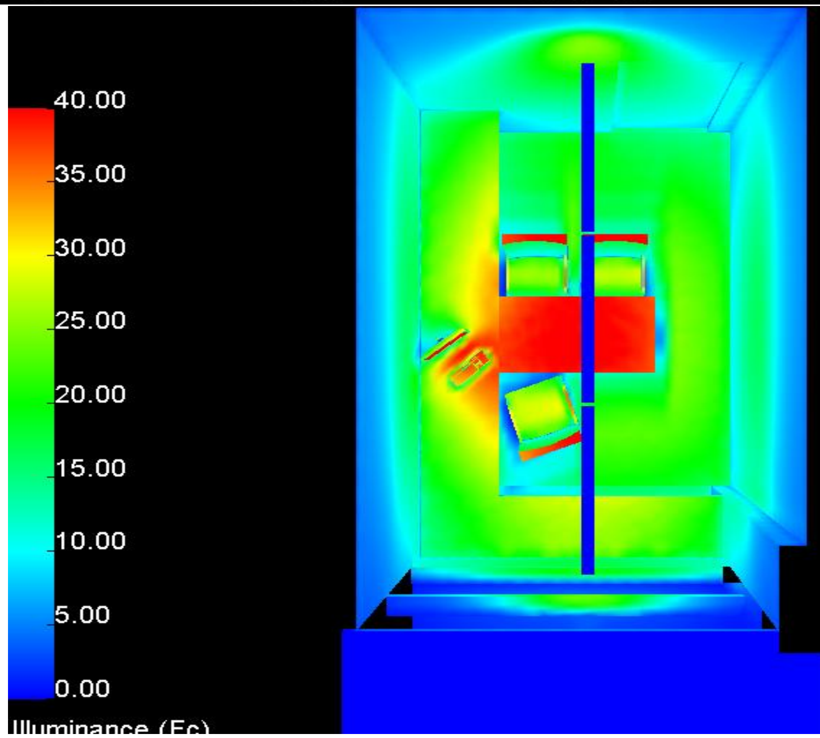



Figure 54: Typical Office - Illuminance Color (All Luminaires On).

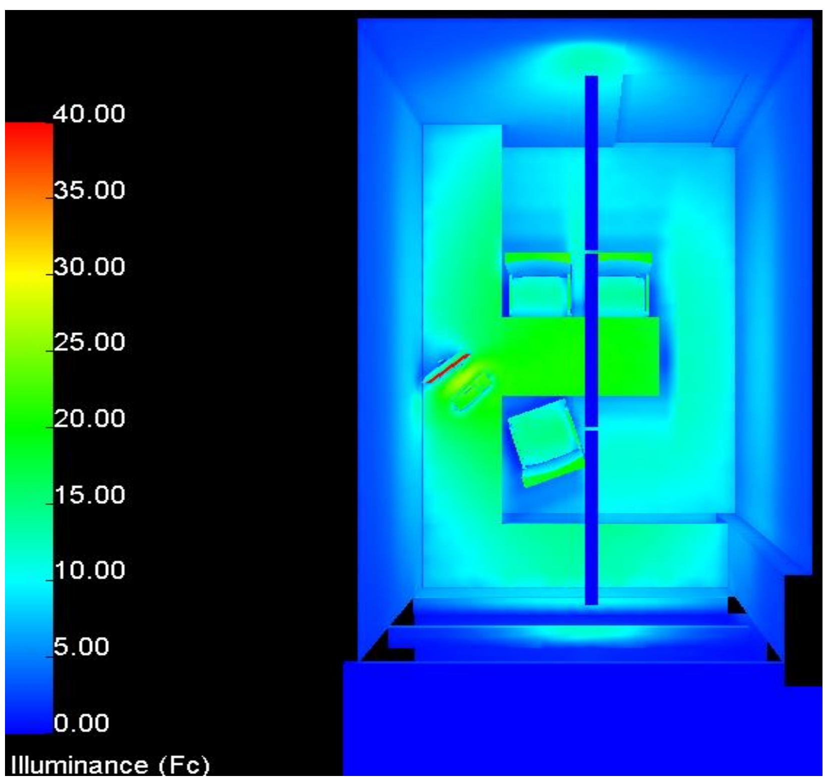



Figure 55: Typical Office - Illuminance Color (Half Luminaires On).

## Controls

The Typical Private Office lighting control layout is a simple wall switch next to the door. The switching zones will allow the occupant of the space to switch either all or half the luminaires. This method allows the occupant to manually control the visual appearance of the space as needed. This option of controls has been chosen due to the private nature of the office, and the varying preference of users from one office to the next. Daylighting controls for electric light have not been incorporated into this perimeter space due to the private nature of the office. For full wiring diagrams of a typical private office, refer to Appendix G: Lighting Wire Diagrams.

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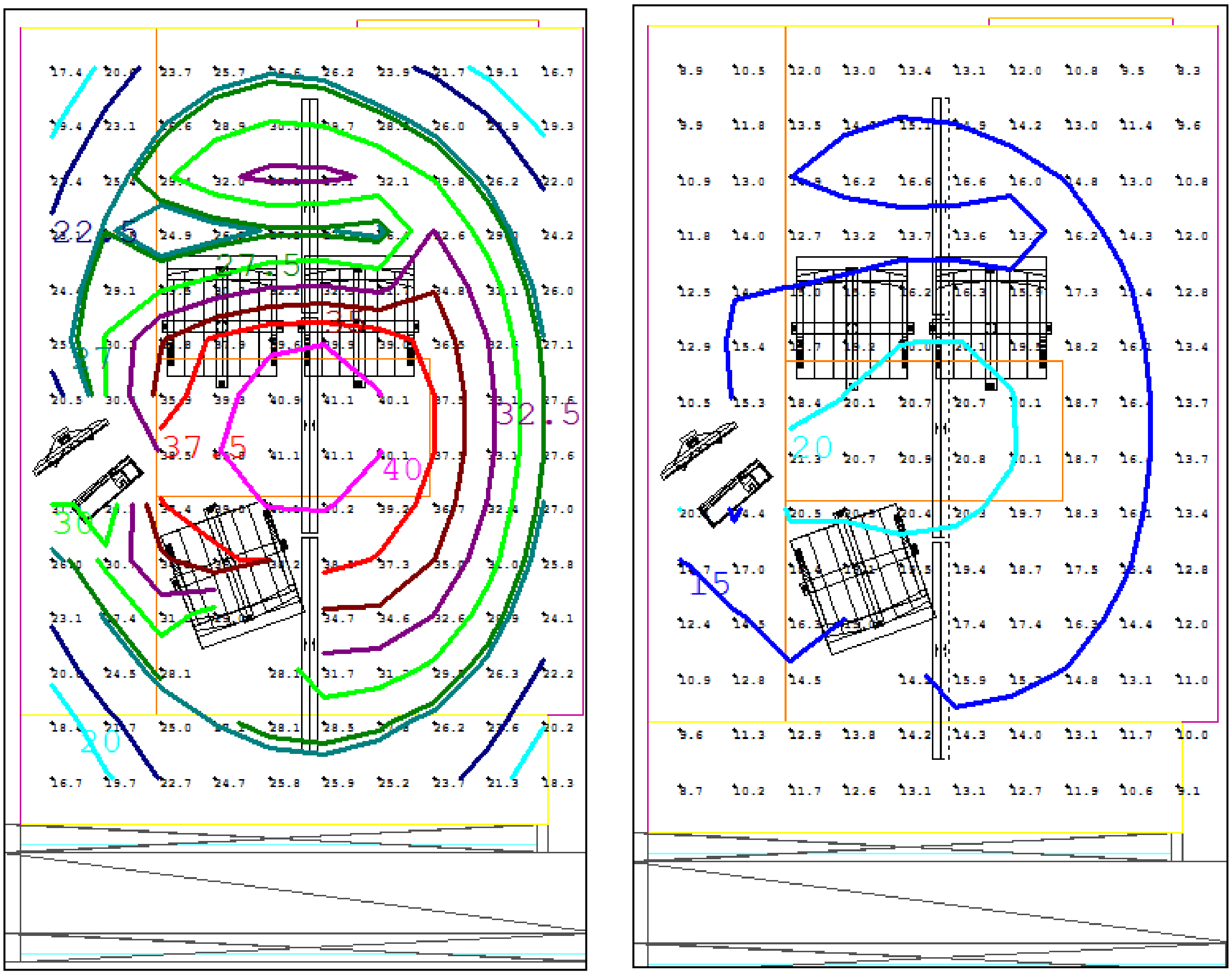


15fc-20fc-22.5fc -25fc - 27.5fc - 30fc -32.5fc -37.5fc - 40fc

**Figure 56: Typical Office Illumination Contours (Left - All Lights On) (Right – Half Lights on).**

**Table 19: Typical Office Performance Summary.**

| Typical Office Performance Data | All Luminaires On | Half Luminaires On |
|---|---|---|
| Avg. Illuminance (FC) | 29.28 | 14.87 |
| Max. Illuminance (FC) | 41.10 | 21.30 |
| Minimum Illuminance (FC) | 16.70 | 8.30 |
| Avg./Min | 1.75 | 1.79 |
| Max/Min | 2.46 | 2.57 |
| Max/Avg. | 1.40 | 1.43 |
| Coefficient of Variation | 0.21 | 0.22 |
| Uniform Gradient | 1.46 | 1.46 |
| Power Density (W/SF) | 1.00 | |

## Integrating Connected Equipment & Plug Loads

Further integration was pursued between the mechanical and electrical designs through Revit MEP. A functional Revit "MEP" model of the third floor was created and included the circuiting of existing electrical loads to their upstream counterparts. The purpose of this depth was to further understand the program as well as help quickly integrate changes in both electrical and mechanical designs in the future.

The original goal was to provide electrical plug loads, equipment loads, and lighting loads to the mechanical designer for the heating and cooling load calculations. Lighting loads have been omitted due to issues with getting electrical loads from light fixtures to "attach" themselves to a space. The issue stemmed from the fact that some of lighting fixtures originally modeled in Revit Architecture had not been done in a way to permit them to work correctly in an electrical model. All existing luminaire families were missing proper electrical input data such as electrical connectors, IES files, voltage systems and identity data. When it was attempted to add this data to the existing luminaires, it was discovered that most of them needed to be upside down in order for their electrical data to be included in a spaces W/SF summation. For the purposes of coordination and time constraints, the existing luminaires were left as is, and spaces have used ASHRAE Standard 90.1 lighting power densities for mechanical load calculation purposes.

### Equipment & Receptacle Circuiting

The third floor of the Millennium Science Complex was the area of focus for the circuiting of existing equipment and receptacle loads. Existing panel schedules were used to verify loads of branch circuits in terms of volt-amperes. Details of the process used in order circuit these items have been written in detail in the Electrical Technical Report #1 (pages 4-9).

The depth topic was executed to better understand the inner functions of doing electrical design in a program such as Revit MEP. The final conclusion of this study is ¼" scale floor power plans as well as panel schedule sheets. Drawings produced from this study can be found on the Building Stimulus website at the following link:

HTTP://WWW.ENGR.PSU.EDU/AE/THESIS/BIMTEAM22010/FINAL/REVIT%20SHEETS.PDF

An Electrical connector is a component in the Revit MEP program that allows the user to connect a piece of equipment to a desired circuit. In order to connect a family to a circuit, an electrical connector must be present. The properties of an electrical connector are the basis of calculations used to create panel schedules. Within the electrical parameter, the option of Load Classification is the parameter that makes the discretion of what the load will be calculated as. Power and Lighting are out of the box options with the availability to add user defined classifications such as motor loads, kitchen loads, or P.C. loads.

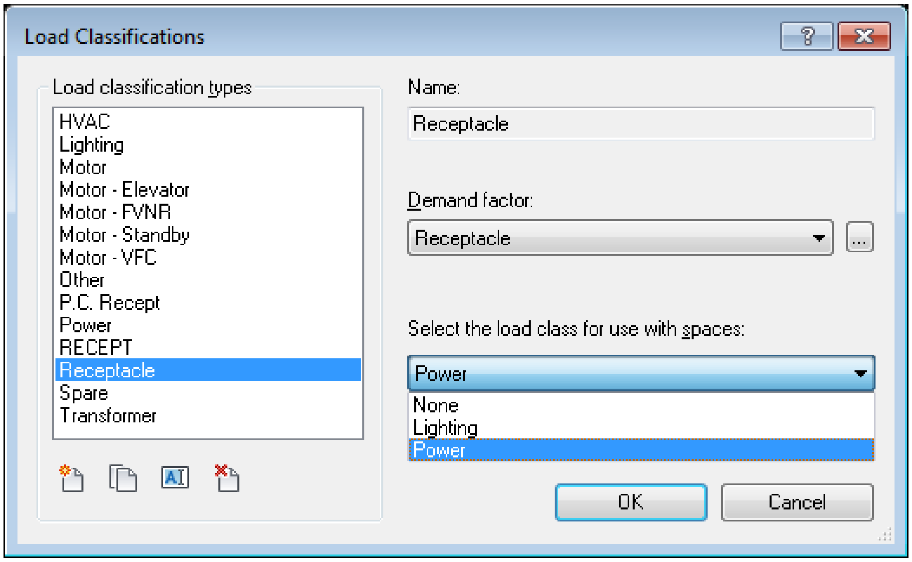



Figure 57: Revit MEP Load Classifications.

Figure 57 above shows the screen where the user can create the user defined load classifications. Classifying a load as either power or lighting for use with spaces will determine which category a space will assign the load to. This is important for collaborating with the mechanical designer what electrical heating loads each space will encounter.

The next step of setting up a load classification is to calculate a demand load for the type of load that has been circuited. For example, 2008 Edition National Electrical Code (NEC 2008) allows a demand factor reduction receptacles if more than 10kVA of receptacles are connected. The table from the NEC that states this is shown in Figure 58 below.

**Table 220.44 Demand Factors for Non-Dwelling Receptacle Loads**

| Portion of Receptacle Load to Which Demand Factor Applies (Volt-Amperes) | Demand Factor (%) |
|---|---|
| First 10 kVA or less at | 100 |
| Remainder over 10 kVA at | 50 |

Figure 58: NEC 2008 – Table 220.44 Demand Factors for Non-Dwelling Receptacle Loads.

Figure 59 below shows the screen at which demand factor is entered into Revit MEP's load classifications. The example shown is of receptacle demand factors as permitted by NEC, Table 220.44.

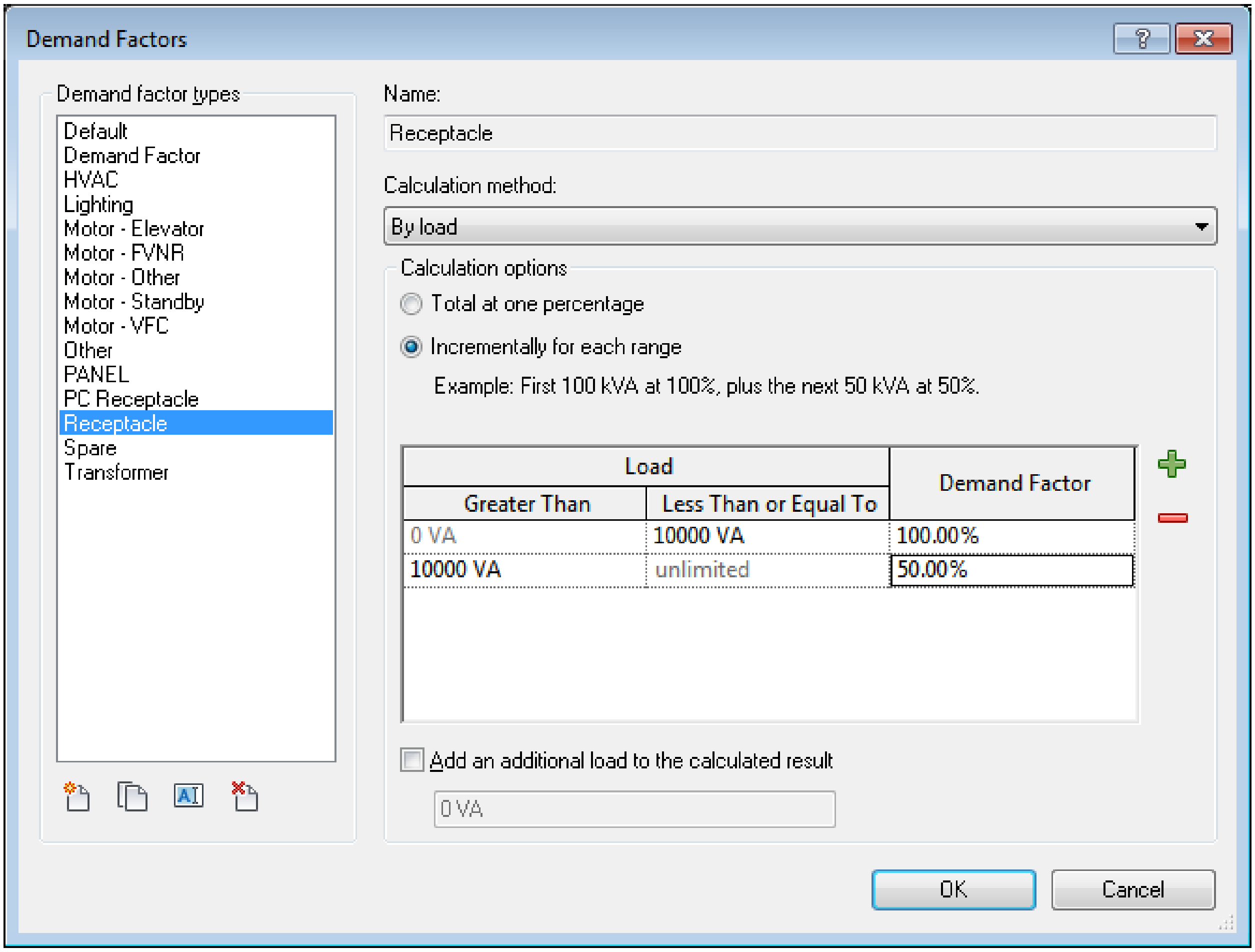



Figure 59: Revit MEP – Assigning Demand Factors.

The demand factor definition also allows the options of assigning a demand factor by quantity of items connected as well as the option of a constant demand factor.  Table 20 summarizes the actual power densities modeled in Revit MEP.

## Electrical Equipment Plug Loads

Table 20: Detailed Space by Space Electrical Loads.

| Room Data | | | Plug Loads | | | |
|---|---|---|---|---|---|---|
| Room Number | Room Name | Area (SF) | Actual Power Load | | Actual Power Load per Area | |
| N-237A | Organic Elec. & Pho Chemical Lab | 574 | 17500 | W | 30.50 | W/ft² |
| N-301 | Dry Lab Typical | 471 | 2340 | W | 4.97 | W/ft² |
| N-302 | Staff Admin | 516 | 3240 | W | 6.28 | W/ft² |
| N-302A | Copy | 67 | 540 | W | 8.12 | W/ft² |
| N-302B | Reception | 135 | 180 | W | 1.33 | W/ft² |
| N-303 | Dry Lab Typical | 471 | 2340 | W | 4.97 | W/ft² |
| N-305 | IT Staff Office | 252 | 1980 | W | 7.85 | W/ft² |
| N-306A | Conference | 193 | 720 | W | 3.73 | W/ft² |
| N-306B | Conference | 193 | 1440 | W | 7.45 | W/ft² |
| N-307 | Storage | 271 | 1260 | W | 4.65 | W/ft² |
| N-308A | Seminar Room | 417 | 2700 | W | 6.48 | W/ft² |
| N-308B | Seminar Room | 417 | 2520 | W | 6.05 | W/ft² |
| N-309 | IT Staff Office | 258 | 1980 | W | 7.67 | W/ft² |
| N-310 | Cafe/Commons | 1960 | 5040 | W | 2.57 | W/ft² |
| N-310B | Kitchen | 232 | 1405 | W | 4.65 | W/ft² |
| N-310C | Copy | 139 | 1080 | W | 7.77 | W/ft² |
| N-310D | Mail | 201 | 720 | W | 3.59 | W/ft² |
| N-310E | Copy | 139 | 1080 | W | 7.77 | W/ft² |
| N-314 | Storage | 83 | 360 | W | 4.36 | W/ft² |
| N-315 | Distinguished Office | 293 | 1620 | W | 5.53 | W/ft² |
| N-316 | MSC Computational | 214 | 1440 | W | 6.74 | W/ft² |
| N-317 | Staff Assistant | 187 | 1080 | W | 5.78 | W/ft² |
| N-319 | Distinguished Office | 229 | 1260 | W | 5.49 | W/ft² |
| N-320 | Staff Assistant | 149 | 900 | W | 6.03 | W/ft² |
| N-321 | Staff Assistant | 149 | 1080 | W | 7.23 | W/ft² |
| N-322 | Faculty | 149 | 1080 | W | 7.23 | W/ft² |
| N-323 | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| N-324 | Student | 157 | 1800 | W | 11.50 | W/ft² |
| N-324A | Organic Elec. & Pho Chemical Lab | 558 | 22600 | W | 40.48 | W/ft² |
| N-325 | Student | 159 | 2160 | W | 13.56 | W/ft² |
| N-326 | Student | 159 | 2160 | W | 13.56 | W/ft² |
| N-327 | Student | 159 | 2160 | W | 13.56 | W/ft² |
| N-328 | Student | 156 | 2520 | W | 16.17 | W/ft² |
| N-328A | Organic Elec & Pho Instrument Lab | 589 | 15790 | W | 26.80 | W/ft² |

| Room Number | Room Name | Area (SF) | Actual Power Load | | Actual Power Load per Area | |
|---|---|---|---|---|---|---|
| **N-329** | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| **N-330** | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| **N-331** | Lounge | 276 | 720 | W | 2.61 | W/ft² |
| **N-332** | Faculty | 157 | 1080 | W | 6.88 | W/ft² |
| **N-333** | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| **N-334** | Student | 157 | 2520 | W | 16.10 | W/ft² |
| **N-335** | Student | 157 | 1800 | W | 11.50 | W/ft² |
| **N-336** | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| **N-337** | Faculty | 157 | 1080 | W | 6.88 | W/ft² |
| **N-338** | Lounge | 277 | 720 | W | 2.60 | W/ft² |
| **N-339** | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| **N-340** | Faculty | 149 | 1080 | W | 7.25 | W/ft² |
| **N-341** | Student | 156 | 2520 | W | 16.17 | W/ft² |
| **N-341A** | Electroact Polys Instrument Lab | 589 | 13110 | W | 22.26 | W/ft² |
| **N-342** | Student | 159 | 2160 | W | 13.56 | W/ft² |
| **N-342A** | Electroact Polys Fabrication Lab | 574 | 29350 | W | 51.09 | W/ft² |
| **N-343** | Student | 159 | 2160 | W | 13.56 | W/ft² |
| **N-344** | Student | 159 | 2160 | W | 13.56 | W/ft² |
| **N-345** | Student | 157 | 1800 | W | 11.50 | W/ft² |
| **N-345A** | Electroact Polys Chemical Lab | 558 | 21170 | W | 37.93 | W/ft² |
| **N-346** | PH.D Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-347** | PH.D Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-348** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-349** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-350** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-351** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-352** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-353** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-354** | Dry Lab Typical | 214 | 1440 | W | 6.74 | W/ft² |
| **N-355** | Staff Office | 149 | 1080 | W | 7.23 | W/ft² |
| **N-356** | Staff Office | 163 | 1080 | W | 6.62 | W/ft² |
| **N-361** | Equipment Corridor | 679 | 6220 | W | 9.16 | W/ft² |
| **N-J346** | Janitor Closet | 38 | 0 | W | 0.00 | W/ft² |
| **N-P346** | Electrical | 36 | 4000 | W | 111.11 | W/ft² |
| **N-P347** | Electrical | 99 | 10000 | W | 100.00 | W/ft² |
| **N-Q301** | Corridor | 367 | 180 | W | 0.49 | W/ft² |
| **N-Q302** | Corridor | 728 | 360 | W | 0.49 | W/ft² |

| Room Number | Room Name | Area (SF) | Actual Power Load | | Actual Power Load per Area | |
|---|---|---|---|---|---|---|
| **N-Q303** | Corridor | 668 | 180 | W | 0.27 | W/ft² |
| **N-Q304** | Corridor | 593 | 720 | W | 1.21 | W/ft² |
| **N-Q305** | Corridor | 500 | 180 | W | 0.36 | W/ft² |
| **N-Q306** | Corridor | 592 | 540 | W | 0.91 | W/ft² |
| **N-Q307** | Corridor | 742 | 180 | W | 0.24 | W/ft² |
| **N-Q308** | Corridor | 562 | 180 | W | 0.32 | W/ft² |
| **N-Q310** | Corridor | 837 | 1800 | W | 2.15 | W/ft² |
| **N-R323** | Women | 209 | 540 | W | 2.58 | W/ft² |
| **N-R324** | Unisex Restroom | 75 | 180 | W | 2.39 | W/ft² |
| **N-R346** | Men | 209 | 540 | W | 2.58 | W/ft² |
| **N-T347** | Telecom | 99 | 2100 | W | 21.22 | W/ft² |
| **Q-335A** | EQPM Corridor G | 304 | 21460 | W | 70.50 | W/ft² |
| **W-301** | BCI Teaching | 470 | 8600 | W | 18.32 | W/ft² |
| **W-302** | Staff Admin | 283 | 1800 | W | 6.36 | W/ft² |
| **W-302A** | Staf Office | 107 | 1120 | W | 10.48 | W/ft² |
| **W-302B** | Staff Office | 107 | 1120 | W | 10.48 | W/ft² |
| **W-302C** | Reception | 138 | 180 | W | 1.30 | W/ft² |
| **W-302D** | Copy | 64 | 1560 | W | 24.38 | W/ft² |
| **W-303** | Elec EQPM Meas/Test | 471 | 6580 | W | 13.96 | W/ft² |
| **W-305** | Grad Student | 259 | 2140 | W | 8.25 | W/ft² |
| **W-306A** | Conference/Library | 416 | 3950 | W | 9.49 | W/ft² |
| **W-306B** | Conference/Library | 416 | 4670 | W | 11.22 | W/ft² |
| **W-307** | Kitchen/Break | 273 | 3340 | W | 12.25 | W/ft² |
| **W-308A** | Conference | 193 | 1520 | W | 7.87 | W/ft² |
| **W-308B** | Conference | 193 | 760 | W | 3.93 | W/ft² |
| **W-309** | Post Doc Office | 258 | 1980 | W | 7.67 | W/ft² |
| **W-311** | Faculty Office | 163 | 1080 | W | 6.61 | W/ft² |
| **W-312** | Faculty Office | 149 | 1080 | W | 7.23 | W/ft² |
| **W-313** | Faculty Office | 149 | 1080 | W | 7.23 | W/ft² |
| **W-314** | Light Machine Shop | 214 | 9740 | W | 45.58 | W/ft² |
| **W-315** | Faculty Office | 149 | 1080 | W | 7.23 | W/ft² |
| **W-316** | Faculty Office | 149 | 1080 | W | 7.23 | W/ft² |
| **W-317** | Faculty Office | 149 | 1080 | W | 7.23 | W/ft² |
| **W-318** | Hershey MD | 149 | 1080 | W | 7.23 | W/ft² |
| **W-319** | Hershey MD | 149 | 1080 | W | 7.23 | W/ft² |
| **W-320** | Senior Post Doc | 149 | 1080 | W | 7.23 | W/ft² |
| **W-321** | Neurophys-Invitro | 472 | 6220 | W | 13.17 | W/ft² |
| **W-321A** | Perfusion | 107 | 5340 | W | 50.14 | W/ft² |

| Room Number | Room Name | Area (SF) | Actual Power Load | | Actual Power Load per Area | |
|---|---|---|---|---|---|---|
| **W-321B** | Tiss Prep | 174 | 11180 | W | 64.21 | W/ft² |
| **W-321C** | Manifold Gas | 74 | 180 | W | 2.43 | W/ft² |
| **W-322** | Neurophys-Invitro | 480 | 5760 | W | 12.00 | W/ft² |
| **W-322A** | EQPM Corridor G | 304 | 18480 | W | 60.70 | W/ft² |
| **W-322A** | EQPM Corridor G | 304 | 18480 | W | 60.70 | W/ft² |
| **W-323A** | Fume Hood | 113 | 9080 | W | 80.52 | W/ft² |
| **W-323B** | Procedure D Surgery | 184 | 6680 | W | 36.21 | W/ft² |
| **W-324A** | Hot Room | 113 | 6320 | W | 56.08 | W/ft² |
| **W-324B** | Proc A | 105 | 9400 | W | 89.14 | W/ft² |
| **W-324C** | Mirco C Comp | 72 | 6160 | W | 85.53 | W/ft² |
| **W-325** | Neurophys-Invitro | 480 | 5940 | W | 12.38 | W/ft² |
| **W-325A** | EQPM Corridor A4 | 304 | 23360 | W | 76.84 | W/ft² |
| **W-326** | Neurophys-Invitro | 742 | 8820 | W | 11.89 | W/ft² |
| **W-326A** | Proc C Maze | 113 | 7060 | W | 62.62 | W/ft² |
| **W-326B** | Procedure B | 184 | 3380 | W | 18.33 | W/ft² |
| **W-327A** | Optical Imaging | 666 | 10540 | W | 15.83 | W/ft² |
| **W-329** | NuerophysInvitro | 734 | 8640 | W | 11.77 | W/ft² |
| **W-329A** | Procedure E In Vivo | 335 | 10900 | W | 32.54 | W/ft² |
| **W-331A** | Proc C Maze | 107 | 1260 | W | 11.83 | W/ft² |
| **W-331B** | Enviro A | 89 | 6780 | W | 75.79 | W/ft² |
| **W-331C** | Micro A | 79 | 5180 | W | 65.57 | W/ft² |
| **W-332** | Neurophys-Invitro | 480 | 5940 | W | 12.38 | W/ft² |
| **W-332A** | EQPM Corridor B1 | 305 | 14680 | W | 48.08 | W/ft² |
| **W-333A** | Fume Hood | 113 | 11660 | W | 103.47 | W/ft² |
| **W-333B** | Confocal A | 105 | 3780 | W | 35.84 | W/ft² |
| **W-333C** | Mirco C Comp | 72 | 6380 | W | 88.58 | W/ft² |
| **W-334A** | Fume Hood | 113 | 9920 | W | 87.79 | W/ft² |
| **W-334B** | Tissue Culture B | 184 | 8340 | W | 45.21 | W/ft² |
| **W-335** | Neurophys-Invitro | 480 | 5760 | W | 12.00 | W/ft² |
| **W-336A** | Proc A | 108 | 9820 | W | 91.31 | W/ft² |
| **W-336B** | Service | 74 | 720 | W | 9.75 | W/ft² |
| **W-336C** | Autoclave | 100 | 6340 | W | 63.71 | W/ft² |
| **W-337** | Neurophys-Invitro | 472 | 6300 | W | 13.34 | W/ft² |
| **W-338** | Senior Post Doc | 149 | 1120 | W | 7.53 | W/ft² |
| **W-339** | Hershey MD | 149 | 1160 | W | 7.78 | W/ft² |
| **W-340** | Faculty Office | 149 | 1120 | W | 7.51 | W/ft² |
| **W-341** | Faculty Office | 149 | 1120 | W | 7.51 | W/ft² |

| Room Number | Room Name | Area (SF) | Actual Power Load | | Actual Power Load per Area | |
|---|---|---|---|---|---|---|
| **W-342** | Faculty Office | 149 | 1160 | W | 7.78 | W/ft² |
| **W-343** | Staff Assistant | 109 | 180 | W | 1.65 | W/ft² |
| **W-344** | Distinguished Office | 294 | 1660 | W | 5.65 | W/ft² |
| **W-345** | Grad Student | 214 | 2240 | W | 10.45 | W/ft² |
| **W-346** | Storage | 82 | 360 | W | 4.37 | W/ft² |
| **W-J337** | Janitor Closet | 74 | 180 | W | 2.43 | W/ft² |
| **W-J338** | Janitor Closet | 15 | 180 | W | 1.82 | W/ft² |
| **W-P338** | Electrical | 99 | 10000 | W | 100 | W/ft² |
| **W-Q301** | Corridor | 365 | 0 | W | 0.00 | W/ft² |
| **W-Q302** | Corridor | 740 | 0 | W | 0.00 | W/ft² |
| **W-Q303** | Corridor | 642 | 180 | W | 0.28 | W/ft² |
| **W-Q304** | Corridor | 604 | 720 | W | 1.19 | W/ft² |
| **W-Q305** | Corridor | 729 | 1400 | W | 1.92 | W/ft² |
| **W-Q306** | Corridor | 560 | 1400 | W | 2.50 | W/ft² |
| **W-R321** | Women | 209 | 720 | W | 3.44 | W/ft² |
| **W-R337** | Men | 208 | 540 | W | 2.60 | W/ft² |
| **W-T338** | Telecom | 99 | 2100 | W | 21.21 | W/ft² |

Once the plug loads were finalized in the Revit MEP model, they were imported into the existing TRACE model completed for the mechanical design. Table 21 details the power densities originally assumed for the base model.

**Table 21: ASHRAE Std. 90.1 Lighting and Equipment Power Densities.**

| Common Space Types | LPD , $W/ft^2$ | EPD , $W/ft^2$ |
|---|---|---|
| **Office –Enclosed** | 1.1 | 1.5 |
| **Office – Open Plan** | 1.1 | 1.5 |
| **Conference/Meeting/Multipurpose** | 1.3 | 1.0 |
| **Classroom/Lecture/Training** | 1.4 | 1.0 |
| **Lounge/Recreation** | 1.2 | 0.5 |
| **Dining Area** | 0.9 | 0.5 |
| **Food Preparation** | 1.2 | 1.5 |
| **Laboratory** | 1.4 | 1.5 |
| **Restrooms** | 0.9 | 0.3 |
| **Corridor/Transition** | 0.5 | 0.3 |
| **Stairs - Active** | 0.6 | 0.3 |
| **Active Storage** | 0.8 | 0.3 |
| **Inactive Storage** | 0.3 | 0.3 |
| **Electrical/Mechanical** | 1.5 | 0.3 |
| **Post Office – Sorting Area** | 1.2 | 1.0 |

## Energy Analysis

The incorporation of the actual plug loads caused a significant increase in the receptacle energy consumption. As shown in Figure 60, the receptacle energy consumption increased by twelve times the amount of the original base model. This translated into an increased source energy consumption of more than 150% for the third floor, as well as a significant increase in the HVAC associated emissions, as illustrated in Figure 62 and Figure 63.

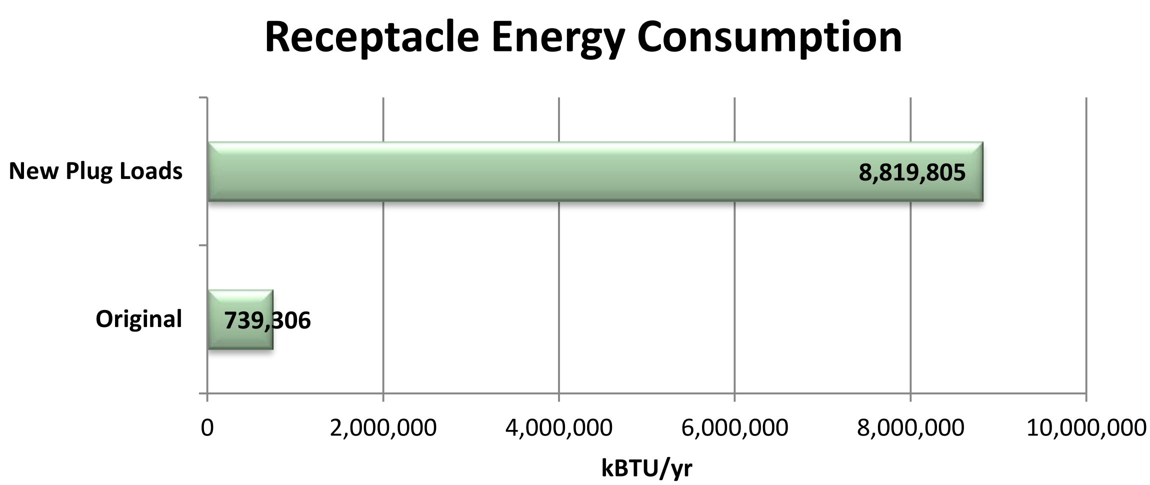



Figure 60: Receptacle Energy Consumption for Third Floor.

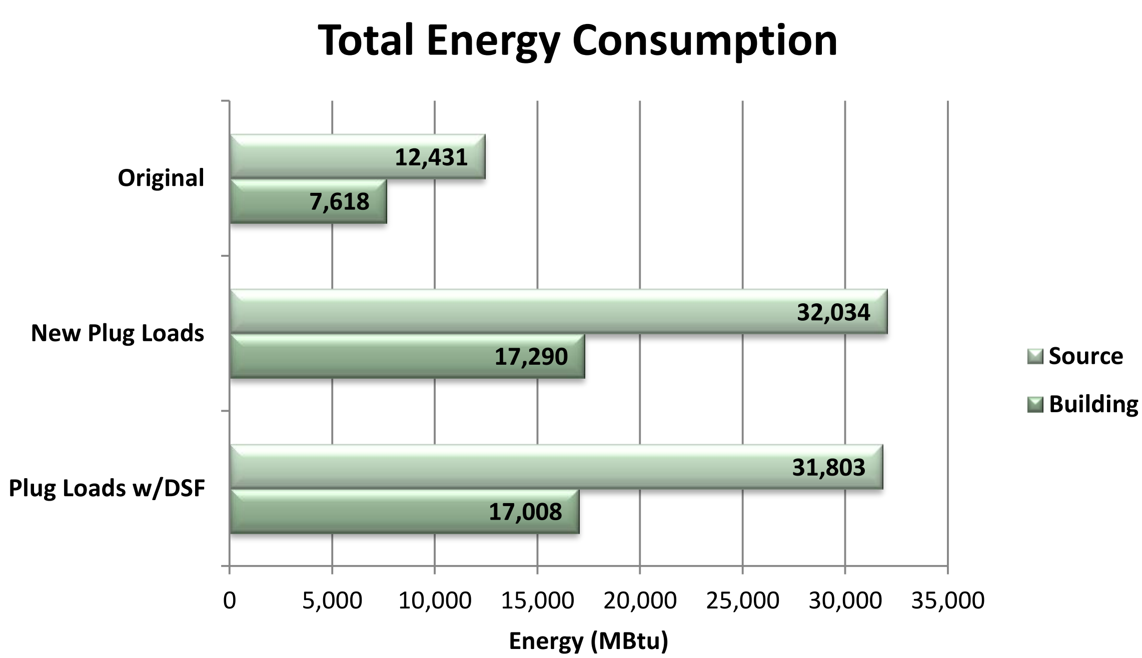



Figure 61: Energy Consumption for Third Floor.

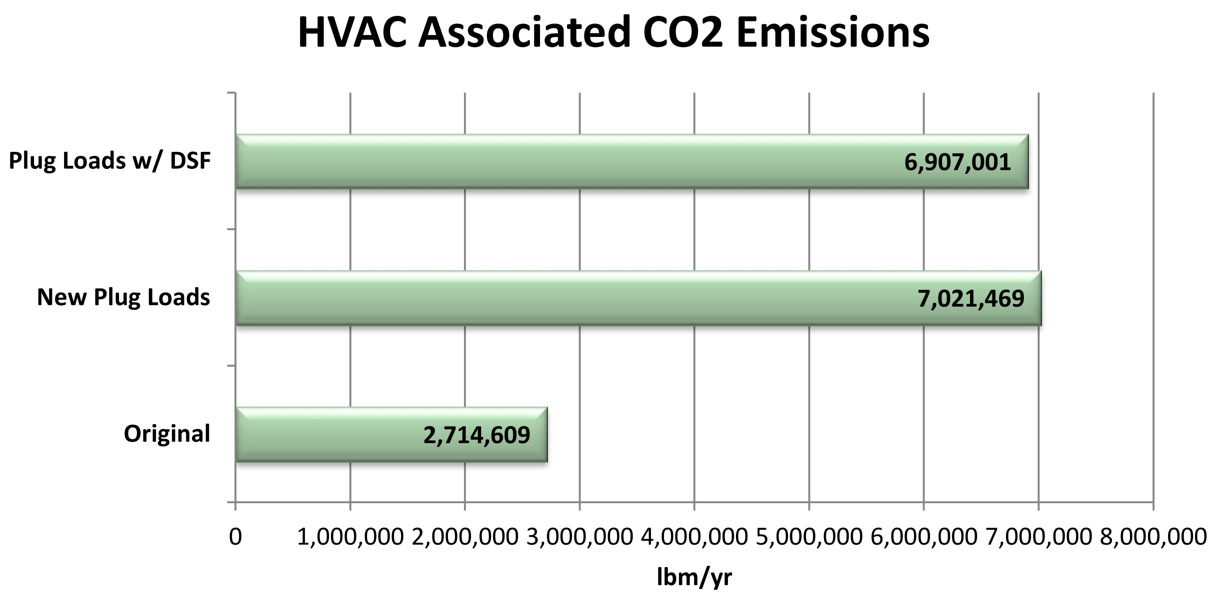



Figure 62: Third Floor Carbon Dioxide Emissions.

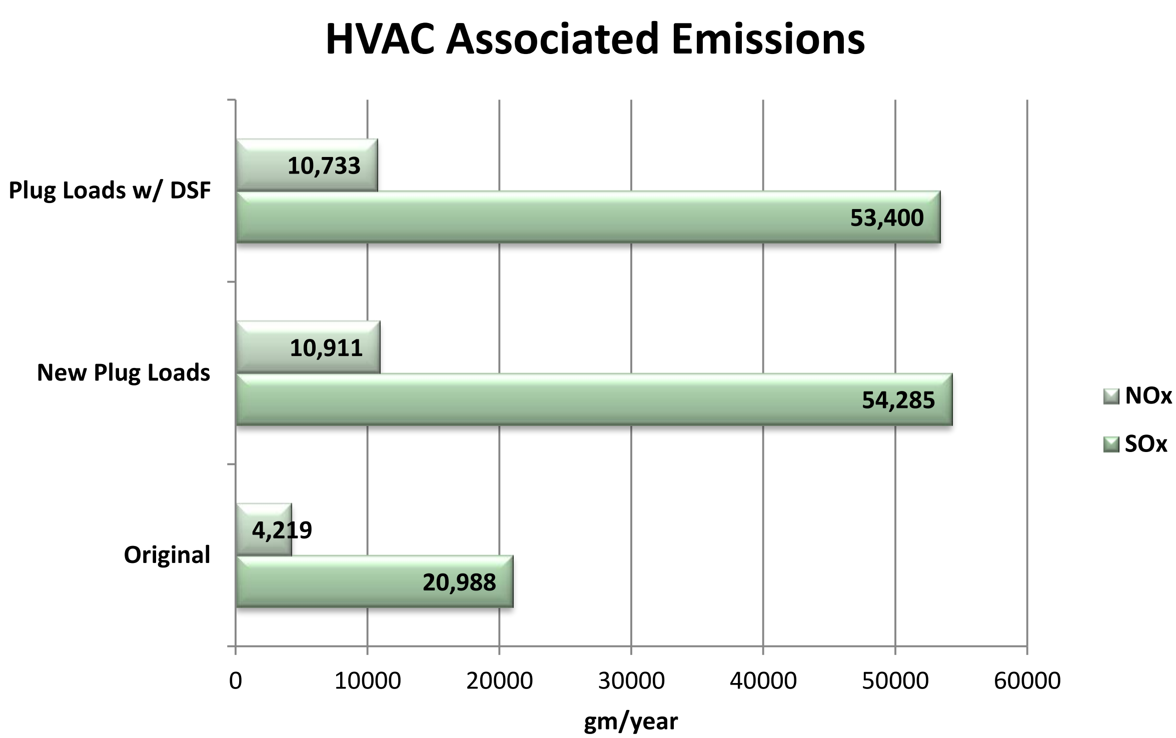



Figure 63: Third Floor Associated Emissions for SOx and NOx.

## Combined Design Parameters

The final energy performance for the building's design alternatives were completed based on the updated power densities for the building. Summarized design outcomes for the original base energy model are presented in Appendix C:. For the combined double skin façade addition and chilled beams used for the perimeter zones, as extrapolated from the third floor analysis, the total building was able to save 716,110 $lb_m$/year in $CO_2$ emissions as well as 2,214 MBtu in source energy consumption.

Table 22: Building Energy Consumption for Final Design Parameters.

| | Building (MBtu) | Source (MBtu) |
|---|---|---|
| New Plug Loads | 106,045 | 196,475 |
| Plug Loads w/DSF | 104,316 | 195,058 |
| CB with Plug | 104,580 | 194,813 |
| CB with DSF, Plug | 104,285 | 194,261 |
| Total Savings for Combined System | **1,760** | **2,214** |

Table 23: HVAC Associated Emissions for Final Design Parameters.

| | $CO_2$ (lbm/yr) | SOx (gm/yr) | NOx (gm/yr) |
|---|---|---|---|
| New Plug Loads | 43,065,010 | 332,948 | 66,921 |
| Plug Loads w/ DSF | 42,362,939 | 327,520 | 65,829 |
| Plug Load w/ Chilled Beam | 42,470,009 | 328,348 | 65,995 |
| Plug: CB and DSF | 42,348,900 | 327,410 | 65,805 |
| Total Savings for Combined System | **716,110** | **5,538** | **1,116** |

As shown in Figure 64, the combination of the double skin façade on Millennium Science Complex's western and southern facades and chilled beams in the office spaces provided 57,567 kWh per year for the building.

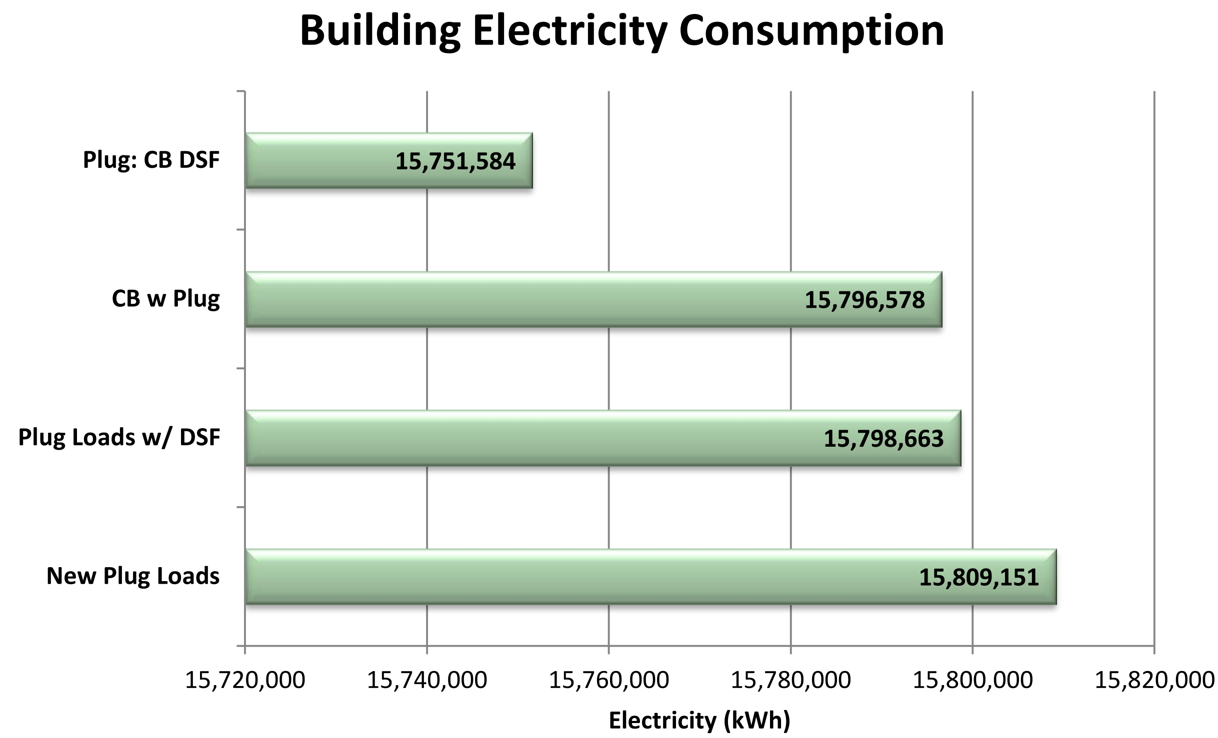



Figure 64: Building Electricity Consumption for Final Design Parameters.

The summarized utility costs for the final design is shown in Table 24. Based on the redesign, Millennium Science Complex is able to save $112,250 per year in utility costs.

Table 24: Yearly Utility Costs for Final Design Parameters.

| | Electricity kWh | Cost of Electricity | Purchased Chilled Water (therms) | Cost of Chilled Water | Purchased Steam (therms) | Cost of Steam | Total Cost |
|---|---|---|---|---|---|---|---|
| New Plug Loads | 15,809,151 | $1,188,374 | 507,386 | $928,517 | 154,873 | $126,996 | **$2,243,886** |
| Plug Loads w/ DSF | 15,798,663 | $1,187,586 | 495,567 | $906,832 | 1749,463 | $122,560 | **$2,216,977** |
| Plug Load w/CB | 15,796,577 | $1,187,429 | 458,105 | $838,332 | 138,233 | $113,351 | **$2,139,112** |
| Plug: CB and DSF | 15,751,584 | $1,184,047 | 456,228 | $834,897 | 137,430 | $112,692 | **$2,131,636** |
| Total Savings for Combined System | **57,567** | **$4,327** | **51,158** | **$93,619** | **17,443** | **$14,303** | **$112,250** |

## Integrated Chilled Beam Cost Analysis

The use of chilled beams as a substitute to variable air volume systems was highly dependent on the location within the facility. Building Stimulus' mechanical designer and construction manager worked cooperatively to determine specific spaces to study on the 3rd floor of Millennium Science Complex. Upon doing so, results could be assumed consistent throughout the facility. A full take-off of VAV boxes to be replaced can be seen in Appendix D: Construction Management. RS Means costs were assigned to the take-offs and compared to estimated costs of the proposed chilled beam systems, which can be seen in Appendix D: Construction Management.

The IQID chilled beam system is integrated with lighting fixtures. To compare costs accurately, the 3rd floor were chosen to directly compare the overall savings and costs incurred due to the use of integrated chilled beams as a replacement for variable-air-volume boxes. It is important to be aware of the original light fixtures being removed from the typical office spaces as well. Overall take-offs of the 3rd floor can be found in Appendix D: Construction Management. Table 26 below shows the overall findings of upfront costs versus the original design.

Table 25: 3rd Floor ICB Cost.

| | Size of Model | Quantity of Units | Cost Per Unit | Labor Cost | Labor Hours | Shipping Cost | Total Unit Cost | Supplier Discount | Total Cost |
|---|---|---|---|---|---|---|---|---|---|
| **3rd Floor** | 4' Model | 311 | $871.00 | $240.00 | 1.472 | $35.00 | $1,146.00 | 0.6 | $213,843.60 |

Table 26: 3rd Floor ICB Cost Summary.

| 3rd Floor Systems | Chilled Beam System | Proposed Lighting Design | Original Lighting Design | Original VAV System | Difference |
|---|---|---|---|---|---|
| Cost | $213,843.60 | $22,504.00 | $49,934.00 | $95,585.50 | $90,828.10 |

Table 27 displays the payback period to meet the costs of the original mechanical and lighting design, as well as the payback period to reach net-zero.

Table 27: Cost and Payback Period.

| Integrated Chilled Beam | Lighting Redesign | Difference to Original Design | Annual Savings | Payback to Original | Payback to Net Zero |
|---|---|---|---|---|---|
| $213,843.60 | $22,504.00 | $90,828.10 | $104,774.00 | 0.87 | $2.26 |

## Integrated Chilled Beam Schedule Implications

The Integrated Chilled Beam system presents many cost benefits due to its annual savings. With a short payback period of 3.54 years to reach the cost of the original system, and a payback period of 9.39 years to reach net-zero, the financial benefits are undeniable. However, the chilled beam system does have negative impacts on the construction schedule. Upon analyzing the 3rd floor, the installation of the integrated chilled beam system requires over twice as much time to complete versus the original design. The table below shows the direct comparison between the original systems versus the installation of 4' long integrated chilled beams.

**Table 28: Chilled Beam Labor Durations**

| | Total Labor Hours | Total Days |
|---|---|---|
| **Original System** | 206.89 | 25.86 |
| **Chilled Beam System** | 457.792 | 57.224 |

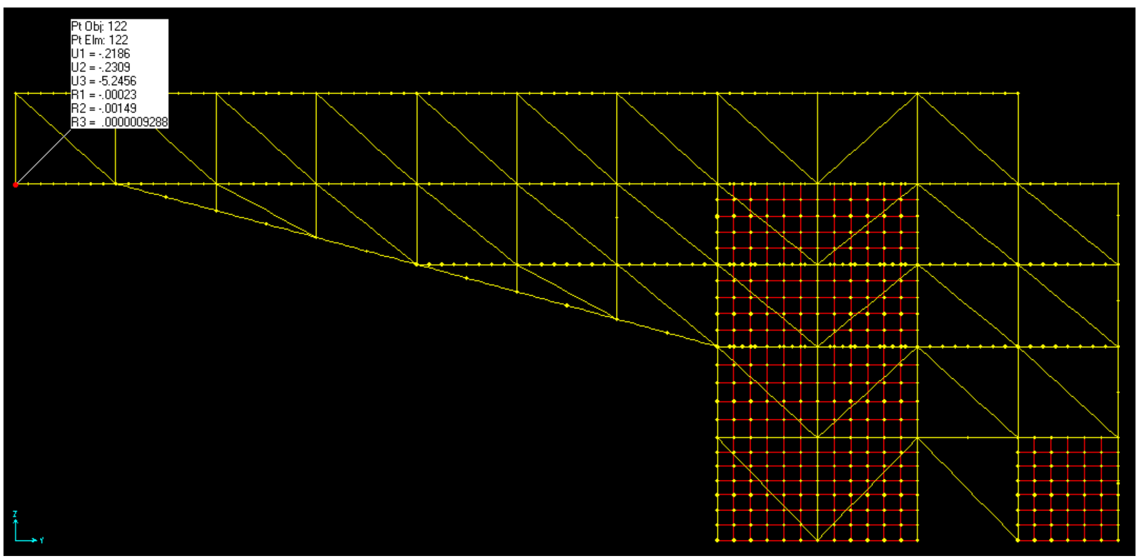
The installation of the original VAV system can be seen in the project schedule provided in Appendix D: Construction Management. RS Means estimated that the 3rd floor installation would require roughly 26 days. In actuality, the Material Sciences labs and core required 13 days, and the Life Sciences labs and core required 13 days for a total of 26 days.

The required labor hours of the integrated chilled beam system can be seen in Appendix D: Construction Management. Ways to significantly reduce the amount of required man hours of installation is to utilize different lengths of chilled beams. The labor hours above were based upon the use of the 4' chilled beam. Models can be designed to lengths of 4', 6', 8', 10', 12' as well as intermediate lengths upon special order, each length requiring minimal additional time. While the values in the table above were done conservatively, it can be assumed that in office spaces where (3) 4' light fixtures were replaced, (1) 12' integrated chilled beam was used. Doing so reduces the required man hours by nearly two thirds per space.

# Cantilever Redesign

## Structural Design

The structure of the cantilever was chosen as an area of interest for redesign because it is the main feature of the Millennium Science Building and provided a unique opportunity to attempt to optimize the efficiency of the truss structure. Through contact with Thornton Tomasetti (TT), it was discovered that the original design of the cantilever structure was initially designed for strength but did not satisfy deflection requirements. It was then redesigned primarily for stiffness to limit deflection at the tip of the cantilever. The deflection limit designed for by TT was 6 inches, specifically it was limited to a deflection of 4 inches under self-weight and an additional 2 inches under live load (chosen by “engineering judgment,” source: TT rep). The existing system shown in Figure 65 utilizes compression bracing to transfer gravity loads to the foundation. By inspection and through modeling in SAP 2000 this has proven to be a very efficient design because of the direct load path to the foundation.



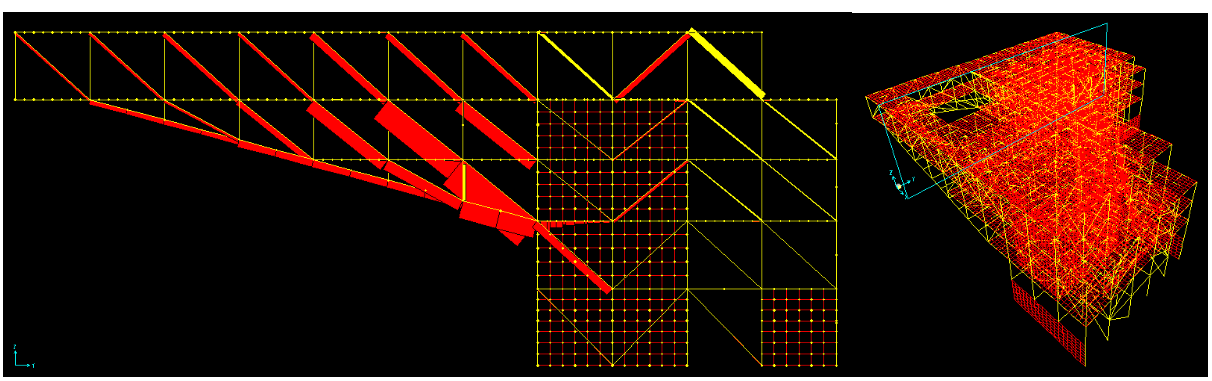



Figure 65: Existing Cantilever Truss Col Line 2.

The existing cantilever structural system was modeled in SAP and all applicable gravity loads applied to the structure, including: self-weight, super-imposed dead load, live load, and façade self-weight. The loading schedule can be found in Appendix A: Structural Analysis. The structure was then checked for strength and deflection. The deflection of the cantilever under total loading was 5.25 in and therefore satisfies the requirements assessed by TT. The strength of the web and chord members of the truss was determined by evaluating each member for the combined loading interaction equation found in Part 6 of AISC. An example calculation of this process can be seen in Appendix A: Structural Analysis. The braces and chords of the truss were relabeled in SAP and used to filter the data output to obtain the member forces of these specific members. The maximum axial load was then calculated and used to determine whether to use equation H1-1a or H1-1b.

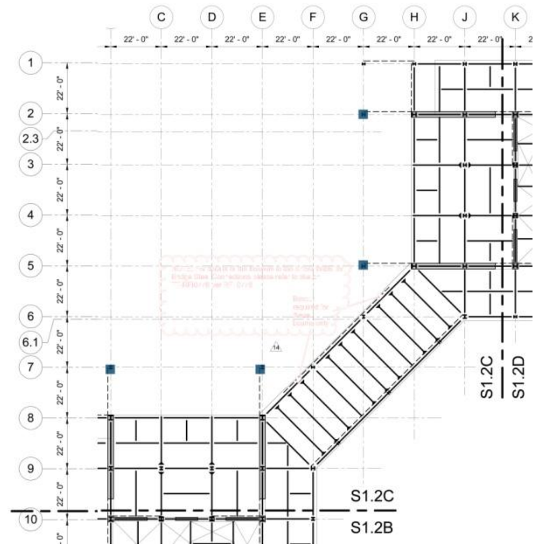



Figure 66: Column Locations (highlighted in blue).

Following this, the combined loading factors were taken from AISC and entered for each specific member and length.


Figure 67: Cantilever Existing Truss, Col Line 2.

The process of redesigning the cantilever structure involved many iterations, a few of which are shown in the figures to follow. To increase the efficiency of the truss structure the first thought was to decrease the unsupported length of the cantilever itself. To do this, additional columns were introduced at the locations shown in Figure 66, thereby reducing the unsupported length of the cantilever by 22 feet. This decreased the deflection at the tip of the cantilever and reorganized the location of the critical web members. In turn, a number of members were required to be sized-up or down in the locations shown in Figure 68 and Figure 69.

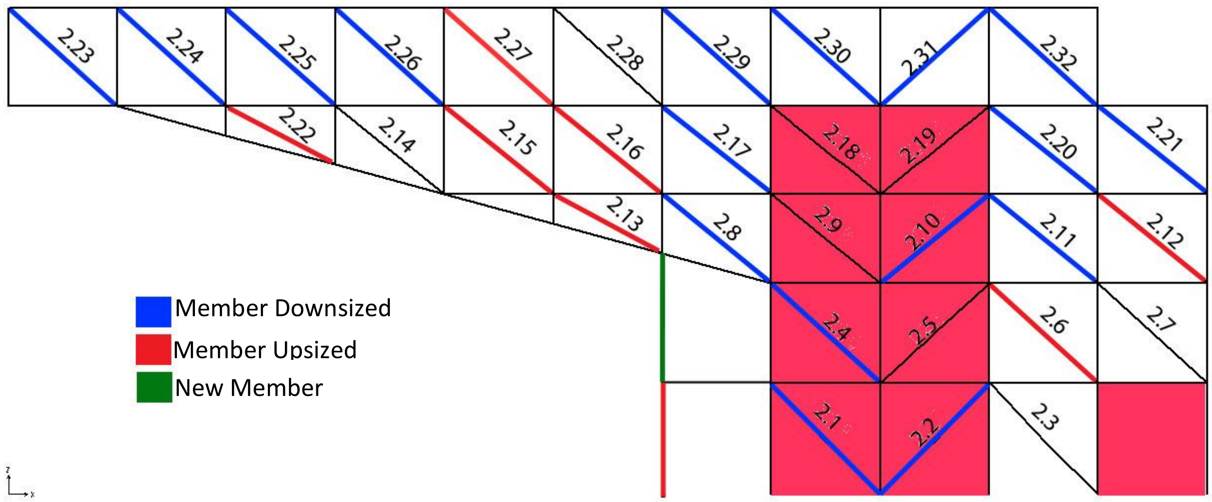



Figure 68: Cantilever Truss Redesign, Col Line 2.

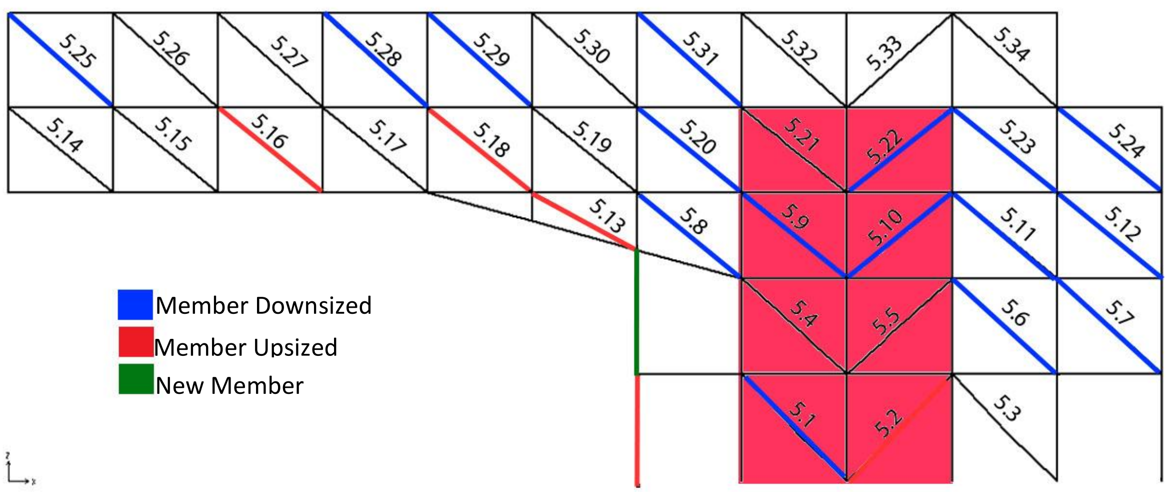



Figure 69: Cantilever Truss Redesign, Col Line 5.

Table 29: Cantilever Redesigned Member Sizes.

| Existing | | | | Redesign | | | |
|---|---|---|---|---|---|---|---|
| ID | Section | ID | Section | ID | Section | ID | Section |
| Frame 2.1 | W14X99 | Frame 5.1 | W14X109 | Frame 2.1 | W14X90 | Frame 5.1 | W14X90 |
| Frame 2.2 | W12X120 | Frame 5.2 | W12X120 | Frame 2.2 | W14X90 | Frame 5.2 | W14X90 |
| Frame 2.3 | W14X90 | Frame 5.3 | W14X90 | Frame 2.3 | W14X90 | Frame 5.3 | W14X90 |
| Frame 2.4 | W14X455 | Frame 5.4 | W14X283 | Frame 2.4 | W14X311 | Frame 5.4 | W14X283 |
| Frame 2.5 | W14X145 | Frame 5.5 | W14X90 | Frame 2.5 | W14X145 | Frame 5.5 | W14X90 |
| Frame 2.6 | W14X90 | Frame 5.6 | W14X193 | Frame 2.6 | W14X90 | Frame 5.6 | W14X90 |
| Frame 2.7 | W14X193 | Frame 5.7 | W14X193 | Frame 2.7 | W14X193 | Frame 5.7 | W14X90 |
| Frame 2.8 | W14X455 | Frame 5.8 | W14X283 | Frame 2.8 | W14X257 | Frame 5.8 | W14X109 |
| Frame 2.9 | W14X193 | Frame 5.9 | W14X159 | Frame 2.9 | W14X193 | Frame 5.9 | W14X145 |
| Frame 2.10 | W14X398 | Frame 5.10 | W14X176 | Frame 2.10 | W14X233 | Frame 5.10 | W14X120 |
| Frame 2.11 | W14X193 | Frame 5.11 | W14X193 | Frame 2.11 | W14X120 | Frame 5.11 | W14X90 |
| Frame 2.12 | W14X193 | Frame 5.12 | W14X193 | Frame 2.12 | W14X120 | Frame 5.12 | W14X120 |
| Frame 2.13 | W14X193 | Frame 5.13 | W14X90 | Frame 2.13 | W14X342 | Frame 5.13 | W14X145 |
| Frame 2.14 | W14X193 | Frame 5.14 | W14X90 | Frame 2.14 | W14X193 | Frame 5.14 | W14X90 |
| Frame 2.15 | W14X193 | Frame 5.15 | W14X90 | Frame 2.15 | W14X211 | Frame 5.15 | W14X90 |
| Frame 2.16 | W14X311 | Frame 5.16 | W14X90 | Frame 2.16 | W14X370 | Frame 5.16 | W14X120 |
| Frame 2.17 | W14X193 | Frame 5.17 | W14X90 | Frame 2.17 | W14X120 | Frame 5.17 | W14X90 |
| Frame 2.18 | W14X193 | Frame 5.18 | W14X90 | Frame 2.18 | W14X193 | Frame 5.18 | W14X145 |
| Frame 2.19 | W14X233 | Frame 5.19 | W14X145 | Frame 2.19 | W14X233 | Frame 5.19 | W14X176 |
| Frame 2.20 | W14X193 | Frame 5.20 | W14X193 | Frame 2.20 | W14X120 | Frame 5.20 | W14X145 |
| Frame 2.21 | W14X193 | Frame 5.21 | W14X159 | Frame 2.21 | W14X120 | Frame 5.21 | W14X159 |
| Frame 2.22 | W14X61 | Frame 5.22 | W14X176 | Frame 2.22 | W14X90 | Frame 5.22 | W14X120 |
| Frame 2.23 | W14X145 | Frame 5.23 | W14X193 | Frame 2.23 | W14X90 | Frame 5.23 | W14X120 |
| Frame 2.24 | W14X145 | Frame 5.24 | W14X193 | Frame 2.24 | W14X90 | Frame 5.24 | W14X120 |
| Frame 2.25 | W14X145 | Frame 5.25 | W14X90 | Frame 2.25 | W14X109 | Frame 5.25 | W14X120 |
| Frame 2.26 | W14X145 | Frame 5.26 | W14X90 | Frame 2.26 | W14X109 | Frame 5.26 | W14X90 |
| Frame 2.27 | W14X145 | Frame 5.27 | W14X90 | Frame 2.27 | W14X159 | Frame 5.27 | W14X90 |
| Frame 2.28 | W14X145 | Frame 5.28 | W14X90 | Frame 2.28 | W14X145 | Frame 5.28 | W14X120 |
| Frame 2.29 | W14X145 | Frame 5.29 | W14X90 | Frame 2.29 | W14X90 | Frame 5.29 | W14X120 |
| Frame 2.30 | W14X145 | Frame 5.30 | W14X109 | Frame 2.30 | W14X90 | Frame 5.30 | W14X109 |
| Frame 2.31 | W14X145 | Frame 5.31 | W14X109 | Frame 2.31 | W14X120 | Frame 5.31 | W14X90 |
| Frame 2.32 | W14X193 | Frame 5.32 | W14X159 | Frame 2.32 | W14X159 | Frame 5.32 | W14X257 |
| | | Frame 5.33 | W14X176 | Frame 2.33 | W14X550 | Frame 5.33 | W14X176 |
| | | Frame 5.34 | W14X193 | Frame 2.34 | W14X550 | Frame 5.34 | W14X211 |
| | | | | | | Frame 5.35 | W14X550 |
| | | | | | | Frame 5.36 | W14X550 |

The next thought was that by switching the direction of the braces and therefore switching the loading of the bracing members from compression to tension loading the cross sectional area of the braces could be reduced and in turn the cost of the structure could be reduced. By switching the direction of the braces to the pattern in Figure 70, with the same members used in the existing design, the deflection at the tip of the cantilever increased to 6.45 in as to be expected. It was initially theorized that by using this type of loading the braces could possibly be changed to HSS members but by inspection the decrease in strength of an HSS member (Fy = 42 ksi) would lead to a further increase in cross sectional area to satisfy strength requirements and prevent excessive deformation. Aside from increasing the strength of the members itself (through an increase in cross-sectional area) the next thought would be increase the depth of truss at the location of greatest stress, ie. directly to the left of the new column. It was chosen as a group to not drastically alter the architecture of the existing cantilever therefore to increase the depth of the cantilever structure at this location either above or below was dismissed as a possible route in increasing the stiffness of the cantilever.

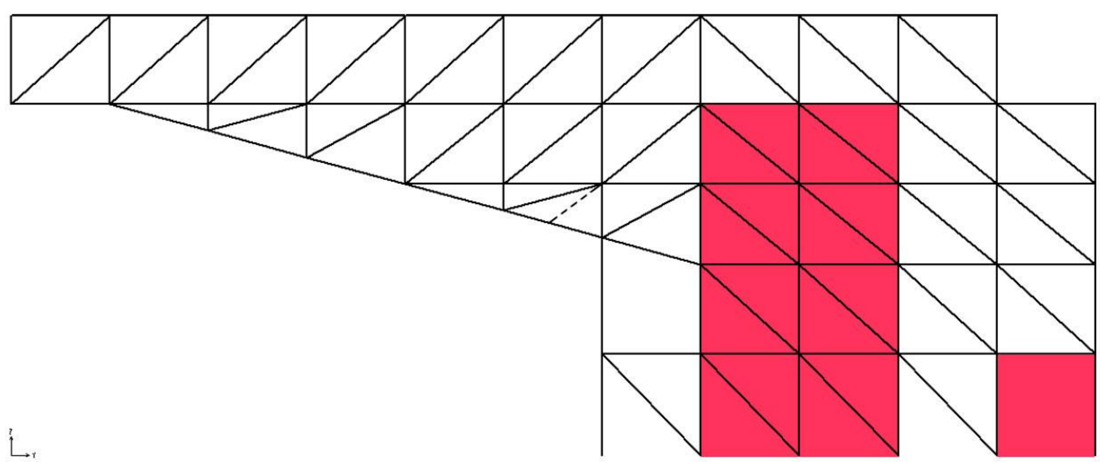
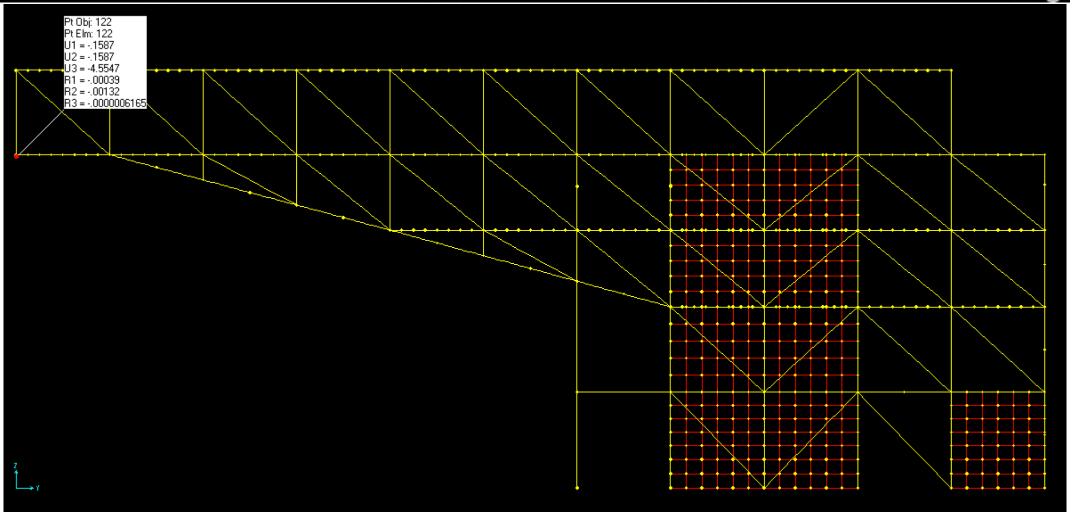


**Figure 70: Cantilever Truss Iteration, Tension Col Line 2.**

The final redesign of the cantilever structure can be seen in the figure below. As described above the final design involved the introduction an additional column 1 bay from the shear wall at each of 4 trusses supporting the cantilever. This allowed for a redesign of particular web and chord members of the truss and resulted in a net savings of 76 tons of steel between the existing and redesigned cantilever structure.



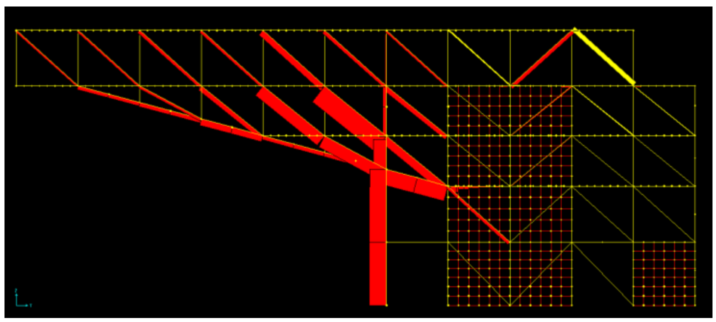
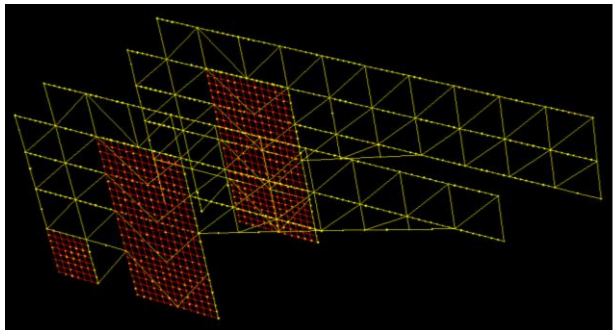



Figure 71: Redesign Cantilever Truss Col Line 2.

To optimize the load sharing between the two trusses, each truss was designed to have similar stiffness. The intent of this was to ensure that each truss was equally supporting the load of the cantilever. This is of particular importance because this would allow the cantilever to deflect uniformly especially at the intersection of the 4 trusses, each set of two spanning from the respective wings of the building. To check this, a 1000 kip unit load was placed at the tip of each individual truss and the resulting deflection was used to calculate the stiffness. This was performed for both the existing and redesigned trusses. Additionally, the percent difference between each truss in the respective designs was calculated and the stiffness of the redesigned trusses was less than that of the existing truss. This would result in a more efficient truss design for the cantilever structure.



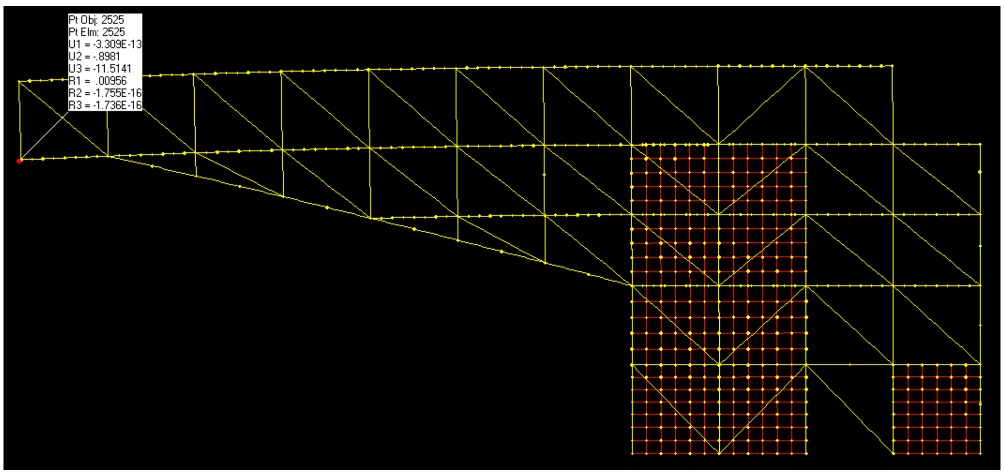



**Figure 72: Stiffness Check Existing Col Line 2.**

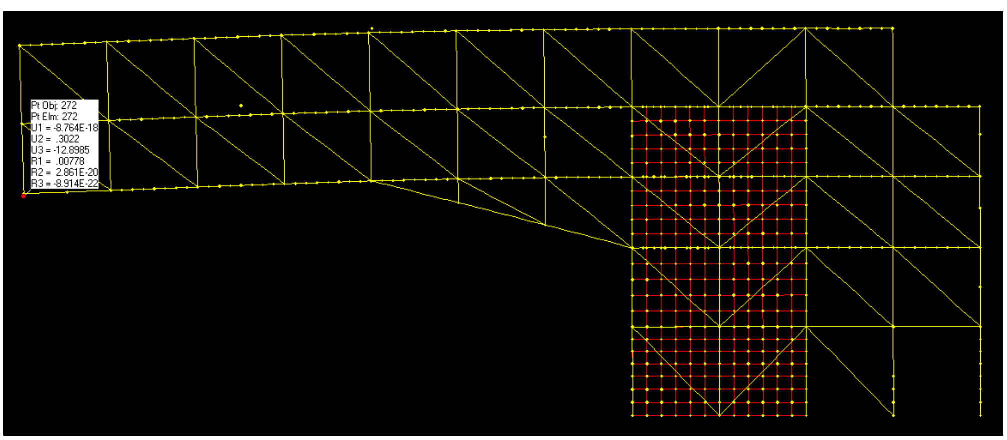



**Figure 73: Stiffness Check Existing Col Line 5.**

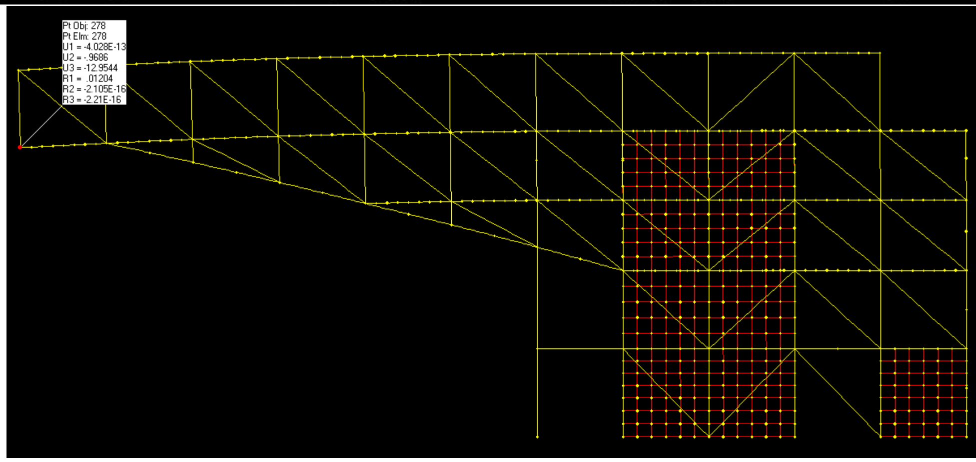



Figure 74: Stiffness Check Redesign Col Line 2.

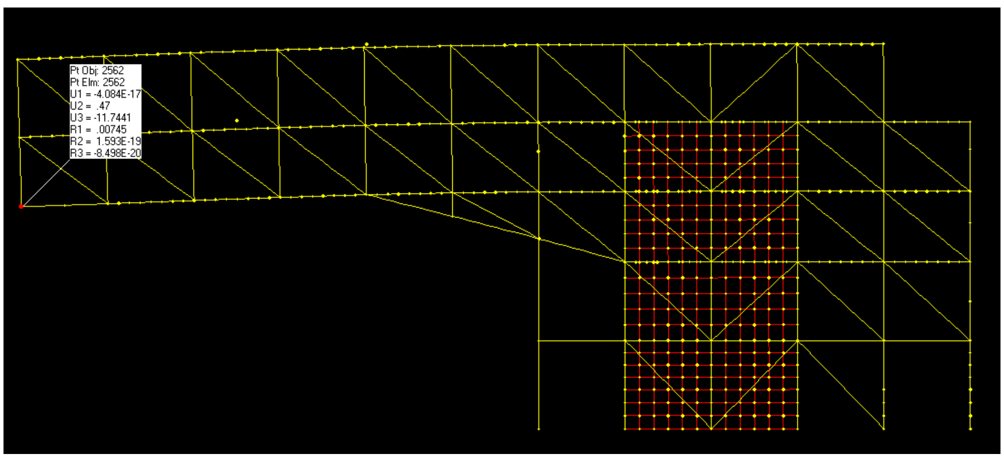



Figure 75: Stiffness Check Redesign Col Line 5.

Table 30: Stiffness Check.

| | Existing | | Redesign | |
|---|---|---|---|---|
| **Frame** | 2 | 5 | 2 | 5 |
| **P** | 1000 | 1000 | 1000 | 1000 |
| **U** | 11.5141 | 12.8985 | 12.9544 | 11.7441 |
| **K** | 0.011514 | 0.012899 | 0.012954 | 0.011744 |
| **% diff** | | 11.34 | | 9.80 |

It should be noted that because of the nature of this thesis project, we were given the opportunity to act as the project architect. This allowed the group to make decisions that the original structural designer on the project would have been limited in making, ie. introducing a series of columns that may spoil the visions of the original architect. It is the opinion of Building Stimulus that the additional columns add significance to the entrance of the wings while not diminishing the "visual statement" of the massive cantilever.

## Process and Material Take-Off

The primary focus of the structural redesign was the 4 major trusses, two running parallel to the Material Sciences wing, and two running parallel to the Life Sciences wing. The construction manager and structural designer, in a cooperative effort, redesigned the truss design including the addition of members as well as the resizing of existing members, and created a detailed estimate of the redesign compared to that of the original design. The full set of take-offs and estimates can be found in Appendix D: Construction Management.

## Structural Costs

After completing take-offs of the original truss system, as well as the redesigned truss system, a detailed estimate was performed using RS Means. Upon accessing RS Means, it was found that data did not exist for the W30x90 structural member, which exists in the original design, as well as the redesign. To obtain an accurate cost for this member data was plotted and, using a linear trend line, a cost was estimated using extrapolation of known cost date.

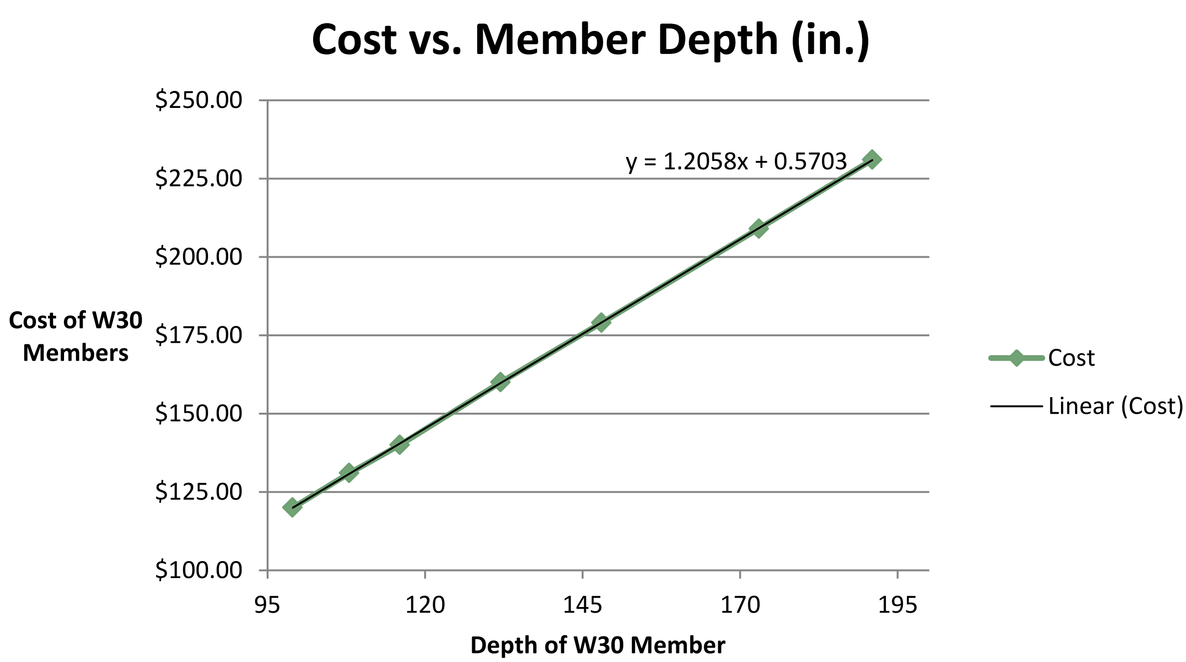



Figure 76: Cost vs. Member Depth Plot.

After developing a trend line equation, it was determined the W30 x 90 members cost $109.09 per linear foot. The full data plotted can be found in Appendix D: Construction Management. After cost was determined, remaining cost variables were estimated conservatively based on existing data. Bare labor cost, bare equipment cost, and labor hours were all chosen from existing RS Means values of similar sized members.

After performing a detailed estimate, it was conclusive that the redesigned truss system reduced costs by $140,569. The resizing of members also reduced overall weight of the truss system. Below is a summary of the findings. Full results are found in Appendix D: Construction Management.

Table 31: Truss System Comparison Summary.

| | Original Truss System | Redesigned Truss System | Difference |
|---|---|---|---|
| **Cost** | $ 4,112,631.06 | $ 3,967,985.69 | $ (144,645.37) |
| **Tons** | 1220.85 | 1143.66 | -77.19 |
| **Labor Hours** | 637.73 | 655.225 | 17.495 |

## Schedule Consideration

As can be seen in the Table 31 in the previous section, the redesigned structure reduces cost, as well as building weight, and requires negligible increase in man-hours of labor. The truss system, both original and redesigned, begins at column line M and ends at column line A in the Material Sciences wing. The Life Sciences truss system begins at column line 12 and ends at column line 1. In **Error! Reference source not found.** below, the trusses are represented by the orange regions, while the trusses column lines of origin are represented by the green regions.


Figure 77: Truss System Location and Origin.

According to Whiting-Turner, the original construction of these column lines lasted a total of 131 days for the Material Sciences wing, and 107 days for the life sciences wing. Below are the construction dates of the original system.

Table 32: Original Truss Construction Schedule.

| Task Name | Duration | OD | Start | Finish |
|---|---|---|---|---|
| **Structural Construction** | | | | |
| **Material Sciences Wing** | **131 days** | **114 days** | **Fri 10/16/09** | **Fri 4/16/10** |
| **Column line M - H** | 74 days | 59 days | Fri 10/16/09 | Wed 1/27/10 |
| **Column Line H - E** | 47 days | 20 days | Tue 1/12/10 | Wed 3/17/10 |
| **Column Line E - A** | 27 days | 35 days | Thu 3/11/10 | Fri 4/16/10 |
| **Life Sciences Wing** | **107 days** | **117 days** | **Thu 11/19/09** | **Fri 4/16/10** |
| **Column Line 12 - 8** | 52 days | 62 days | Thu 11/19/09 | Fri 1/29/10 |
| **Column Line 8 - 5** | 37 days | 20 days | Tue 1/26/10 | Wed 3/17/10 |
| **Column Line 5 - 1** | 27 days | 35 days | Thu 3/11/10 | Fri 4/16/10 |

The time of the year for the scheduled construction must be noted with regards to the climate of State College, PA. These scheduled dates occur during the coldest months of the year for northeastern United States. Column OD in Table 32, which represents the activity's 'Original Duration', shows significant discrepancies between the Material Sciences wing's planned construction, and its actual construction. Column lines M-H, as well as H-E, were both planned to occur during the heart of the winter months, while the later activities occurring during the milder months made up for some lost time. It can be concluded that the structural redesign is of truss system in the Millennium Science complex provides financial benefits to the project. It is very difficult, however, to compare the estimated duration of the redesigned truss system versus the estimated and actual duration of the original design. While the estimated durations are essentially identical in duration, it is clear that unpredictable and uncontrollable delays dictate the true on-site duration.

## Exterior Plaza Lighting Design

### Spatial Summary

The main entrance of the Millennium Science Complex is located where each of the two wings joins each other. The cantilevered connection creates a plaza area that houses an entrance to each Material Science and Life Science wings. Under the square opening in the structure above, a pathway exist that sends walkers through a swirling pattern that leads from one entrance to the other. The design of the pathway has been intended to be directionless to discourage use. The structure below is a quiet lab area has been deemed extremely vibration sensitive and heavy use will disrupt the research and experiments below.

### Drawings & Layout


Figure 78: Exterior Plaza - Plan View.

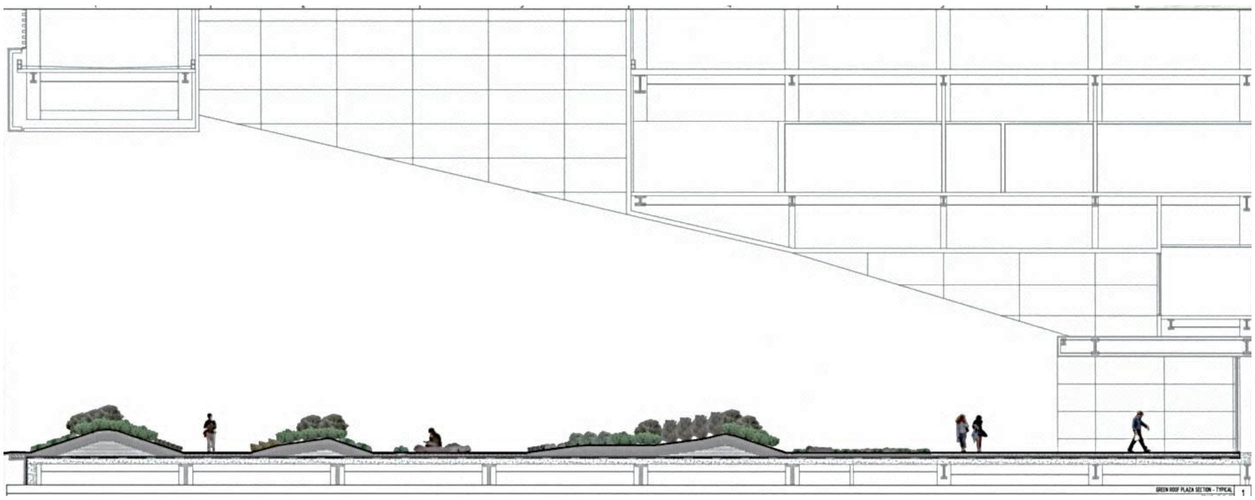


Figure 79: Exterior Plaza - North Section.

## Tasks & Activities

The exterior plaza serves as the main entrance to both wings of the building. The space contains the primary architectural feature of the building, the 154 foot double cantilever that covers the exterior plaza. The meandering pathway under the cantilevered structures oculus exists to create a relaxing environment for users. The indirect routes and topography have been noted as deterrents of heavy traffic in this area due to the Nanotechnology lab below as vibrations are a primary structural design concern in this lab space. Primary tasks of this area will be simple foot travel into and out of the building with somewhat limited use of the gardens meandering pathway.

## Materials

Table 33: Exterior Plaza Materials List.

| Surface | Reflectance |
|---|---|
| *Grass*** | *0.26* |
| *Fern Area*** | *0.24* |
| *Ornamental Grass*** | *0.26* |
| *Ground Cover*** | *0.15* |
| *Mulch*** | *0.20* |
| *Pathway*** | *0.22* |
| *Sidewalk*** | *0.28* |
| *Brick*** | *0.26* |
| *Silver Paneling*** | *0.34* |
| *Copper Paneling*** | *0.34* |

**Values from AGi32 swatches for similar materials

## Design Considerations

- Gardens:
  - Considerations (IESNA Handbook)
    - Appearance of Space and Luminaires
    - Color Appearance
    - Direct Glare Avoidance
    - Light Distribution on Surfaces
    - Light Pollution/Trespass
    - Modeling of Faces
    - Peripheral Detection
    - Reflected Glare
    - Shadows
  - Design Suggestions
    - Horizontal 1.0fc (IESNA Handbook – Gardens: Paths)
    - Vertical 0.3fc (IESNA Handbook – Gardens: Paths)
    - Power Densities (ASHRAE 90.1, Table 9.4.5)
      - Building Grounds (walkways less than 10'wide)
        - 1.0W/Linear Foot (Tradable)
      - Walkways greater than 10' wide & Plaza Areas
        - 0.2W/SF (Tradable)
      - Canopies & Overhangs
        - 1.25W/SF (Tradable)
      - Building Facades
        - 1.25W/SF (Non-Tradable)

The exterior plaza will fall under ASHRAE 90.1, Table 9.4.5 LPD classification of Canopies and Overhangs, thus allowing the area of focus to be categorized at 1.25W/SF. The area under the cantilever is 28,423SF, allowing the use of 35,528 total connected watts of lighting fixtures in this area.

## Luminaire Schedule

Table 34: Exterior Plaza Luminaire Schedule.

| Type | Manuf. | Catalog No. | Description | Location | Ballast | Lamp | VA | Input Watts | BF | Volt |
|---|---|---|---|---|---|---|---|---|---|---|
| CAN-Ua | Elliptipar | M152-210C-V-06-2-V00 | Adjustable wall mounted cooper color finish metal halide uplight. | Cantilever Underside Wash | Philips: AS205WQUA DEE | (1) Philips: CDM210/T9/930/ U/E | 257.78 | 232.00 | 1.00 | 277V |
| CAN-Ub | Elliptipar | M151-070G-X-06-2-V00 | Adjustable wall mounted cooper color finish metal halide uplight. | Cantilever Underside Wash | Philips: 71A5237P | (1) Philips: CDM70/T6/842 | 94.44 | 85.00 | 1.00 | 277V |
| CAN-R | Cooper: Iris | P406TAT-MH4CMH 39T6E-E4CMHCB-MB | Recessed medium beamlens downlight with 4"x4" square aperture. | Exterior Plaza Entryways and Sidewalks | Philips: 71A5037BP | (1) Philips: CDM35/T6/842 | 53.33 | 48.00 | 1.00 | 277V |
| CAN-W | Cooper: Iris | P406TAT-MH4CMH 39T6E- E4LWW-8H-SF-MTP4MB | Recessed Lens Wall Wash Luminaire with 4"x4" aperture. | Exterior Plaza Lobby Entryways | Philips: 71A5037BP | (1) Philips: CDM35/T6/842 | 53.33 | 48.00 | 1.00 | 277V |
| CAN-L | Elliptipar | F164-T128-H-07-2-000 | 2' cantilevered-pole-mounted fluorescent wall washing luminaire. Finish is to match metal paneling. | Cantilever Oculus | Philips - Centium: ICN-4S54-90-C2LS | (1) Philips: 54W/840 Min Bipin T5 HO ALTO | 59.56 | 58.50 | 0.99 | 277V |
| XPO-1 | Louis Poulsen | Kipp Model 416 with post 4.5-12 Black | PSU Campus standard pole mounted luminaire. 12' post height/ | Exterior Pathways | Philips: 71A5337BP | (1) Philips: CDM 100W/840 Med ED17P CL ALTP+FB | 131.11 | 118.00 | 1.00 | 277V |

Note: Comprehensive Luminaire Schedule can be found in Appendix F: Comprehensive Luminaire Schedule.

Table 35: Exterior Plaza Light Loss Factors.

| Fixture Type | LDD | LLD | RSDD | BF | Total LLF |
|---|---|---|---|---|---|
| CAN-Ua | 0.90 | 0.913 | 0.75 | 1.00 | 0.616 |
| CAN-Ub | 0.90 | 0.852 | 0.75 | 1.00 | 0.575 |
| CAN-R | 0.90 | 0.867 | 0.95 | 1.00 | 0.741 |
| CAN-W | 0.90 | 0.867 | 0.95 | 1.00 | 0.741 |
| CAN-L | 0.90 | 0.890 | 0.79 | 0.99 | 0.626 |
| XPO-1 | 0.85 | 0.860 | 0.90 | 1.00 | 0.658 |

*LDD calculated from new IESNA guidelines for Clean Environment based on 12 month cleaning interval.

## Renderings & Color Images

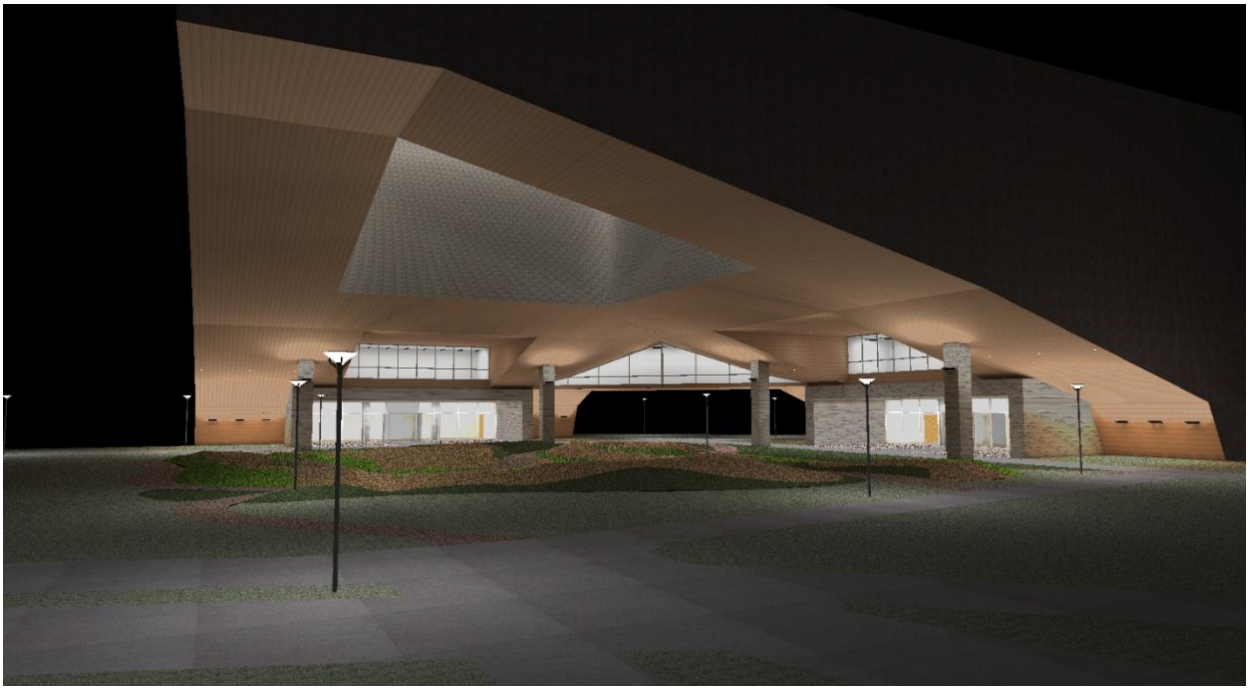


Figure 80: Exterior Plaza Lighting Design - Perspective View.

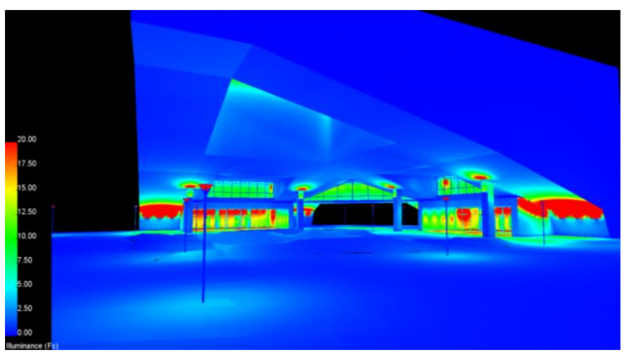



Figure 81: Exterior Plaza Lighting Design - Perspective View (Color: Illuminance).

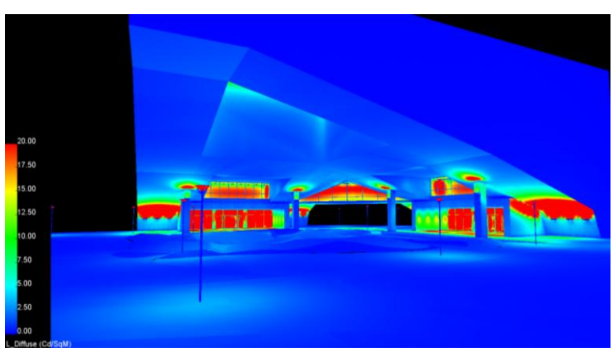



Figure 82: Exterior Plaza Lighting Design - Perspective View (Color: Luminance).

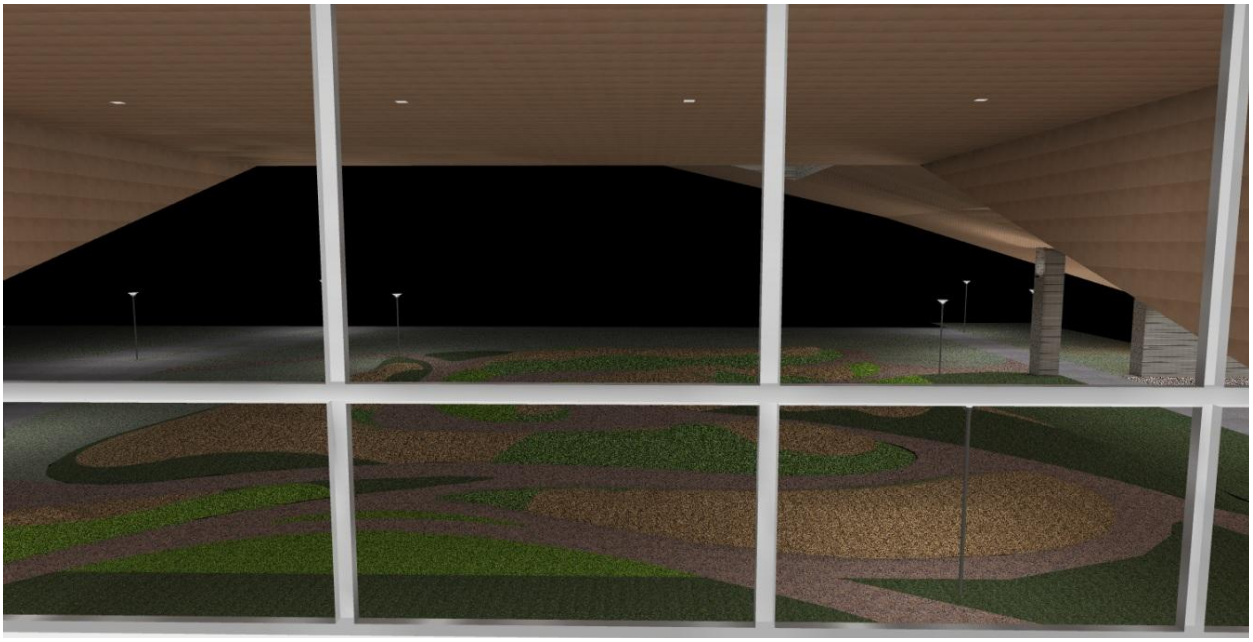


Figure 83: Exterior Plaza Lighting Design - Perspective View from 2nd Floor.

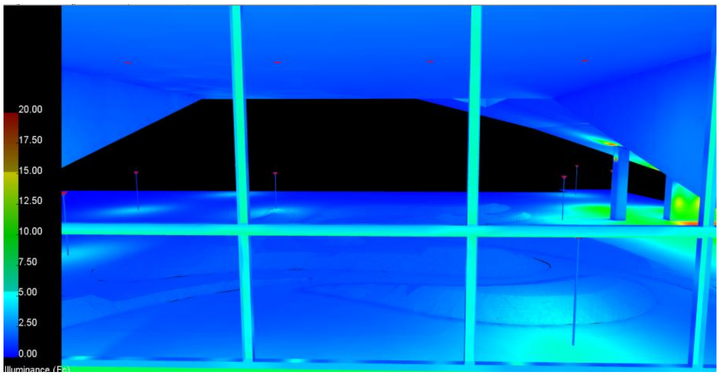



Figure 84: Exterior Plaza Lighting Design - Perspective View from 2nd Floor (Color: Illuminance).

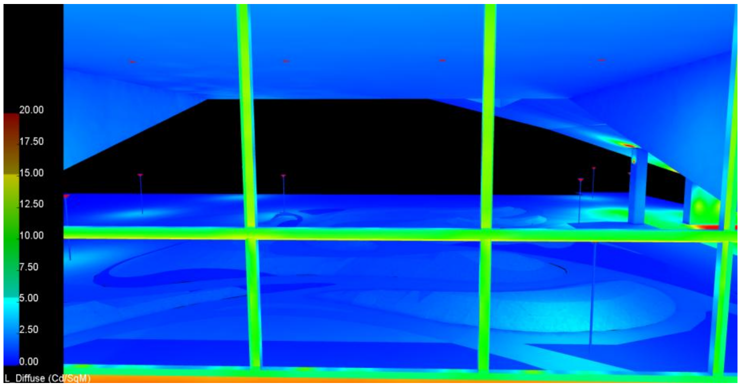



Figure 85: Exterior Plaza Lighting Design - Perspective View from 2nd Floor (Color: Luminance).

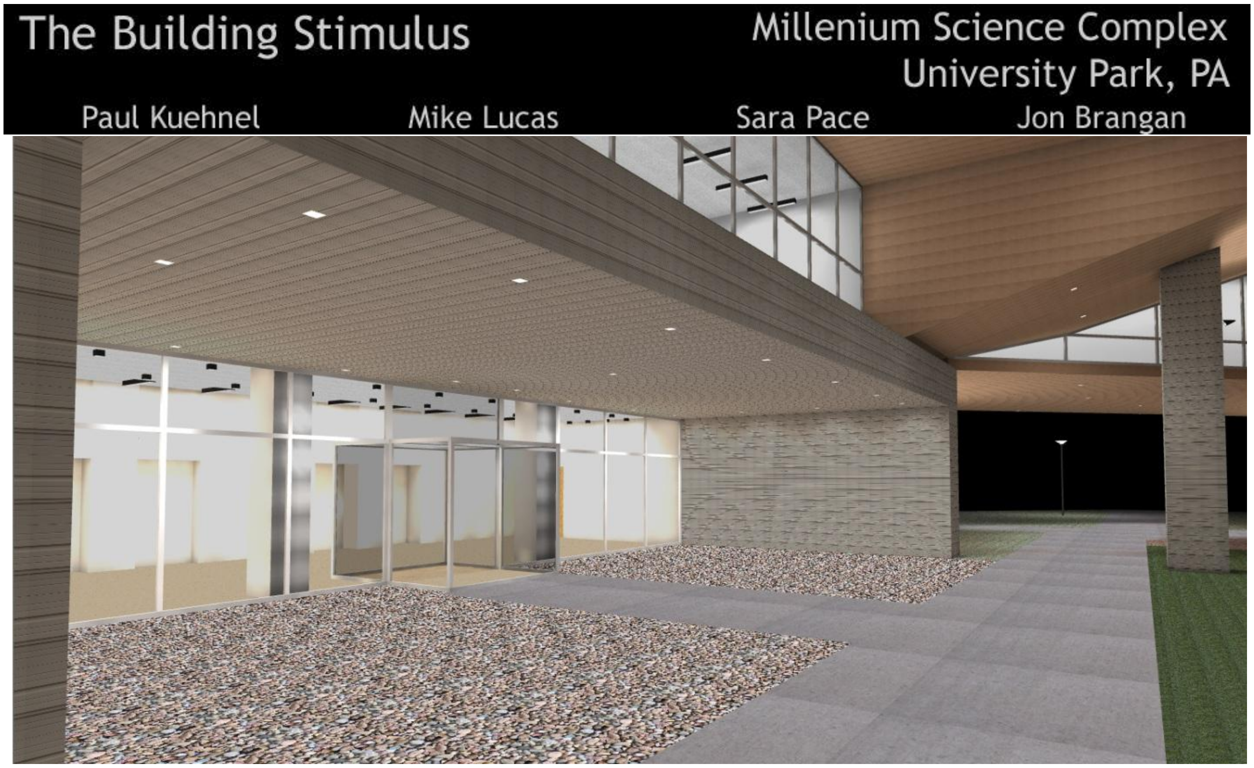



Figure 86: Exterior Plaza Lighting Design - Perspective View of Entrance & Lobby.

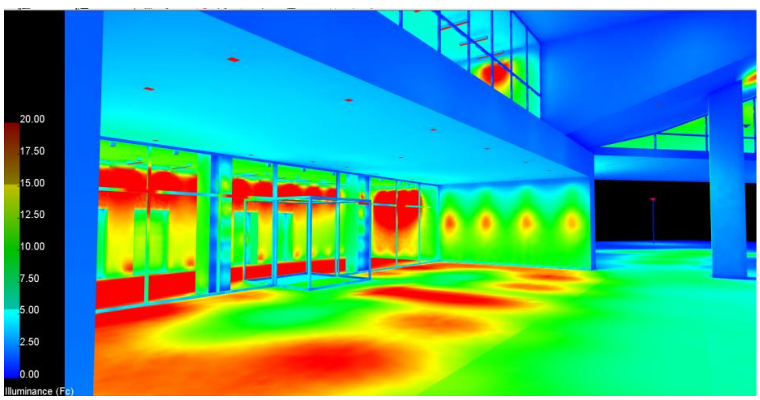



Figure 87: Exterior Plaza Lighting Design - Perspective View of Entrance & Lobby (Color: Illuminance).

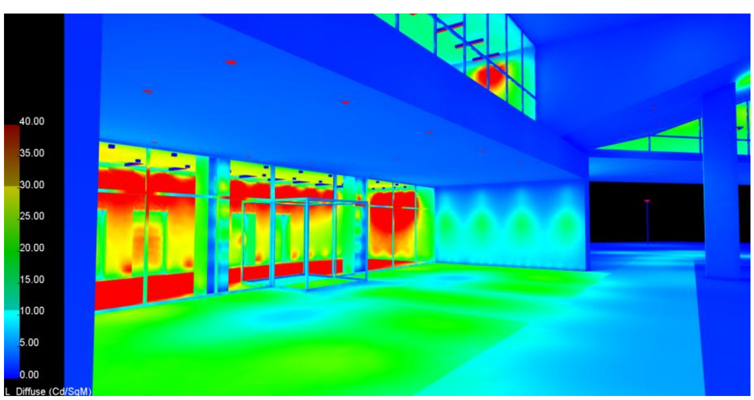



Figure 88: Exterior Plaza Lighting Design - Perspective View of Entrance & Lobby (Color: Illuminance).

Figure 89: Exterior Plaza Lighting Design - Perspective View from South of Bridge.

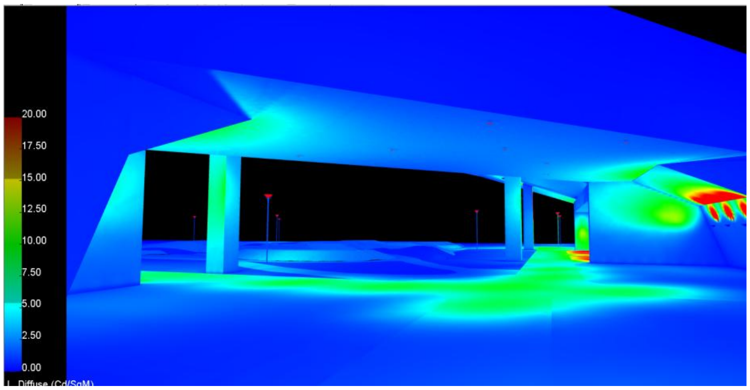



Figure 90: Exterior Plaza Lighting Design - Perspective View from South of Bridge (Color: Illuminance).

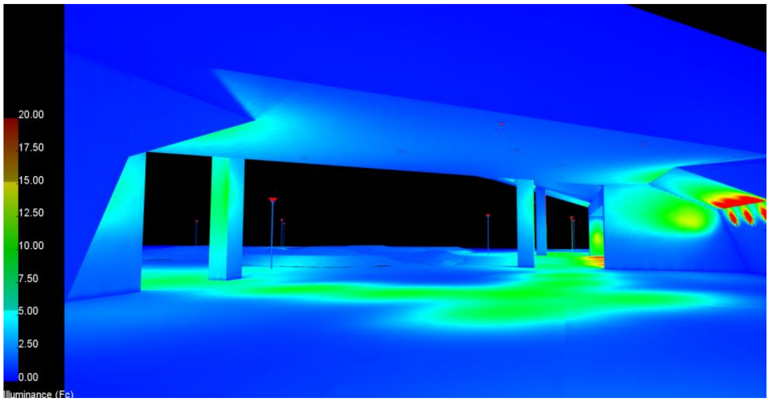
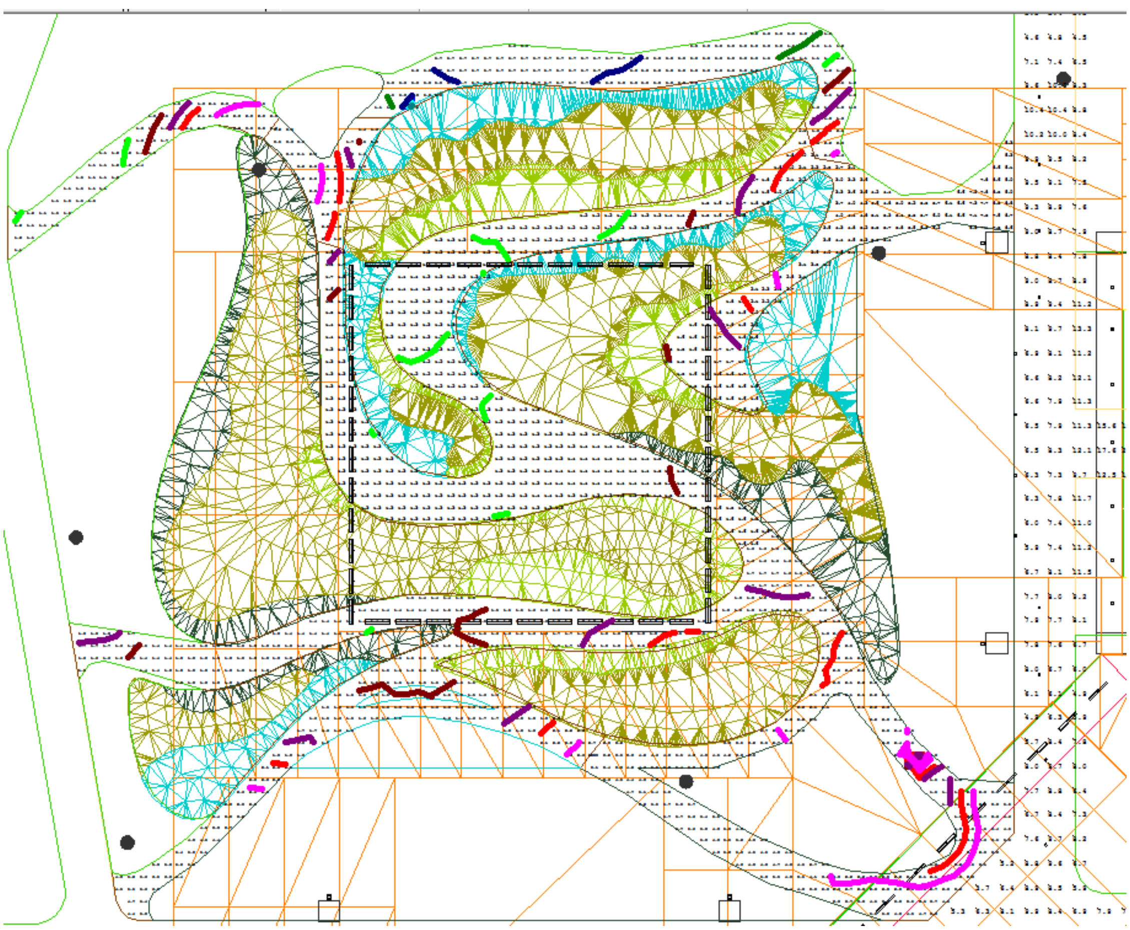



Figure 91: Exterior Plaza Lighting Design - Perspective View from South of Bridge (Color: Illuminance).

## Performance Summary

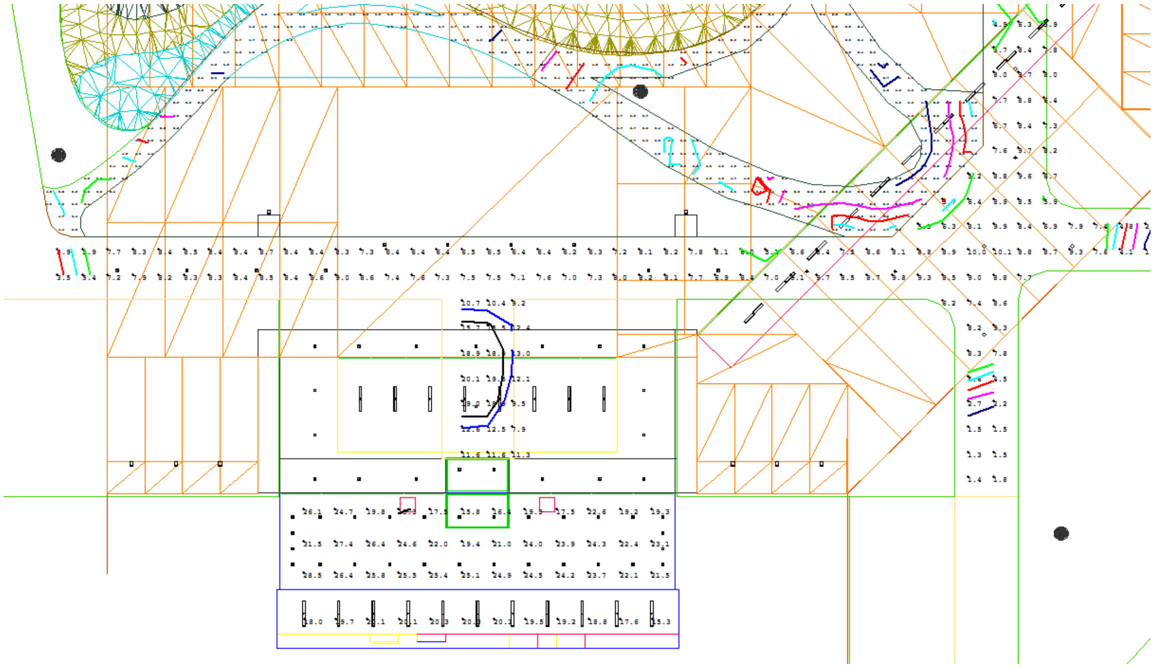
Table 36: Exterior Plaza Illumination Summary.

| Exterior Plaza Illumination Summary | Sidewalks | Meandering Path | Entryway |
|---|---|---|---|
| Avg. Illuminance (FC) | 9.00 | 2.12 | 13.09 |
| Max. Illuminance (FC) | 20.90 | 9.30 | 20.10 |
| Minimum Illuminance (FC) | 3.10 | 0.60 | 7.90 |
| Avg/Min | 2.90 | 3.53 | 1.66 |
| Max/Min | 6.74 | 15.5 | 2.54 |
| Max/Avg | 2.32 | 4.39 | 1.53 |
| Coefficient of Variation | 0.35 | 0.92 | 0.23 |
| Uniform Gradient | 2.69 | 1.17 | 2.21 |
| Power Density (W/SF) | | 0.357 | |



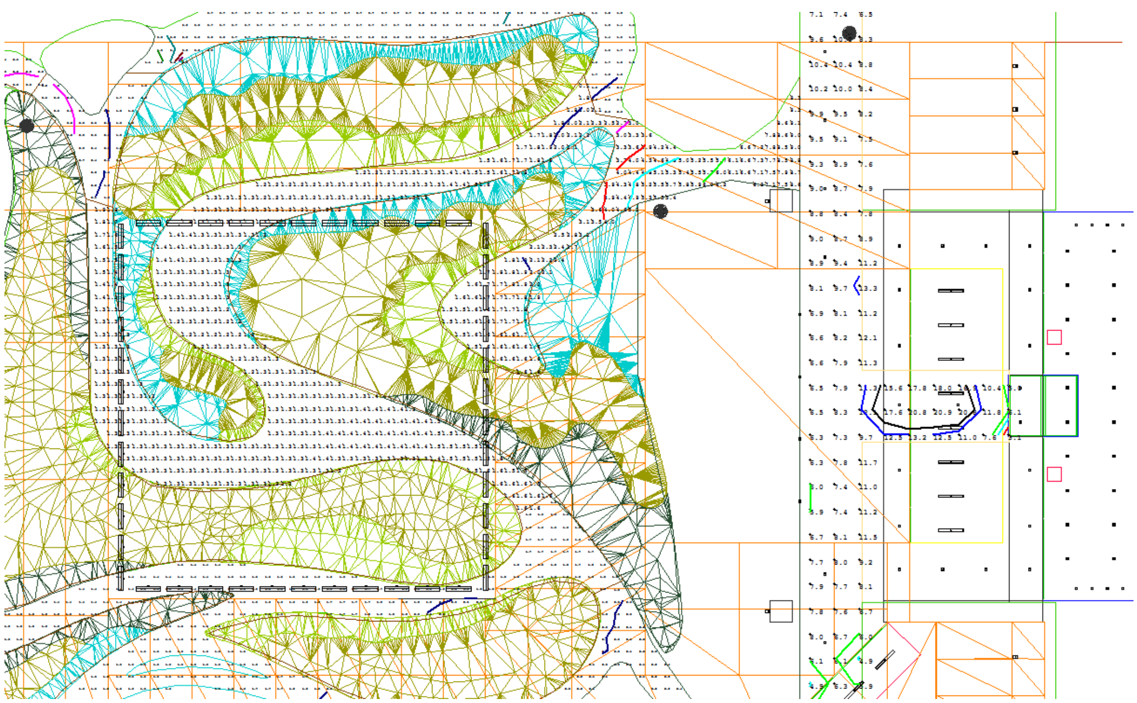
0.1fc - 0.25fc -0.5fc - 0.75fc - 1fc - 1.25fc - 1.5fc - 1.75fc- 2fc - 2.5fc

Figure 92: Meandering Path Illumination Contours.



0.1fc - 0.3fc - 0.6fc - 0.9fc - 1fc - 2fc - 3fc - 4fc - 6fc - 5fc - 12.5fc- 15fc

Figure 93: Life Science Entrance Illumination Contours.



0.1fc - 0.3fc - 0.6fc - 0.9fc - 1fc - 2fc - 3fc - 4fc - 6fc - 5fc - 12.5fc- 15fc

Figure 94: Life Science Entrance Illumination Contours.

## Controls

The exterior plaza lighting will be controlled along with other site lighting via two lighting control panels and remote control breakers. There will be a normal power system lighting control panel as well as a normal/emergency lighting control panel feeding all exterior lighting for the Millennium Science Complex. These panels will be located in the basement of the Material Science wing in room N-P052.

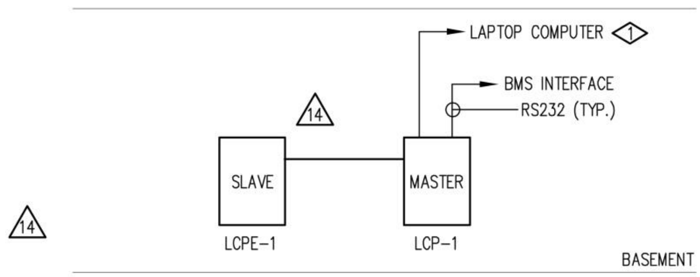
Eaton Cutler Hammer's lighting control panel Pow-R-Command 750 will allow use of up to 3 additional 42-panels, called expansion panels, for a total of 168 remote control breakers. The main panel will control the expansion panels via a subnet communication integrated controller.

The normal distribution system will feed LCP-1, which will use subnet communication systems to control breakers on LCPE-1. The zone control settings will be as follows:

Table 37: Exterior Lighting Control Schedule.

| Zone | Time On | LCP-1 | LCPE-1 |
|---|---|---|---|
| Exterior Pathways | Dusk to Dawn | 4,6,29,31,33 | |
| Exterior Stairwells | Dusk to Dawn | | 2,4,9,11 |
| Plaza Sidewalks | Dusk to Dawn | 5,30,32 | 7 |
| Plaza Entryways | Dusk to Dawn | 17,21,24,26 | |
| Cantilever Wash | Dusk to 12PM | 11,28 | |
| Oculus Lighting | Dusk to 12PM | 14,18,25,27 | |
| Lobby Lighting | 24 Hours | 1,7,9,13,15,12,35,36 | 37,43 |
| Loading Dock | Dusk to Dawn | | 8 |

The existing system is set up in a similar fashion, and a detailed system description can be found on the following page in Figure 95: Existing Controls for Exterior Lighting.




LIGHTING CONTROL SCHEMATIC DIAGRAM
N.T.S

NOTES:

1 CONTRACTOR TO SUPPLY A NOTEBOOK WITH THE FOLLOWING SPECIFICATIONS:

| | |
|---|---|
| SYSTEM COMPONENTS: | DELL LATITUDE D420<br>INTEL® CORE™ DUO PROCESSOR ULV U2400 (1.06GHZ, 533MHZ), GENUINE WINDOWS XP PROFESSIONAL, SP2, WITH MEDIA<br>UP TO 3.0 HOURS BATTERY |
| CATALOG NUMBER: | 4 BLDWGSD |
| MODULE | DESCRIPTION |
| LATITUDE D420 | INTEL ®CORE™ DUO PROCESSOR ULV U2400 (1.06GHZ, 533MHZ) |
| OPERATING SYSTEMS | GENUINE WINDOWS XP PROFESSIONAL, SP2, WITH MEDIA |
| LCD | 12.1 INCH WIDE SCREEN WXGA LCD PANEL |
| MEMORY | 1.5GB DDR2-533 SDRAM, (512MB INTEGRATED) 2 DIMMS |
| INTERNAL KEYBOARD | INTERNAL ENGLISH KEYBOARD |
| GRAPHICS | INTEL ®INTEGRATED GRAPHICS MEDIA ACCELERATOR 950 |
| HARD DRIVES | 60GB HARD DRIVE, 8MM, 4200RPM |
| FLOPPY DRIVE | NO FLOPPY DRIVE |
| AC ADAPTER | 65W A/C ADAPTER |
| PRIMARY EXTERNAL OPTICAL DRIVE OPTIONS | D-BAY PLUS 8X DVD+/-RW W/ROXIO™ AND CYBERLINK POWER DVD™ |
| WIRELESS LAN (802.11) | INTEL ®3945 802.11A/G DUAL-BAND MINI CARD |
| RESOURCE CD | RESOURCE CD AND REFERENCE GUIDE |
| BATTERIES | 4 CELL PRIMARY BATTERY |
| CARRYING CASES | DELL CORPORATE BACKPACK |
| WARRANTY & SERVICE | 3 YEAR LIMITED WARRANTY PLUS 3 YEAR MAIL-IN SERVICE |
| FILE SYSTEM | NTFS FILE SYSTEM FOR ALL OPERATING SYSTEMS |
| ADDITIONAL BATTERIES | ADDITIONAL 9 CELL EXTENDED BATTERY |
| MISCELLANEOUS | D420 DUAL |
| PURCHASE INTENT | PURCHASE IS NOT INTENDED FOR RESALE. |
| OS LABELS | WINDOWS XP BRAND |

ACCESSORIES

KENSINGTON POCKETMOUSE PRO USB WIRELESS LASER MOUSE
DELL PART# A0625678
MANUFACTURER PART# 72268
DELL PART# A0625678

**Figure 95: Existing Controls for Exterior Lighting.**

## Building Information Modeling

The definition of B.I.M (Building Information Modeling) as defined by the industry is:

"Building Information Modeling is the process of generating and managing building data during its life cycle."

This is a broad definition that encompasses many of the modeling and design aspects of architectural engineering. As a team of Architectural Engineers, Building Stimulus has come to realize that with a building of this size and stature, the end user is the one who can benefit the most from a detailed B.I.M. model.

### Planning with BIM

During pre-construction, the BIM process can enhance coordination amongst all disciplines before construction even begins. 3D models can act as site utilization plans, communicating how the project will change through various phases of construction. Models can produce take-offs providing the most accurate quantities that can be used to develop detailed estimates as well. As pre-construction progresses, owners, as well as sub-contractors, are given a better understanding of the project at hand.

While CPM schedules can show the linear progression of important activities, it fails in helping to visualize the actual construction of the project. Developing an intricate schedule, and linking to accurate 3D models, a 4D model can be created, producing a tool to visualize and communicate the actual construction process to sub-contractors and owners.

Building Stimulus developed a 4D model consisting of the existing steel structure, as well as the architectural precast panels and the glazing. The model was linked to the revised schedule of the proposed double-skin façade. The 4D model was used as a descriptive visualization tool meant to detail the erection process of the architectural precast panels. Below are screenshots of the animation:

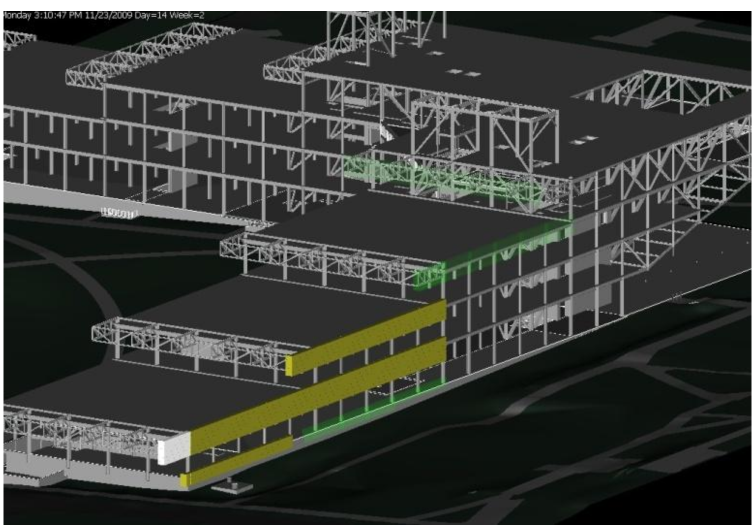



Figure 96: 4D Model of North Façade.

Figure 96 is a screen shot from Building Stimulus' 4D model. The image depicts the installation of precast panels along the North façade. Green regions represent panels in the process of being installed while the yellow represent secured and installed panels.

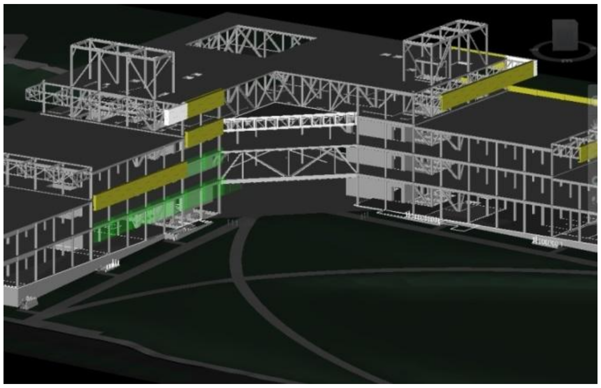


Figure 97: Precast Panel 4D Model.

For buildings such as the Millennium Science Complex, the sequence of an activity, in this case the installation of precast panels, may change locations as the project progresses, as see in Figure 97. 4D models are an optimum tool for expressing the sequence of activities of large projects such as the Millennium Science Complex.

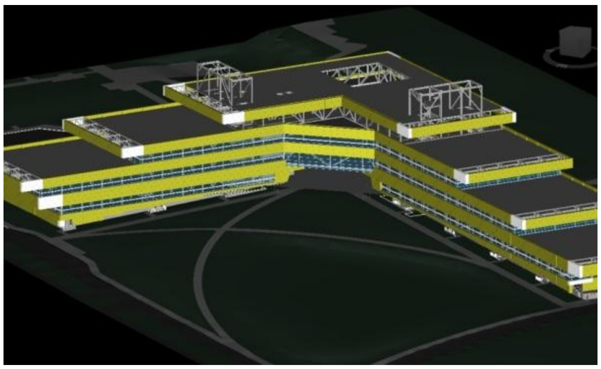


Figure 98: Completed Precast Panel 4D Model.

The use of a double-skin façade significantly altered the sequence of construction for the Millennium Science Complex, yet using the 4D model, the installation of precast panels is easily conveyed

## Construction & Coordination

Precise 3D modeling allows MEP trades to hash out conflicts in a conference room rather than in the field. James Faust, Facilities Manager for the Federal Reserve Bank and professor at the Pennsylvania State University once said, "It costs the owner $1 to change an idea on a computer screen, $10 on paper, and $100 in the field." With this motto in mind, Building Stimulus can help catch construction and planning issues before they become a problem in the field.

Building Stimulus developed detailed 3D models for structural, mechanical, and electrical systems. Using these models, clash detections were run on two week intervals. While clash detections can be a great benefit to a team's progress, the process is useless without proper communication. At the conclusion of each clash detection, the clashes were separated by types and systems involved. During weekly meetings, team members were informed of current clashes and areas of each model in need of revision. Clash detections benefited Building Stimulus by expediting the development of each 3D model. In doing so, accurate take-offs and measurements could be acquired from the most recent models. Below are instances of frequent clashes encountered by Building Stimulus:

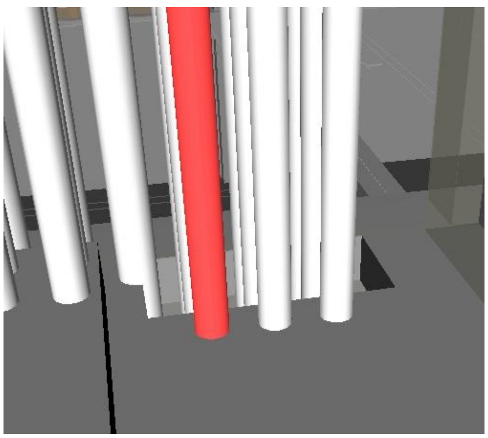


Figure 99: Conduit/Floor Slab Clash.

Figure 99 represents a sample clash encountered by Building Stimulus. As clash detection runs, it transposes the structural 3D model on to the electrical 3D model and alerts you of where they models intersect. Here it is clear that conduit risers are missing the opening in the floor slab that was intended for them to run through. In this case, the electrical designer is notified at team meetings and adjusts the locations of his conduits to meet the needs of the model.

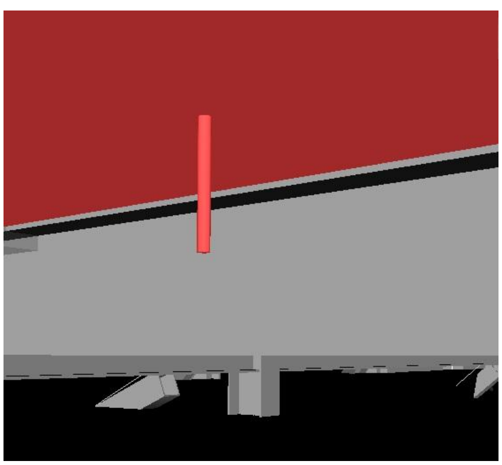


Figure 100: 2nd Floor Light Fixture Clash.

Building Stimulus ran clash detections for the 3$^{rd}$ floor spaces only. Figure 100 is an image of the underside of the 3$^{rd}$ floor slab (in red) on the structural beam. The vertical metal rod (also red) represents the upper connection of a 2$^{nd}$ floor light fixture coming up from below. This clash requires 2$^{nd}$ floor light fixtures to be offset 1' downwards.

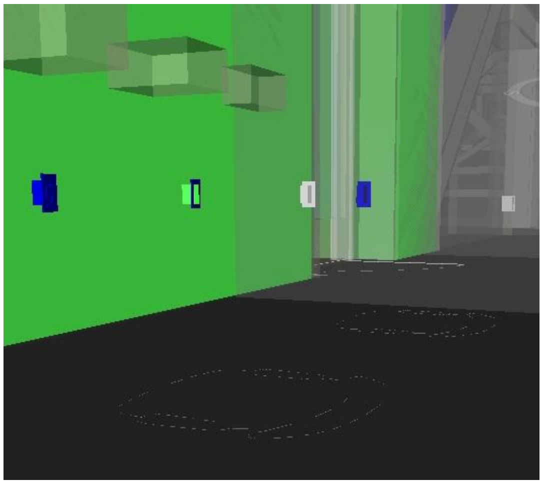


Figure 101: "Allowed" Clash.

While clash detections can help bring model conflicts to light, the process is not perfect. Benign clashes, such as the one in Figure 101, need to be addressed and acknowledged. Figure 101 shows a receptacle in a wall. The model recognizes the receptacle as a ‘clash’ even though it is in the correct location. The ‘clash’ is addressed and labeled ‘Allowed’, hence the green, not red, color. The clash is then removed from the list of unaddressed clashes.

## Facilities Management

As the owner pays for a BIM model, there must be a significant cost savings created by the process in order for it to be justified. In addition to improved estimating, scheduling, construction coordination, and the capability of accurate pre-fabrication, the end-user application of facility management has many reoccurring benefits to the owner.

A trained facility management team can use a B.I.M. model as a solid resource for a vast array of equipment information. Each piece of equipment throughout the B.I.M. model has the ability to be tagged with information such as manufacturer, equipment model & equipment number, web-links, replacement parts numbers, user and operation manuals, and countless other parameters. If Penn State's Facility Management team at the Millennium Science Complex wished to, they could require that the building designers and construction team input specific data into the model as per their own requirements.

A small example of building information into a model for facilities management teams has been completed for luminaires affected by lighting design changes in the third floor. Examples of the information put into the BIM model can be found in Appendix H: Lighting Fixture Cutsheets after each of their respective cutsheets. The following section details an example of the process and the information used to compile a BIM Model.

## Light Fixture Modeling & Circuiting

Modeling and circuiting lighting fixtures is quite similar to that of circuit and modeling receptacles. There is more use from supplying families and types with more information, for the information can be used to fill a luminaire schedule created from Revit MEP. Each lighting fixture type for lighting redesigns on the third floor were modeled in Revit and given the following parameters:

- Family Name
    - Family Type
        - Electrical
            - Lamp
            - Number of Lamps
            - Wattage Comments
        - Electrical Loads
            - Load Type
            - Apparent Load
        - Photometrics
            - Tilt Angle
            - Photometric Web File (.ies File)
            - Light Loss Factors
            - Initial Intensity
            - Initial Color
        - Identity Data
            - URL (Link to Manufacturer Webpage)
            - Model Number
            - Manufacturer
            - Lighting Fixture Type
            - Description (For Luminaire Schedule)
            - Ballast Manufacturer
            - Ballast Number
            - Keynote
- Electrical Connector
    - Number of Poles
    - Power Factor State
    - Load Classification
    - Voltage
    - Apparent Load Phase 1
    - Apparent Load Phase 2
    - Apparent Load Phase 3
    - Power Factor

Electrical connector properties and family properties for each of the luminaire families used in the Building Stimulus third floor electrical model can be found after the respective cutsheet in Appendix H: Lighting Fixture Cutsheets.

## Renovations

As an intensive science research building, Millennium Science Complex will undoubtedly have research labs and environments changed as research needs change. Exchanging fit-outs in labs can be a hassle for the users and owners, as down time means money lost. Providing the owner and facilities management team with a descriptive and accurate existing conditions three-dimensional model can help expedite the speed of both design and construction of future lab fit-out renovations.

## BIM Execution Plan

**Table 38: BIM Goals Table.**

| PRIORITY (HIGH/ MED/ LOW) | GOAL DESCRIPTION | POTENTIAL BIM USES |
|---|---|---|
| **H** | Assess Cost Associated with Design Changes – compare money spent/saved vs. quantitative benefit of design change | Cost Estimation, Existing Conditions Modeling |
| **H** | Increase Effectiveness of Design – Increase efficiency of structural system, lighting/electrical system, and mechanical system | Design Authoring, Design Reviews, 3D Coordination, Engineering Analysis, Existing Conditions Modeling |
| **H** | Interdisciplinary Design Coordination – Effectively implement BIM through open communication and periodical design reviews | Design Reviews, 3D Coordination |
| **M** | Increase Effectiveness of Sustainable Goals – Increase thermal and lighting efficiency through implementation of double skin façade | Engineering Analysis, LEED Evaluation, Daylight Integration |
| **M** | Improve On-Site Coordination and Efficiency | Site Utilization Planning, 4D Modeling |

Table 39: BIM Use Analysis

| BIM Use* | Value to Project | Responsible Party | Value to Resp Party | Capability Rating | | | Proceed with Use |
|---|---|---|---|---|---|---|---|
| | | | | Resources | Competency | Experience | |
| Design Authoring | Medium | Sara | Medium | 1 | 3 | 3 | Yes |
| | | Mike | Medium | 1 | 3 | 3 | |
| | | Paul | Medium | 1 | 3 | 3 | |
| Record Modeling | Medium | Sara | Low | 2 | 2 | 2 | No |
| | | Mike | Low | 2 | 2 | 2 | |
| | | Paul | Low | 2 | 2 | 2 | |
| Site Utilization Planning | Medium | Jon | High | 3 | 2 | 1 | Yes |
| Existing Conditions Modeling | High | Jon | Low | 2 | 3 | 2 | Yes |
| LEED Evaluation | High | Sara | High | 2 | 2 | 1 | Yes |
| | | Mike | High | 2 | 2 | 1 | |
| | | Paul | Low | 2 | 2 | 1 | |
| | | Jon | Medium | 2 | 2 | 1 | |
| Energy Analysis | High | Sara | High | 3 | 3 | 2 | Yes |
| Structural Analysis | High | Paul | High | 3 | 3 | 2 | Yes |
| Cost Estimation | High | Jon | High | 3 | 2 | 2 | Yes |
| 4D Modeling | Medium | Jon | High | 3 | 2 | 2 | Yes |
| 3D Coordination (Design) | High | Sara | Medium | 3 | 2 | 2 | Yes |
| | | Mike | Medium | 3 | 3 | 3 | |
| | | Paul | Medium | 3 | 2 | 2 | |
| | | Jon | High | 3 | 2 | 2 | |
| Daylight Integration & Lighting Analysis | Medium | Mike | High | 3 | 2 | 2 | Yes |
| Building Systems Analysis | Medium | Sara | High | 2 | 2 | 2 | No |
| | | Mike | Medium | 2 | 2 | 2 | |
| | | Paul | Low | 2 | 2 | 2 | |
| Design Reviews | Medium | Sara | High | 3 | 3 | 3 | Yes |
| | | Mike | High | 3 | 3 | 3 | |
| | | Paul | High | 3 | 3 | 3 | |
| | | Jon | High | 3 | 3 | 3 | |

* Additional BIM Uses as well as information on each l

## Design Authoring

Description: "A process in which 3D software is used to develop a BIM model based on criteria that is important to the translation of the building's design. Two groups of applications at the core of BIM – base design process are design authoring tools and audit and analysis tools.

Authoring tools create models while audit and analysis tools analyze or add to the richness of information in a model. Most of audit and analysis tools can be used for Design Review and Engineering Analysis BIM Uses. Design authoring tools are a first step towards BIM and the key is connecting 3D model with powerful database of properties, quantities, means and methods, costs and schedules." (BIM Project Execution Planning Guide)

Goal: Building Stimulus felt it would be necessary to develop and maintain an updated model from the aspect of all disciplines. Design authoring tools could enhance the use of BIM by allowing each discipline to create and update models, and create collaboration across disciplines. The design authoring of models can enhance each group members overall understanding of the project through the design process.

Outcome: Whiting-Turner, as well as RV Architects, provided Revit Architectural and Structural models that enabled certain disciplines to pursue the design and modeling routes initially planned. However, some models lacked the key information or details that could have created a more effective model. Structural models lacked key connection details, and architectural models were aesthetically accurate, yet occasionally lacked dimensional details on certain assemblies.

## Site Utilization Planning

Description: "A process in which a 4D model is used to graphically represent both permanent and temporary facilities on site, with the construction activity schedule. Additional information incorporated into the model can include labor resources, materials and associated deliveries, and equipment location. Because the 3D model components are directly linked to the schedule, site management functions such as visualized planning, short-term re-planning , and resources can be analyzed over different spatial and temporal data." (BIM Project Execution Planning Guide)

Goal: 3D modeling can be very effective in portraying on-site activities at a given point in time. 3D models can be used to develop site utilization plans to show the various phases of the construction process. This model could help focus on changes to General Conditions estimates, as well as on-site coordination.

Outcome: While site utilization plans are a very effective and informative tool to provide owners and sub-contractors, they demand an extensive coordination effort for the entire project. Site utilization plans were provided, yet without the use of 3D software. Building Stimulus found that site utilization revisions using 3D models would have been cumbersome, and time consuming, without providing substantial benefits.

## Engineering Analysis

Description: "A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the basis for what will be passed on to the owner and/or operator for use in the building's systems with respect to energy analysis. These analysis tools and performance simulations can significantly improve the design of the facility and its energy consumption during its lifecycle in the future."

### Energy Analysis

Goal: Energy modeling is an effective design approach to determine a more realistic profile of the building's profile. The purpose of this BIM use was to further develop the existing 3D model to incorporate more accurate power densities for the building.

Outcome: Throughout this project, energy models were developed in Revit MEP and Trane TRACE by exporting .gbXml files from Revit MEP to TRACE. This allowed the energy analysis to be updated to more accurately represent the actual energy consumption. It involved an iterative process that could not be fully realized until towards the end of the design phase to allow all the equipment and energy consumption parameters to be modeled to provide a more accurate energy profile.

### Structural Analysis

Goal: Structural analysis is necessary to design the supporting structure of the building for applicable lateral and gravity loading. The goal of this BIM use was to accurately model the redesign structure for use in performing a structural take off, 4D modeling, and clash detection.

Outcome: A 3D analytical model of the structural system of the Millennium Science Complex was created in ETABS for the lateral model and SAP 2000 for the cantilever redesign. The main issue with utilizing BIM and structural analysis is the cross-platform interoperability of analysis software and BIM software such as Revit. Neither ETABS or SAP have a plug-in available for importing models to Revit for integration uses. Thus, in this thesis project a model had to be maintained concurrently in both the analysis software and modeling software. This is obviously not an optimal solution for achieving the best BIM processes.

### Daylight Integration & Lighting

Goal: To achieve energy efficient lighting designs by incorporating natural daylight contribution into a room to help achieve desired illuminance levels, increase user comfort and visual appearance of the space.

Outcome: Throughout perimeter public spaces of the Millennium Science Complex, the dimming of electrical lighting has coincided with daylight levels to maintain a constant illuminance levels in public spaces. This has lowered electrical usage throughout the building. In private spaces, luminaire switching allows for occupants create a personalized environment that can maximize their perception of their space. Dynamic shading louvers on the plan-west and plan-south facades help eliminate blinding glare of direct sunlight while allowing ambient sunlight to fill the space. Existing fabric roller shades on the remaining facades proved efficient in minimizing direct glare.

## Building Systems Analysis

Description: A process that measures how a building's performance compares to the specified design. This includes an analysis of the mechanical system operational characteristic including the energy use of a building. Other aspects of this analysis could include, but are not limited to, ventilated façade studies, lighting analysis, internal and external CFD airflow, and solar analysis.

Goal: Alternative energy sources, such as wind turbines, were evaluated to determine the applicability for the building's use. Also, a new mechanical system was evaluated for energy savings possibilities.

Outcome: Wind turbines were analyzed by completing an external CFD airflow model of the building and its surrounding structures. The CFD software Phoenics was used. Through the implementation of BIM, .stl files for the buildings' shapes and sizes were exported from AutoCad 3D files to Phoenics to more accurately simulate the airflow. BIM also enhanced the coordination between the lighting and mechanical systems during the redesign to incorporate luminaire integrated chilled beams. The allowed an enhanced integrated discipline design for the building systems.

## Cost Estimation

Description: "A process in which a BIM model can be used to generate an accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns. This process also allows designers to see the cost effects of their changes in a timely manner which can help curb excessive budget overruns due to project modifications." (BIM Project Execution Planning Guide)

Goal: The material take-off process can be a tedious effort. 3D models can provide quick and effect take-offs to be used with cost data, resulting in a hastened estimate process. Cost estimations using 3D software demand accurate and detailed models from all disciplines to obtain the most accurate estimate. The BIM process is greatly enhanced when cost data is incorporated and communicated to all parties involved. Trades and disciplines become aware of the financial state of the design and if any changes must be made to reduce costs.

Outcome: 3D models and computer software greatly expedited the take-off process. Revit Architecture developed and automatically updated and maintained fixture schedules and quantities. Electronic cost databases were not available, so other means of cost research was required.

While some software was extremely beneficial, the lack of accurate models did hinder the take-off process of the structural system. Structural Revit models lacked the required detail to create an accurate take-off of the area of focus so electronic take-offs were performed by other means.

In coordination with the structural designer, the construction manager utilized SAP 2000 software to obtain accurate take-offs and quantities of existing structural systems, as well as the redesigned systems.

## 4D Modeling

Description: "A process in which a 4D model (3d models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. 4D modeling is a powerful visualization and communications tool that can give a project team much better understanding of project milestones and construction plans." (BIM Project Execution Planning Guide)

Goal: 4D modeling is a very effective tool to illustrate the sequence of construction as well as coordinate construction. Building Stimulus decided early on to use a 4D model in any fashion as long as it was effective and useful. The Construction Management student would determine the extent of its use and what the focus of the model would be.

Outcome: Building Stimulus decided to use the 4D model to illustrate the sequence of panel installation on the Millennium Science Complex. Using Revit models provided, including the panel models and structural model, the 4D animation shows the direction of installation and speed at which construction occurs.

## 3D Coordination

Description: “A process in which clash detection software is used during the coordination process to determine field conflicts by comparing 3D models of buildings systems. The goal of clash detection is to eliminate the major system conflicts prior to installation.” (BIM Project Execution Planning Guide)

Goal: The focus of select disciplines within Building Stimulus was to develop and maintain an updated 3D model of designed systems. Using these models, the Construction Management discipline would utilize clash detection technology to compare updated designs. Upon detection of clashes, the location and clash type will be distributed amongst relevant team members at weekly meetings for revision.

Outcome: Building Stimulus found the clash detection process to be a very quick and effective method to monitor discrepancies and clashes between models. Beginning in mid-March, clash detections were performed on 2-week intervals and given to relevant disciplines for revision. Electrical and structural models experienced the most clashes, with many instances of conduit running through floor slabs and/or structural beams. Many clashes that were experienced were the result of models recognizing acceptable lighting and electrical fixtures not as compatible building systems, but clashes. These clashes were acknowledged as ‘acceptable’ and discarded.

## Integrated Project Delivery

With the assistance of Thornton Tomasetti and faculty of the Architectural Engineering program at Penn State, the Integrated Project Delivery (IPD) process was explored and utilized to complete this year-long senior thesis project. The American Institute of Architects (AIA) defines IPD as a project delivery method that, “leverages early contributions of knowledge and expertise through the utilization of new technologies, allowing all team members to better realize their highest potentials while expanding the value they provide throughout the project lifecycle.” To effectively implement IPD the goals of the group were established at the beginning of the project and continually evaluated based on developments by each group member.

The IPD approach relies heavily on excellent communication. Establishing methods of communication between four students on different schedules with varying responsibilities in and out of the project, was of particular importance. In today’s culture we are rarely without some form of electronic communication. This poses many advantages in terms of staying in touch and up to date on the latest project developments on an instant basis. However, electronic communication cannot account for all transmission of information between group members. Many of the most influential discussions during this thesis project were achieved at a conference table with a pencil and paper. It was during these roundtable discussions where the ability to draw and effectively communicate spatially truly highlights the purpose of learning the principles of architectural drafting in 2nd and 4th year Architectural Studios.

All of this is not to say technology is a hindrance to effective communication, in fact it is much the opposite. It provides an entirely new dimension to the communication process. Outside the use of BIM a number of different technologies were used to effectively communicate and keep the project moving on schedule, including: Google Calendar, Google Chat, Doodle, and Microsoft Project. The figure below is an example of how Google Calendar was used for reference when the master schedule was not available via Microsoft Project. This technology required that each group member had a Google account, all of whom previously did. This calendar format allowed for group members to view their duties in a color format with the ability to receive reminders on upcoming tasks via text message or email. This format also allowed users to view the project schedule with the rest of their personal calendar to manage their time effectively even when on the go, as this format is viewable on a smartphone.

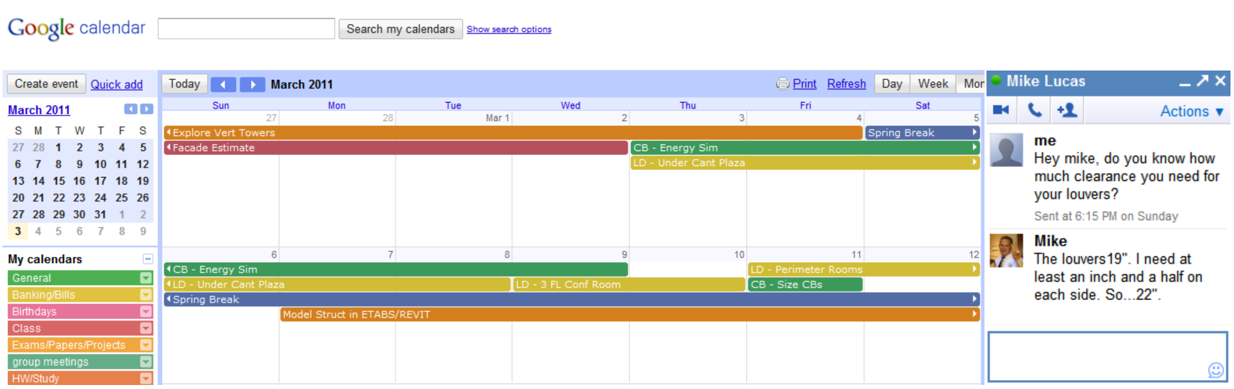



Figure 102: Communication Techniques.

In addition to Google Calendar, Google Chat was also used as a communication tool when group members were working in separate environments. This proved useful when to communicate a small amount of information in a quick an efficient manner.

As stated previously, to work effectively as a team it was necessary to meet at the minimum on a weekly basis in person. Often times the group members were in the thesis lab at the same time and impromptu meetings occurred on a regular basis. However, there were a number of times when trying to plan the next meetings and a common time could not be established. When this situation occurred the group relied on a free online meeting scheduler service called Doodle. As shown in the figure below, Doodle allows the author of the meeting to enter a few available dates and times he/she is available and send an invitation for team members to select when they are available and at what time. This was use periodically throughout the year to schedule meetings when it proved to be difficult in person.

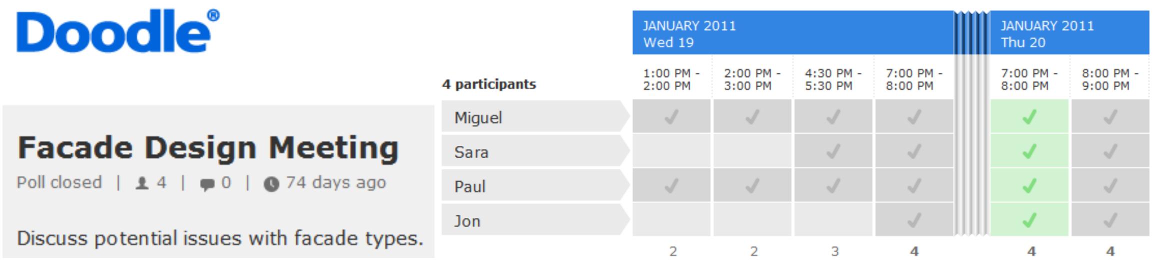



Figure 103: Meeting Time Scheduling Techniques.

Microsoft Project was used to keep track of the master schedule for Building Stimulus. This proved to be a very effective format because each team member was able to view their color coded schedule clearly and easily while being able to view the overall project schedule organized by area of design, ie: façade, cantilever structure, Navisworks update, etc. Another useful tool in Project is the ability to assign a percent complete value to each task. As a group it was agreed that the schedule would be updated at least once per week, by Monday at noon. This allowed for group members to view the progress of certain tasks of other group members and determine whether there was potential for an issue to develop or if progress was on track.

The use of technology certainly aided the process of communication, progress monitoring, and following a schedule. However, technology is a tool that requires motivation and desire for it to be effective. It is easy to delete an email reminder or ignore a meeting invitation but, when a fellow group member asks about the status of task it is much easier to diagnose issues that may be developing and determine the proper method of resolving the problem. Group members of Building Stimulus understood this from the beginning of the project and found effective methods of communication and provided constructive advice to group members experiencing troubles with design or motivation. At team meetings there was always an open line of communication and trust among team members that provided the foundation for each person to feel comfortable taking advice, asking questions, and giving advice. This is essential for highly effective teamwork and producing quality integrated work.

## Conclusion

The intent of this thesis report was to explore the redesign of particular systems of the Millennium Science Building utilizing an Integrated Project Delivery Method and Building Information Modeling. Integration and communication among disciplines was key to the success of the project. At the start of the project, overall goals were established and developed using the BIM Execution Plan. Building Stimulus focused the design alternatives to achieve an overall team goal of improving the efficiency and performance of the building while still maintaining the architectural integrity that the architect, Raphael Vinoly, intended for its contribution to the University Park Campus. In order to accomplish this overall goal, three areas of concentration were identified.

The main focus for the design team in order to improve the efficiency of the building's performance involved redesigning the façade of the Millennium Science Complex. This allowed an extensive implementation of integrated project development as this component affected each discipline. A double skin façade was designed to allow for enhanced thermal performance and daylighting control for the perimeter spaces of Millennium Science. After several iterative processes, this design was implemented on two of the building's faces, resulting in an additional cost of $71,686.34, to optimize the cost to performance ratio. The glazing was redesigned to enhance its thermal performance by decreasing the U-value from 0.29 to 0.126, this resulted in a building associated utillity savings $26,909 per year. The current precast panels were redesigned to decrease the panel thickness and in turn cost, and structural load imposed on the building. The panel configuration was also redesigned to accommodate the twenty-four inch air gap necessary for the double skin.

Through the use of BIM processes and Revit MEP, enhanced accuracy in terms of modeling the building's energy performance was also achieved. By modeling the mechanical and electrical components, the original energy model developed in the fall semester was revised to account for accurate plug loads designated in the laboratory spaces to obtain a more realistic energy profile. In order to facilitate the energy performance, lighting designs were created to efficiently meet IESNA design criteria and ASHRAE 90.1 lighting power densities. Lighting designs were also incorporated with the mechanical system through the implementation of chilled beams in the office spaces to reduce energy consumption by 1465 MBTU per year.

The final area of concentration for Building Stimulus lied with the most iconic portion of the building, the large cantilever. At the cantilever is where the two wings of the building, Life Science and Material Science, join to merge the two research facilities. The truss system of the cantilever was modified by introducing an additional column to each truss, decreasing the unsupported length of the cantilever by 22 feet. This resulted in a reduction in deflection at the tip of the cantilever of 0.7 in. The web and chord members were also redesigned to be optimized for strength and deflection, resulting in a savings of 76 tons of steel and $144,645.37 . Underneath the cantilever, a new lighting design for the existing plaza was created to enhance the iconic stature of the cantilever.

Building Stimulus utilized BIM throughout the duration of this thesis project. The use of BIM software, such as Revit and Navisworks, allowed the team to work collaboratively in redesigning the alternative systems purposed by Building Stimulus. Specifically, the 3$^{rd}$ floor was chosen as the area of primary focus for BIM analysis. The time commitment needed to perform BIM on the entire project would have taken away from time needed to focus on the alternative redesigns. This was determined to be an effective method for utilizing BIM, while also having enough time to thoroughly redesign the alternative systems recommended in the proposal. Certain shortcomings influenced the interoperability of the software packages as they relate to BIM, however the overall goals of integrated project delivery were successfully met and achieved.

# Individual Thesis Requirements

## Lighting Designs

### Lighting Design Summary

Five spaces have been focused on for lighting design. Each of these spaces has been design to meet IESNA Design Criteria and ASHRAE 90.1-2007 lighting power densities.

Spaces that have been focused on for electrical lighting design include a third floor conference room (N-308A/B and W-306A/B), the exterior plaza located under the cantilevered structure, a typical student study area that are located throughout the buildings perimeter areas, corridor lighting, and a typical office.

The typical student study area has also included a detailed daylighting study that has been integrated into the Building Stimulus' façade design.

The main entrance of the Millennium Science Complex is located where each of the two wings of the building joins. The cantilevered connection creates a plaza area that houses an entrance to each Material Science and Life Science wings. Under the square opening in the structure above, a pathway exist that sends walkers through a swirling pattern that leads from one entrance to the other. The design of the pathway was intended to be directionless to discourage use. The structure below is a quiet lab area has been deemed extremely vibration sensitive and heavy use will disrupt the research and experiments below.

A conference room on the third floor offers a chance to create a lighting design with multiple scenes for the differing tasks in the space. Since tasks such as meetings and presentations, and conferencingwill take place in this space, different scenes have been designed to accomadate all activities.

The Student Study Areas throughout the complex are located periodically along the perimeter of the science complex. Daylight integration into these spaces was a primary focus of the lighting design in this space, and has been coordinated with other disciplines to ensure the most efficient overall design of the system on all fronts. Electric light in this space has been designed to complement the daylight integration and work in tandem to create a visually uniform and appealing workspace.

Due to the addition of chilled beams, a typical private office has been added to the lighting design list in order to explore the opportunity of integrated luminaires and chilled beam as one fixture.

## Conference Room Lighting Design (Multiple Scenes)

### Spatial Summary

The third floor has two conference rooms that lie adjacent to the oculus, one in the Material Science wing, and on in the Life Science wing. Both rooms are identical, with a removable partition splitting the room in half. The plans show that furniture layouts (Figure 104: W306A/B Conference Room - Plan View.) have a conference table and office chairs on one half of the room, while office chairs are aligned for presentation audiences on the other half. Two sets of cabinetry are recessed in the wall along the between the two entrances to the space.

The space is 42' x 18'2" with the cabinetry wall recesses being 3'x1.5" x 12'1.25" each. The total area of the space is 845.65ft$^2$. Using the ASHRAE 90.1, Table 9.6.1 Lighting Power Density of 1.3W/ft$^2$ for conference rooms, the total allotment for lighting should not exceed 1099W for the space.

Further research in the design of the space shows that a hard isolation ceiling is located above the 10' finished ceiling. The hard isolation ceiling is placed at 11' above the third floor, and was designed to create a sturdy place to mount projection screens. The concrete floor above is an unacceptable mounting point for the projectors due to mechanical equipment being placed directly above the space. The isolation ceiling also provides an acoustic barrier between the space and the penthouse mechanical equipment.

### Drawings & Layout

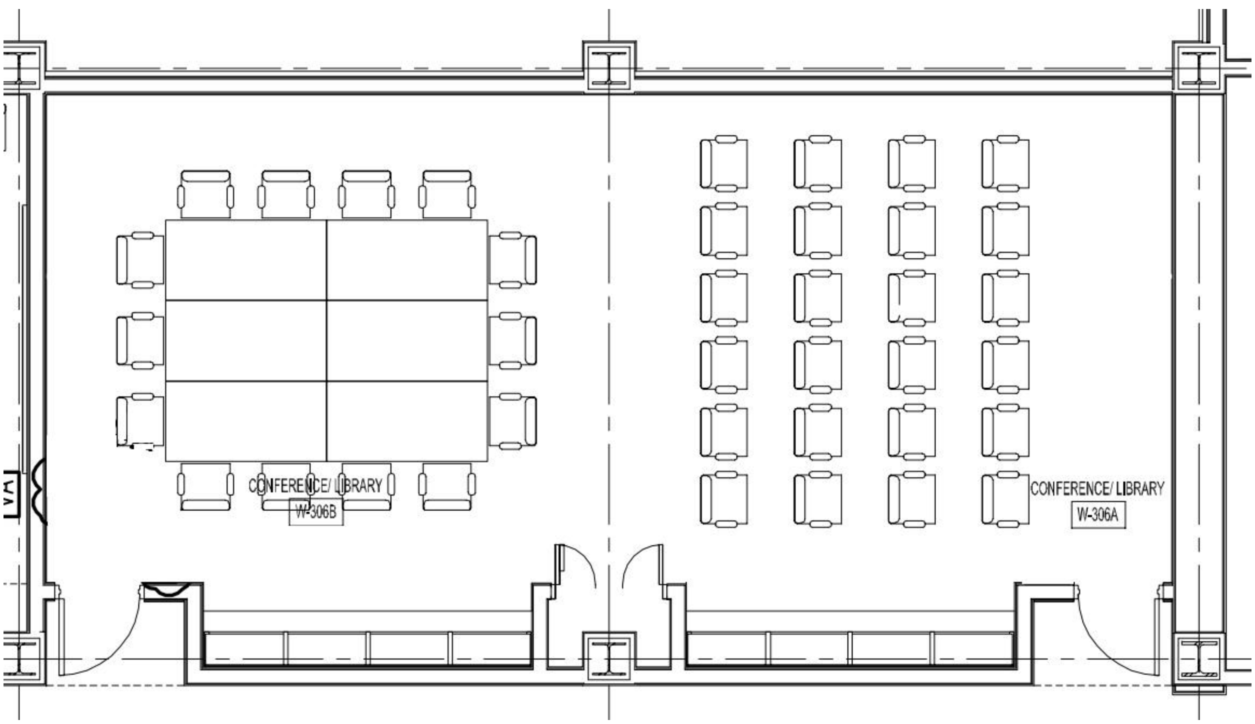



Figure 104: W306A/B Conference Room - Plan View.

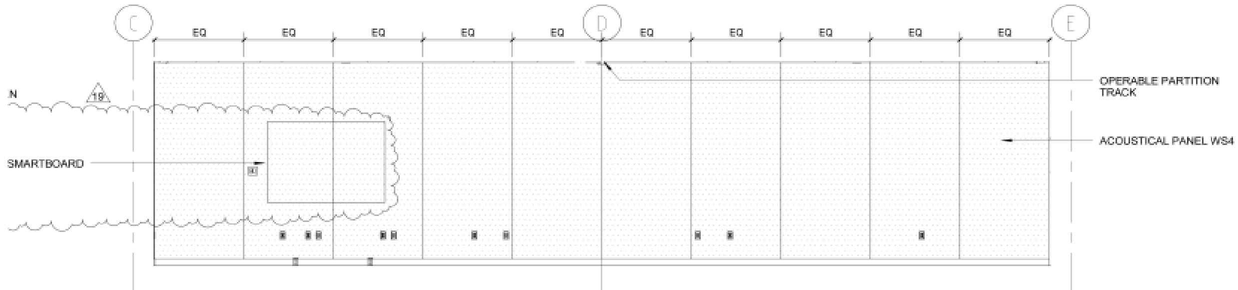



Figure 105: W-306A/B North Elevation.

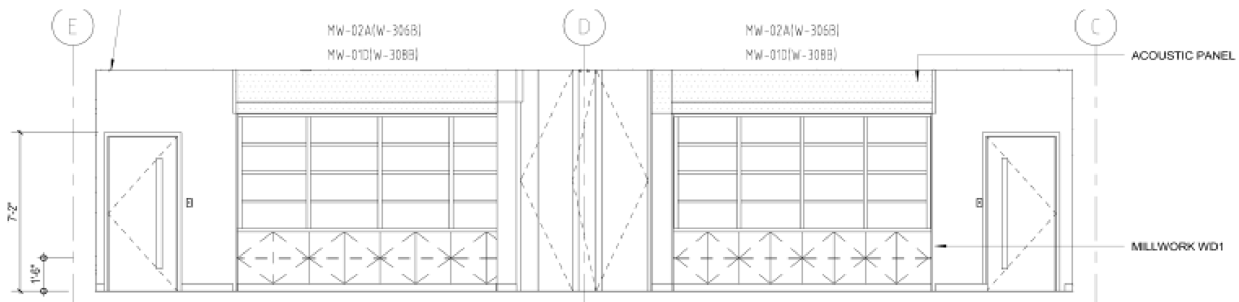



Figure 106: W-306A/B South Elevation.

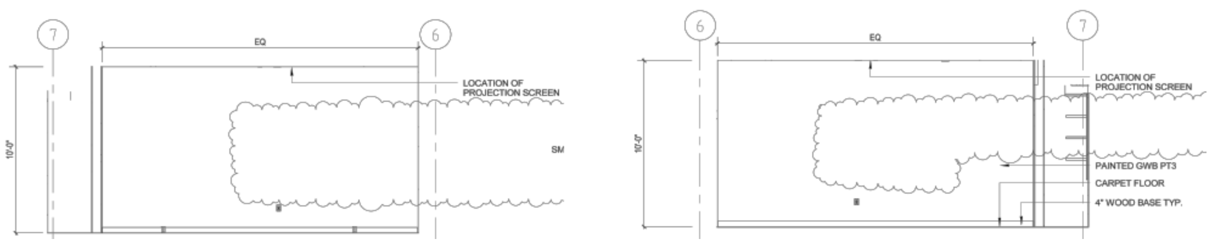



Figure 107: W-306A/B East & West Elevation.

## Tasks & Activities

Major uses of this space will include meetings and conferencing. Some video conferencing may also take place as well, but with the lack of video conferencing equipment scheduled to be installed in the spaces, it can be assumed that video conferencing use will be at a minimum as suggested from comments at the December Lutron Presentation.

## Materials

Table 40: Conference Room Materials List.

Conference Room Materials

| Surface | Reflectance | Transmittance |
|---|---|---|
| Gypsum Ceiling | 0.86 | |
| ACT Ceiling | 0.78 | |
| Door Glazing | | 0.5 |
| Door** | 0.50 | |
| Door Trim** | 0.50 | |
| Floor** | 0.13 | |
| Floor Molding** | 0.30 | |
| Shelving** | 0.50 | |
| Wall | 0.76 | |
| Wall Paneling | 0.23 | |

**Values from AGi32 swatches for similar materials

## Design Considerations

The IESNA Handbook suggests several high priority considerations for conference/seminar rooms for meeting tasks and video conferencing. These considerations are as follow:

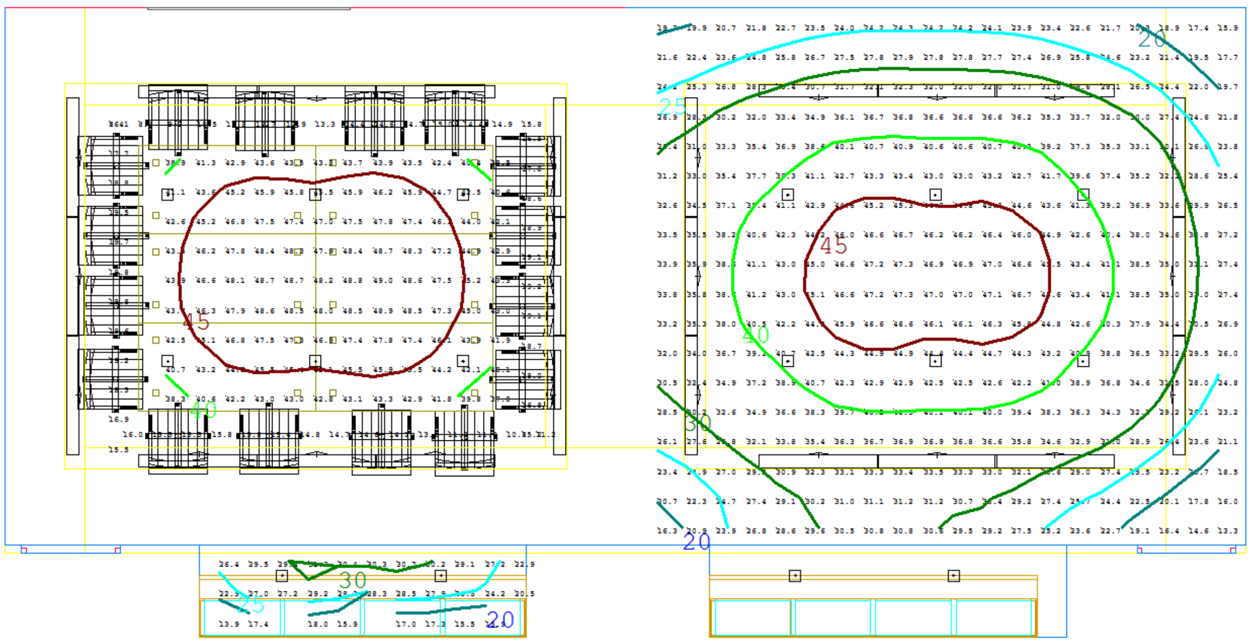
- Meeting tasks:
  - Considerations (IESNA Handbook)
    - Appearance of Space and Luminaires
    - Direct Glare Avoidance
    - Modeling of Faces
  - Design Suggestions
    - Horizontal 30fc (IESNA Handbook)
    - Vertical 5fc (IESNA Handbook)
    - Power Density 1.2W/SF (ASHRAE 90.1, Table 9.6.1)
- Video Conferencing
  - Considerations (IESNA Handbook)
    - Direct Glare Avoidance
    - Modeling of Faces
    - Source-Task-Eye Geometry
  - Design Suggestions
    - Horizontal 50fc (IESNA Handbook)
    - Vertical 30fc (IESNA Handbook)
    - Power Density 1.2W/SF (ASHRAE 90.1, Table 9.6.1)
- Luminance Ratios (IESNA Handbook)
  - Paper-VDT 3:1/1:3
  - Task-Surroundings 3:1/1:3
  - Task-Remote Surface 10:1/1:10

*Page intentionally left blank.*

## Performance Summary

### Scene 1: Video Conferencing

Scene1 is the video conference setting on the Grafik Eye system. This setting will utilize all luminaires in the space, at full power. The desk surface reaches upwards of 49fc in the center, while the perimeter of the desk averages 42.5fc.



20fc -25fc-30fc-40fc -45fc

**Figure 108: Conference Room Scene 1 Illuminance Contours.**

**Table 41: Conference Room Lighting Performance for Scene 1.**

| Conference Room Illumination Summary | Conference Table (Horz.) | Conference Table (Vert.) | Presentation Space | Cabinet Counter Top |
|---|---|---|---|---|
| Avg. Illuminance (FC) | 45.01 | 17.03 | 33.79 | 25.84 |
| Max. Illuminance (FC) | 49.00 | 21.90 | 47.30 | 32.80 |
| Minimum Illuminance (FC) | 37.80 | 11.10 | 13.30 | 14.50 |
| Avg/Min | 1.19 | 1.53 | 2.54 | 1.78 |
| Max/Min | 1.30 | 1.97 | 3.56 | 2.26 |
| Max/Avg | 1.09 | 1.29 | 1.40 | 1.27 |
| Coefficient of Variation | 0.06 | 0.15 | 0.24 | 0.23 |
| Uniform Gradient | 1.06 | N/A | 1.28 | 1.80 |
| Power Density (W/SF) | 1.2 | | | |

*Note: Vertical illuminance does not meet IESNA Design criteria. As per Lutrons comments, the space does not include substantial video conferencing equipment, therefore it can be assumed all video conferencing will be done will mobile video conferencing stations. It has been assumed these mobile stations will include lighting fixtures to meet criteria.

Figure 109: Conference Room Lighting Design - Perspective View of Scene 1.

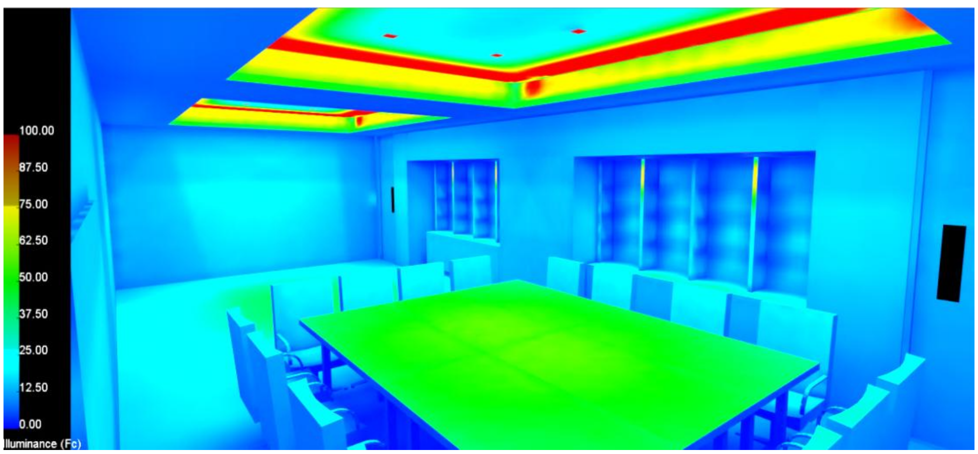



Figure 110: Conference Room Lighting Design - Perspective View (Pseudo Color: Illuminance) of Scene 1.

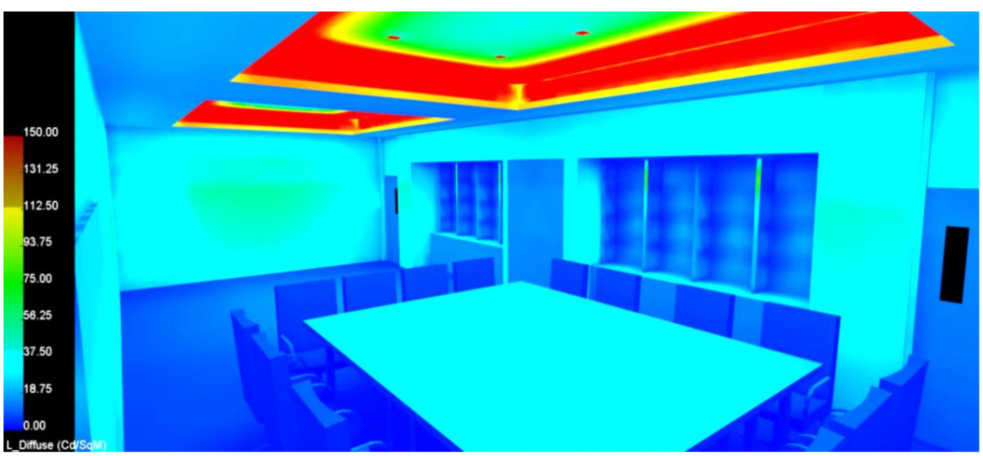
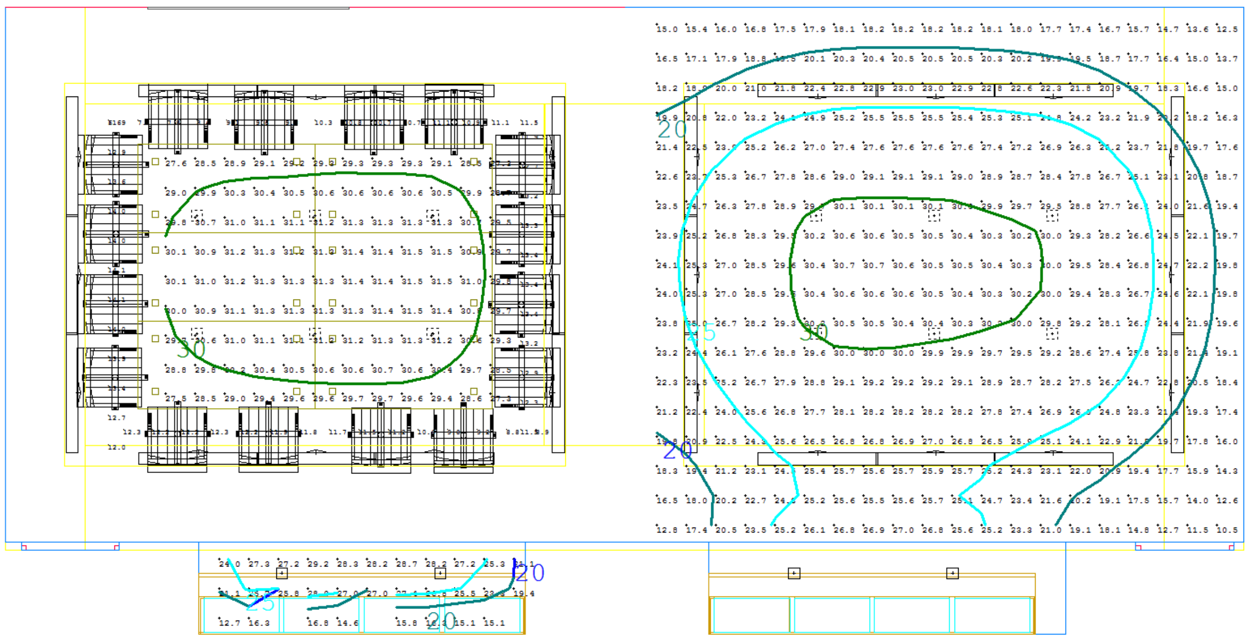



Figure 111: Conference Room Lighting Design - Perspective View (Pseudo Color: Luminance) of Scene 1.

## Scene 2: Meetings & Conferences

Scene2 is the meeting and conferencing setting on the Grafik Eye system. This setting will utilize cove luminaires as well as the cabinetry downlighting at full power. The desk surface reaches 31.50fc in the center, while the perimeter of the desk averages 30.30fc.



20fc -25fc-30fc

Figure 112: Conference Room Scene 2 Illuminance Contours.

Table 42: Conference Room Lighting Performance for Scene 2.

| Conference Room Illumination Summary | Conference Table (Horz.) | Conference Table (Vert.) | Presentation Space | Cabinet Counter Top |
|---|---|---|---|---|
| Avg. Illuminance (FC) | 30.30 | 12.23 | 24.22 | 23.15 |
| Max. Illuminance (FC) | 31.50 | 14.10 | 30.70 | 29.20 |
| Minimum Illuminance (FC) | 27.30 | 9.60 | 10.50 | 12.70 |
| Avg/Min | 1.11 | 1.27 | 2.31 | 1.82 |
| Max/Min | 1.15 | 1.47 | 2.92 | 2.30 |
| Max/Avg | 1.04 | 1.15 | 1.27 | 1.26 |
| Coefficient of Variation | 0.03 | 0.16 | 0.19 | 0.23 |
| Uniform Gradient | 1.05 | N/A | 1.36 | 1.85 |
| Power Density (W/SF) | 1.2 | | | |

Figure 113: Conference Room Lighting Design - Perspective View of Scene 2.


Figure 114: Conference Room Lighting Design - Perspective View (Pseudo Color: Illuminance) of Scene 2.

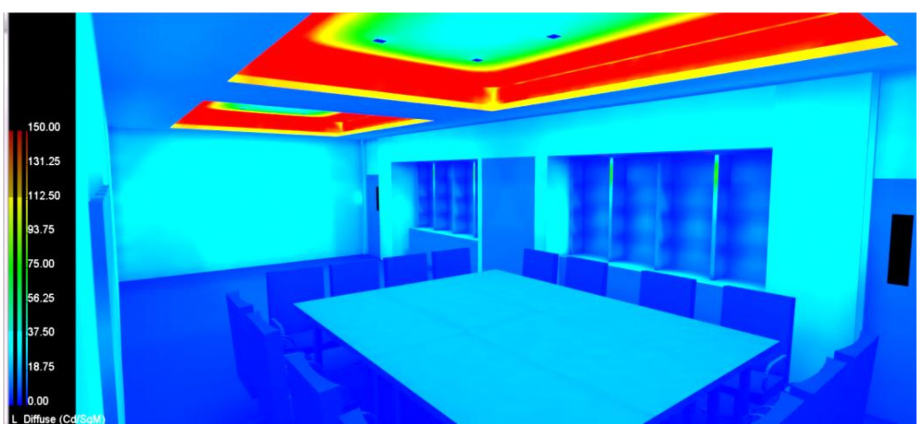
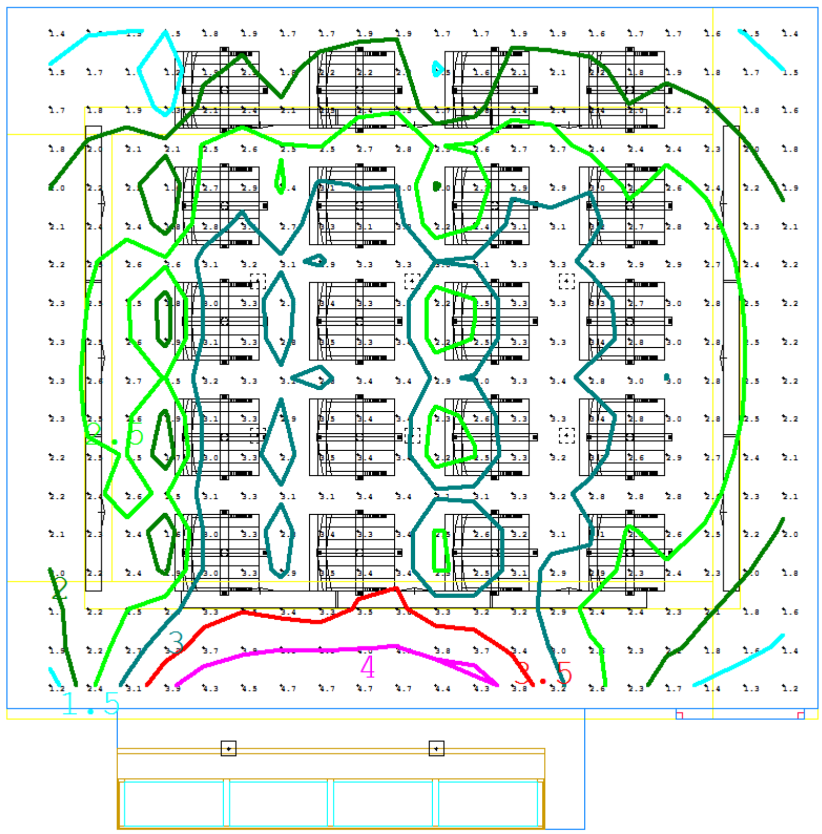



Figure 115: Conference Room Lighting Design - Perspective View (Pseudo Color: Luminance) of Scene 2.

## Scene 3: Presentations

Scene3 is the setting for presentation scenes on the Grafik Eye system. This setting utilizes cove luminaires at 10% dimming level while the cabinetry downlighting is at 25% power. The desk surface reaches 31.50fc in the center, while the perimeter of the desk averages 30.30fc.



1.5fc-2.0fc-2.5fc -3.0fc - 3.5fc - 4.0fc

**Figure 116: Conference Room Scene 3Illuminance Contours.**

**Table 43: Conference Room Lighting Performance for Scene 3.**

| Conference Room Illumination Summary | Presentation Space |
|---|---|
| Avg. Illuminance (FC) | 2.63 |
| Max. Illuminance (FC) | 4.70 |
| Minimum Illuminance (FC) | 1.20 |
| Avg/Min | 2.19 |
| Max/Min | 3.92 |
| Max/Avg | 1.79 |
| Coefficient of Variation | 0.26 |
| Uniform Gradient | 2.00 |
| Power Density (W/SF) | 1.2 |

Figure 117: Conference Room Lighting Design - Perspective View of Scene 2.


Figure 118: Conference Room Lighting Design - Perspective View (Color: Illuminance) of Scene 2.

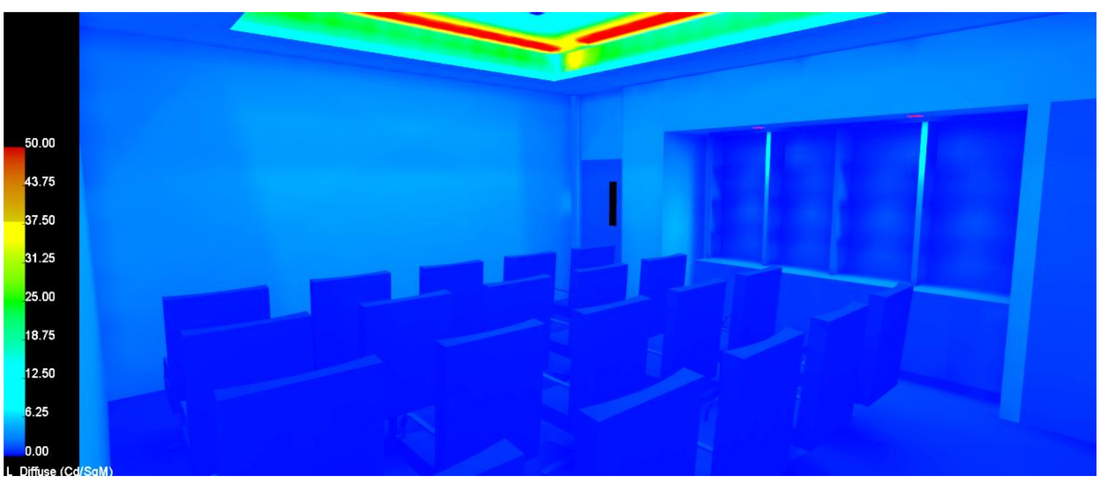



Figure 119: Conference Room Lighting Design - Perspective View (Color: Luminance) of Scene 2.

## Controls

The three scenes shown in this design are to be controlled using a lighting control system by Lutron known as the Grafik Eye. Since the room is able to be separated by a foldable partition, each section is to be controlled separately. The Grafik Eye system has been programmed to have four settings known as scenes, and they are as follows:

1. Video Conferencing Scene
2. Meeting Scene
3. Presentation Scene
4. User Defined Scene

Each scene allows users to easily select different lighting settings for the rooms various purposes. Each button on the control system will be engraved with a short text description its respective scene, as well as a small descriptive image. The user defined setting will allow users to program an additional scene as they deem necessary.

The control system divides the lighting fixtures in each space into three zones, which are as follows:

1. Cove Lighting (switching zones a & g)
2. Cove Downlights (switching zones b & f)
3. Cabinetry Downlights (switching zones c & e)

Each space has also be equipped with a passive infrared occupancy sensor. Lutron's LOS-CUS-500-WH has been used, as it is able to cover the 450SF of each space without being falsely turned on by occupants passing by in the corridor. When LOS-CIR-450-WH occupancy sensor is used in conjunction with the Grafik Eye lighting control system, the sensor requires a power pack to be installed. Lutron's PP-230H Power Pack has been used in this design. Wiring diagrams can be found in Appendix G: Lighting Wiring Diagrams, and control diagrams can be found on page 386, in Appendix I: Lighting Control Cutsheets.

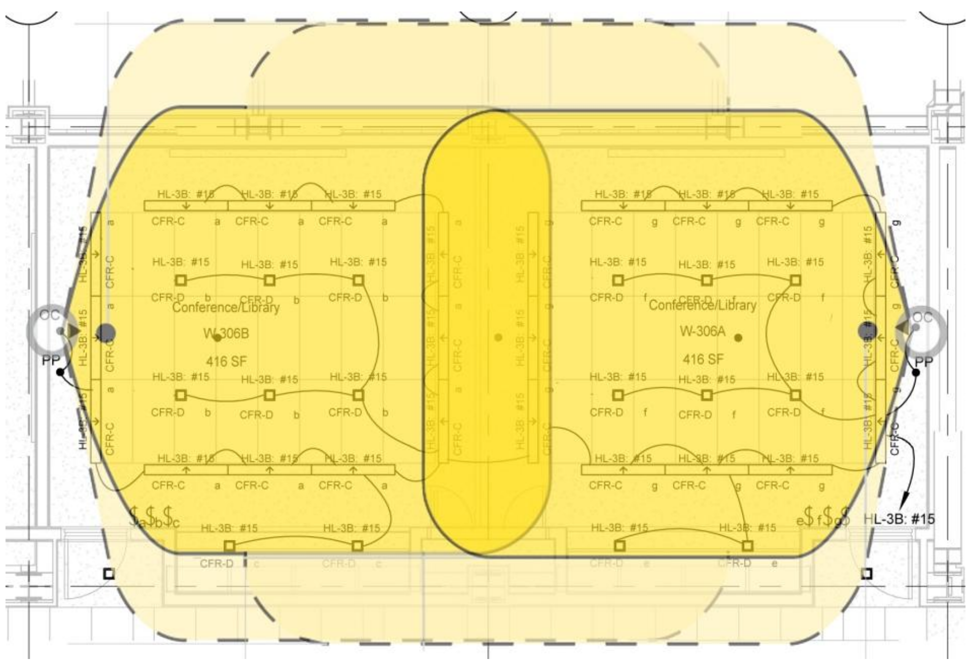



Figure 120: Conference Room Occupancy Coverage Diagram.


Figure 121: Scene 1 - Video Conferencing Grafik Eye Setup (Zone 1 = 100%; Zone 2 = 100%; Zone 3 = 100%.


Figure 122: Scene 2 - Meeting Grafik Eye Setup (Zone 1 = 100%; Zone 2 = Off; Zone 3 = 100%).


Figure 123: Scene 3 - Presentations Grafik Eye Setup (Zone 1 = 10%; Zone 2 = Off; Zone 3 = 25%).

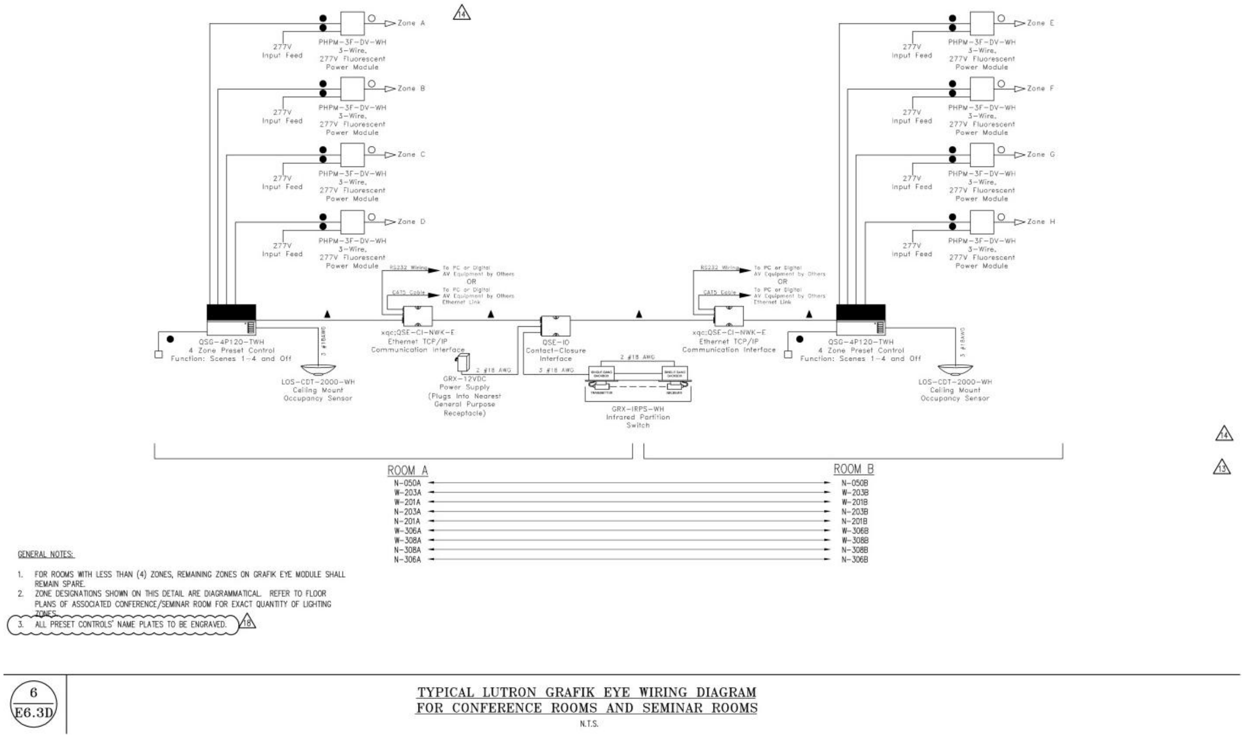



Figure 124: Existing Conference Room Control Diagram.

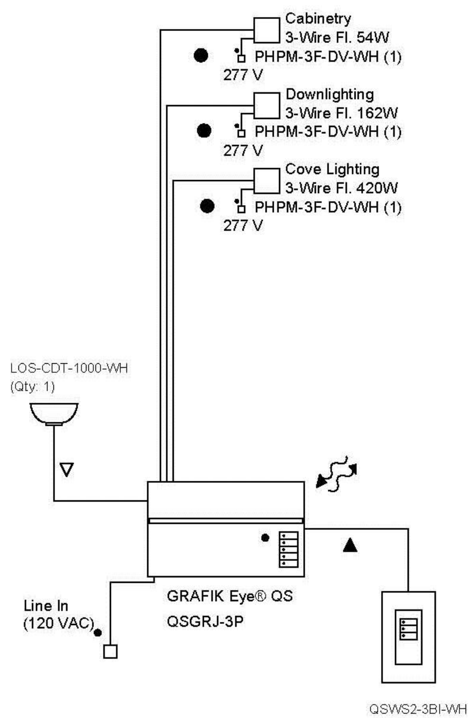



Figure 125: Redesigned Conference Room Control Diagram.

## Cove Lighting Installation Detail

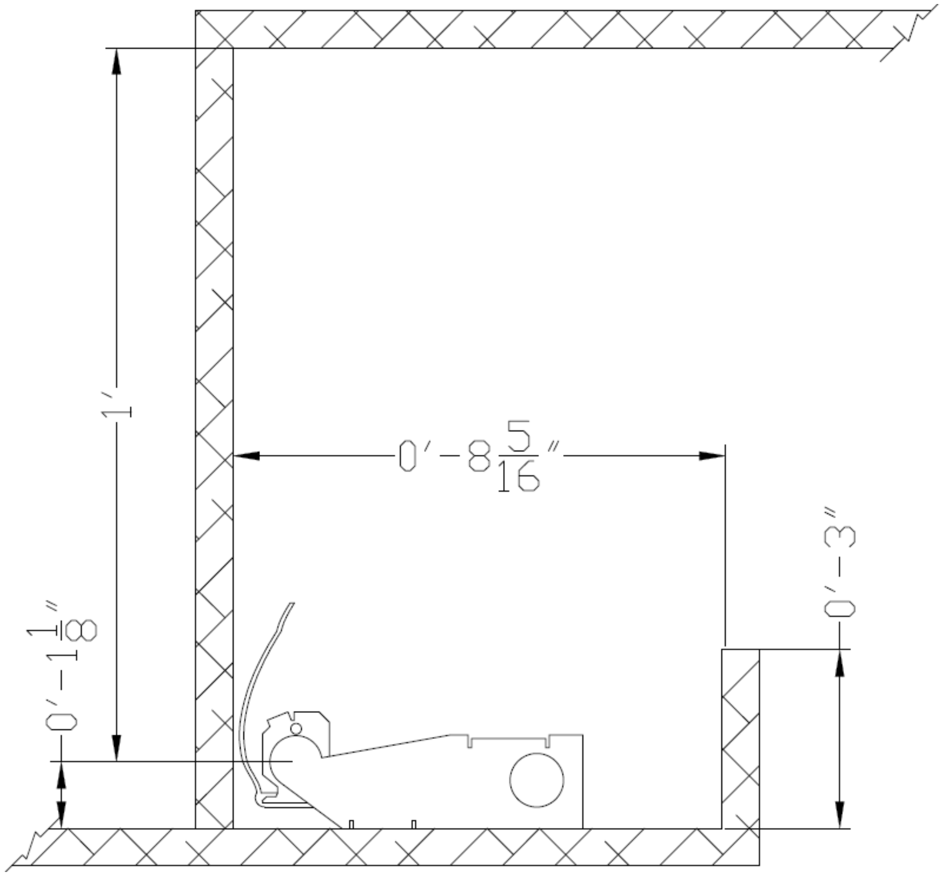



Figure 126: Conference Room Cove Lighting Detail.

## Process and Material Take-Off

As the lighting redesign progressed throughout the building, it became critical to maintain an updated drawing and fixture schedule to compare to the original plan. For comparisons, the 3rd floor was chosen to show direct benefits and drawbacks of the lighting design. The original take-offs can be found in Appendix D: Construction Management. Utilizing RS Means 2011 values for interior lighting, the overall costs of the 3rd floor amounted to $30,881.55 with the bulk of the costs resulting from the NF-1 light fixtures (1' x 4' recessed fluorescent downlights) found throughout the corridors and office spaces.

## Lighting Costs

At the conclusion of the lighting design, a floor – by – floor cost analysis was performed comparing the costs saved by removing existing lighting, and the costs incurred by installing new fixtures. The full estimates of 1st, 2nd, and 3rd floor lighting changes can be seen in in Appendix D: Construction Management. The table below summarizes costs and savings per building space for each floor.

Table 44: Lighting Cost Summary.

| Floor | Corridor Savings | Office Savings | Study Area Savings | Conf. Room Savings | Total Floor Savings |
|---|---|---|---|---|---|
| 1st | $ 1,200.00 | $ 3,927.00 | $ - | $ - | $ 5,127.00 |
| 2nd | $ 1,330.00 | $ 12,219.00 | $ 2,400.00 | $ - | $ 15,949.00 |
| 3rd | $ 1,080.00 | $ 13,107.00 | $ 1,200.00 | $ 2,125.00 | $ 17,512.00 |

Upon completion of the Millennium Science Complex lighting redesign, the switch from fixtures requiring fewer lamps clearly shows significant cost benefits. However, the large savings seen in office spaces can be misleading. As seen in the full estimate in in Appendix D: Construction Management, all NF – 1B fixtures were removed from office spaces and replaced with OFF – D fixtures. However, the cost of OFF-D fixtures was not taken into account in these estimates as the OFF – D fixture is the Integrated Chilled Beam/Lighting assembly and is included in mechanical costs, not lighting costs. While tremendous savings are seen in this table in office spaces, the reality is not so. This issue is further discussed in the Existing Office Costs vs. Proposed Office Costs portion of the Chilled Beam/Lighting Integration sections.

## Electrical

### SKM Analysis

This electrical depth topic was performed cooperatively between the electrical/lighting students of each IPD/BIM team. Due to time constraints and the repetitive nature of the distribution system, the scope of the depth topic was limited to distribution equipment that serves the third floor of the Millennium Science Complex. Each individual IPD/BIM team also focused their thesis on the third floor of the building for coordination. The intent of this depth topic is to gain experience in using SKM Power Tools for Windows. The equipment that was modeled in SKM can be seen in Table 45 on the following page.

Table 45: SKM Model Equipment Schedule.

| SKM Model Equipment Schedule | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Lvl** | **Name** | **Location** | ***Floorplan*** | **Voltage** | **RATING** | **Series Rating** |
| Switchgear | 0 | MDS-01A | W-P003 | *E2.0B-P* | 480/277V | 5,000A | 100 kAIC |
| Switchgear | 0 | MDS-01B | W-P003 | *E2.0B-P* | 480/277V | 5,000A | 100 kAIC |
| Switchgear | 0M | MDS-02A | N-P051 | *E2.0MD-LP* | 480/277V | 2,000A | 100 kAIC |
| Switchgear | 0M | MDS-02B | N-P051 | *E2.0MD-LP* | 480/277V | 2,000A | 100 kAIC |
| Switchgear | 0M | EMDS-1 | N-P052 | *E2.0MD-LP* | 480/277V | 2,000A | 65 kAIC |
| Switchboards | 0M | EDPS-1E1 | N-P052 | *E2.0MD-LP* | 480/277V | 800A | 65 kAIC |
| Switchboards | 0M | EDPS-1E2 | N-P052 | *E2.0MD-LP* | 480/277V | 800A | 65 kAIC |
| Switchboards | Level 2 | SDP-2B | W-P249 | *E2.2B-P* | 480/277V | 1,000A | 65 kAIC |
| Switchboards | Level 2 | SDP-2D | N-P258 | *E2.2BD-P* | 480/277V | 1,000A | 65 kAIC |
| Switchboards | Level 2 | SDP-2D1 | N-P238 | *E2.2E-P* | 480/277V | 1,000A | 65 kAIC |
| Switchboards | Lvl 3 | EDPS-3B | W-P338 | *E2.3B-P* | 208/120V | 800A | 65 kAIC |
| Switchboards | Lvl 3 | EDPS-3D | N-P347 | *E2.3D-P* | 208/120V | 800A | 65 kAIC |
| Switchboards | Penthouse | EDPS-M41 | N-M401 | *E2.4C-P* | 480/277V | 800A | 65 kAIC |
| Switchboards | Penthouse | EDPS-M42 | N-M401 | *E2.4C-P* | 480/277V | 800A | 65 kAIC |
| Switchboards | Penthouse | MDP-M41 | N-M401 | *E2.4C-P* | 480/277V | 1,000A | 65 kAIC |
| Switchboards | Penthouse | MDP-M42 | N-M401 | *E2.4C-P* | 480/277V | 1,000A | 65 kAIC |
| Panelboards: Level 3 | Level 3B | HL-3B | W-P338 | *E2.3B-P* | 480/277V | 200A | 14 kAIC Min. |
| Panelboards: Level 3 | Level 3B | HMS-3B | W-P338 | *E2.3B-P* | 480/277V | 100A | 14 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LB-3B1/2 | W-Q304 | *E4.3B* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LB-3B3/4 | W-321 | *E4.3B* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LB-3B5/6 | W-337 | *E4.3B* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LB-3B7 | W-Q304 | *E4.3B* | 208/120V | 225A/MLO | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LBS-3B1/2 | W-Q304 | *E4.3B* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LBS-3B3/4 | W-321 | *E4.3B* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LR-3B | W-P338 | *E2.3B-P* | 208/120V | 150A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LR-3B5/6 | W-337 | *E4.3B* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3B | LS-3B | W-P338 | *E2.3B-P* | 208/120V | 100A | 10 kAIC Min. |
| Panelboards: Level 3 | 3C | LB-3C1/2 | W-Q302 | *E2.3C-P* | 208/120V | 150A | 10 kAIC Min. |
| Panelboards: Level 3 | 3C | LR-3C1/2 | N-Q307 | *E2.3C-P* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | HL-3D | N-P347 | *E2.3D-P* | 480/277V | 200A | 14 kAIC Min. |
| Panelboards: Level 3 | Level 3D | HM-3D | N-P347 | *E2.3D-P* | 480/277V | 100A | 14 kAIC Min. |
| Panelboards: Level 3 | Level 3D | HMS-3D | N-P347 | *E2.3D-P* | 480/277V | 100A | 14 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LB-3D1/2 | N-361 | *E4.3D* | 208/120V | 175A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LB-3D5/6 | N-361 | *E4.3D* | 208/120V | 175A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LB-3D7/8 | N-361 | *E4.3D* | 208/120V | 175A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LBS-3D1/2 | N-Q304 | *E4.3D* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LBS-3D5/6 | N-361 | *E4.3D* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LR-3D1/2 | N-P346 | *E2.3D-P* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LR-3D3/4 | N-P346 | *E2.3D-P* | 208/120V | 225A | 10 kAIC Min. |
| Panelboards: Level 3 | Level 3D | LS-3D | N-P347 | *E2.3D-P* | 208/120V | 100A | 10 kAIC Min. |
| | **Lvl** | **Name** | **Location** | ***Enl. Plan*** | **Rating** | **Poles/Ph/Voltage** | **Series Rating** |
| Distribution Equipment | Mezzanine | ATS-HS1 | N-P052 | *E2.0MD-LP* | 800 A | 4P, 480V | 65 kAIC |
| Distribution Equipment | Mezzanine | ATS-HS2 | N-P052 | *E2.0MD-LP* | 800 A | 4P, 480V | 65 kAIC |
| Distribution Equipment | Mezzanine | ATS-HS3 | N-P052 | *E2.0MD-LP* | 800 A | 4P, 480V | 65 kAIC |
| Distribution Equipment | Mezzanine | ATS-HS4 | N-P052 | *E2.0MD-LP* | 800 A | 4P, 480V | 65 kAIC |
| Distribution Equipment | Lvl 2 | TRN-SDP-2B | W-P249 | *E2.2B-P* | 300 kVA | 480Δ - 208Y/120V | N/A |
| Distribution Equipment | Lvl 2 | TRN-SDP-2D | N-P258 | *E2.2D-P* | 300 kVA | 480Δ - 208Y/120V | N/A |
| Distribution Equipment | Lvl 2 | TRN-SDP-2D1 | N-P238 | *E2.2E-P* | 300 kVA | 480Δ - 208Y/120V | N/A |
| Distribution Equipment | Level 3 | TRE-EDPS-3B | W-P338 | *E2.3B-P* | 225 kVA | 480Δ - 208Y/120V | N/A |
| Distribution Equipment | Level 3 | TRE-EDPS-3D | N-P347 | *E2.3D-P* | 225 kVA | 480Δ - 208Y/120V | N/A |
| Distribution Equipment | Level 3 | UPS-3D-1/2 | N-361 | *E4.3D* | 50 kVA | N/A | Unknown |
| Distribution Equipment | Level 3 | UPS-3D-5/6 | N-361 | *E4.3D* | 50 kVA | N/A | Unknown |
| | **Lvl** | **Name** | **Location** | **Motor Size** | **Sizing Remarks** | | **Column Not Used** |
| Mech. Equipment | Penthouse | ACF-1 | N-M401 | 100 hp | 200 A MCP, 175 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-2 | N-M401 | 100 hp | 200 A MCP, 175 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-3 | N-M401 | 100 hp | 200 A MCP, 175 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-4 | N-M401 | 100 hp | 200 A MCP, 175 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-5 | N-M401 | 100 hp | 200 A MCP, 175 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-6 | N-M401 | 60 hp | 110 A MCP, 100 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-7 | N-M401 | 60 hp | 110 A MCP, 100 A FS | | ----- |
| Mech. Equipment | Penthouse | ACF-8 | N-M401 | 60 hp | 110 A MCP, 100 A FS | | ----- |

The Power Tools for Windows analysis software from SKM is an excellent tool for calculating voltage drop, arc flash characteristics, short circuit current, equipment sizing, motor starting, and breaker coordination. Each of the aforementioned analyses is critical to ensure the safety of a distribution system. One goal of engineering design, in any area of study, is to ensure the safety of users and occupants. By knowing arc flash and short circuit characteristics of equipment, each piece of distribution equipment can be safely sized to avoid loss of life during maintenance or fires associated with electrical equipment.

When starting a model in SKM, there are two screens to work from – the component editor and the one-line diagram. The component editor allows the designer to specify exactly the equipment that will be constructed by the contractor. Within the component editor, specific equipment characteristics can be drawn out from the SKM library. The one-line diagram holds the same purpose as a one-line diagram in paper drawings – to orient the viewer with how equipment is fed and ordered throughout the building. Figure 127 below shows the library and component editor overlaid on the one-line diagram for a bus that is used as a main switchgear.

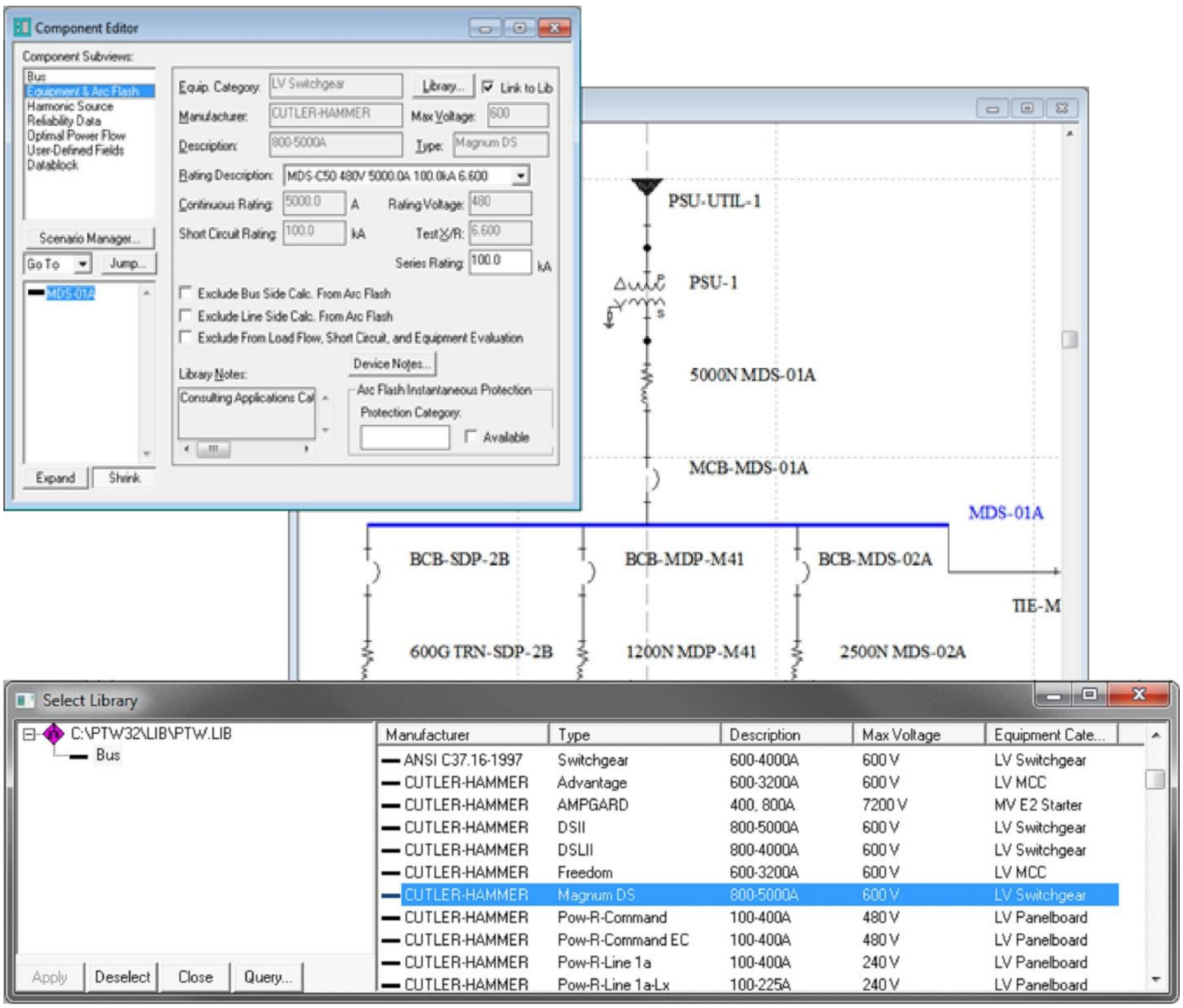



Figure 127: MDS-01A Equipment Inputs.

As the circuits continue, the switchgear feed other distribution panels. Between these two bus types, the engineer can specify wire sizes, insulation, lengths, and ampacity according to the National Electric Code's table 310.16. Many values for wire sizes can be drawn out of SKM in the same fashion as discussed in the previous example. The wire sizing example can be seen in 'Figure 128: Wire Sizing in SKM' below:

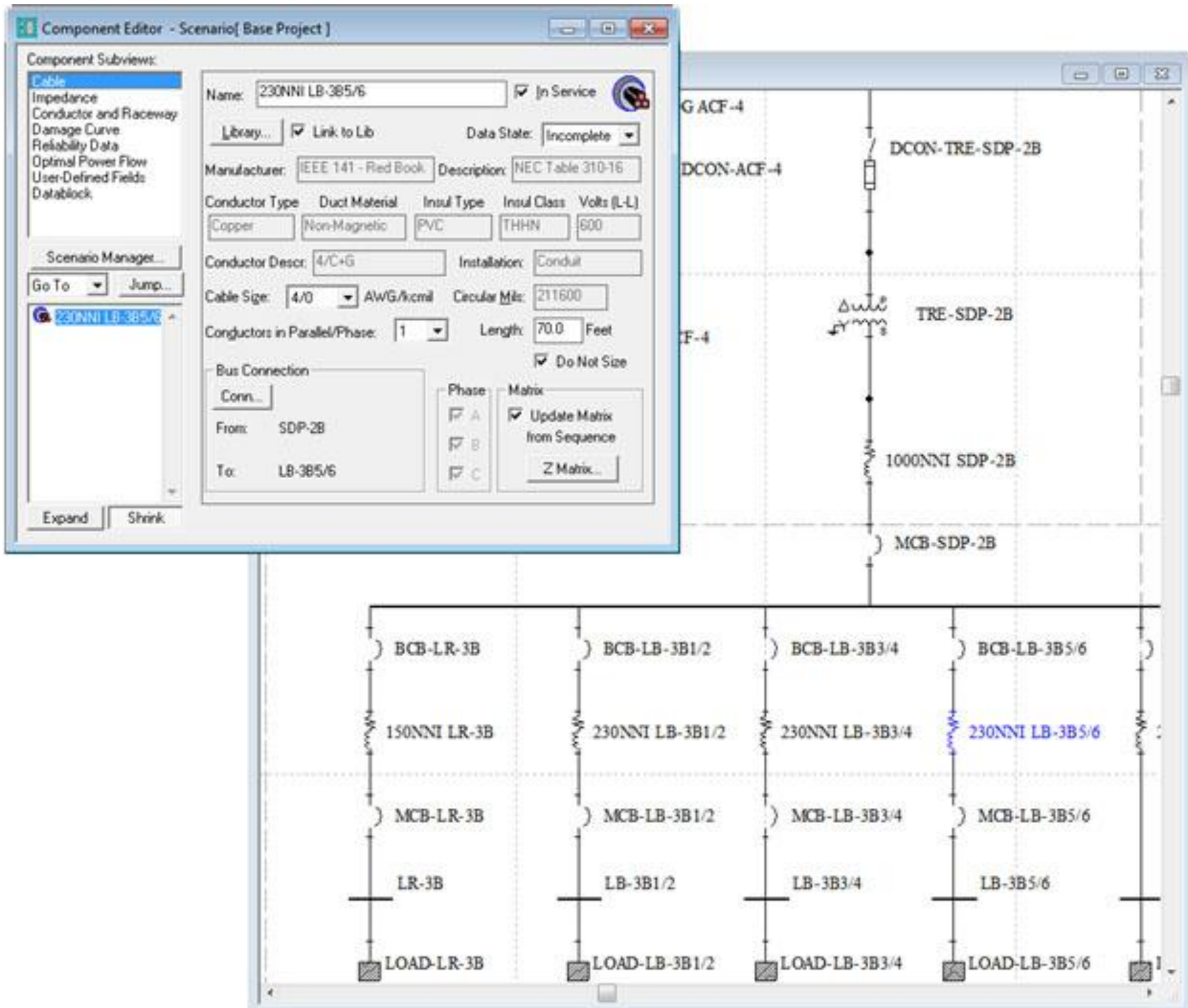



Figure 128: Wire Sizing in SKM.

Panelboards further down the one-line diagram are powered by voltage-reducing transformers from 480V to 208Y/120V. As with the previous examples, it is possible to specify various attributes to these transformers such as primary and secondary voltages, impedance, kVA rating and connection type. There is also a contingent of equipment in the SKM library to assist the designer – see Figure 129below:

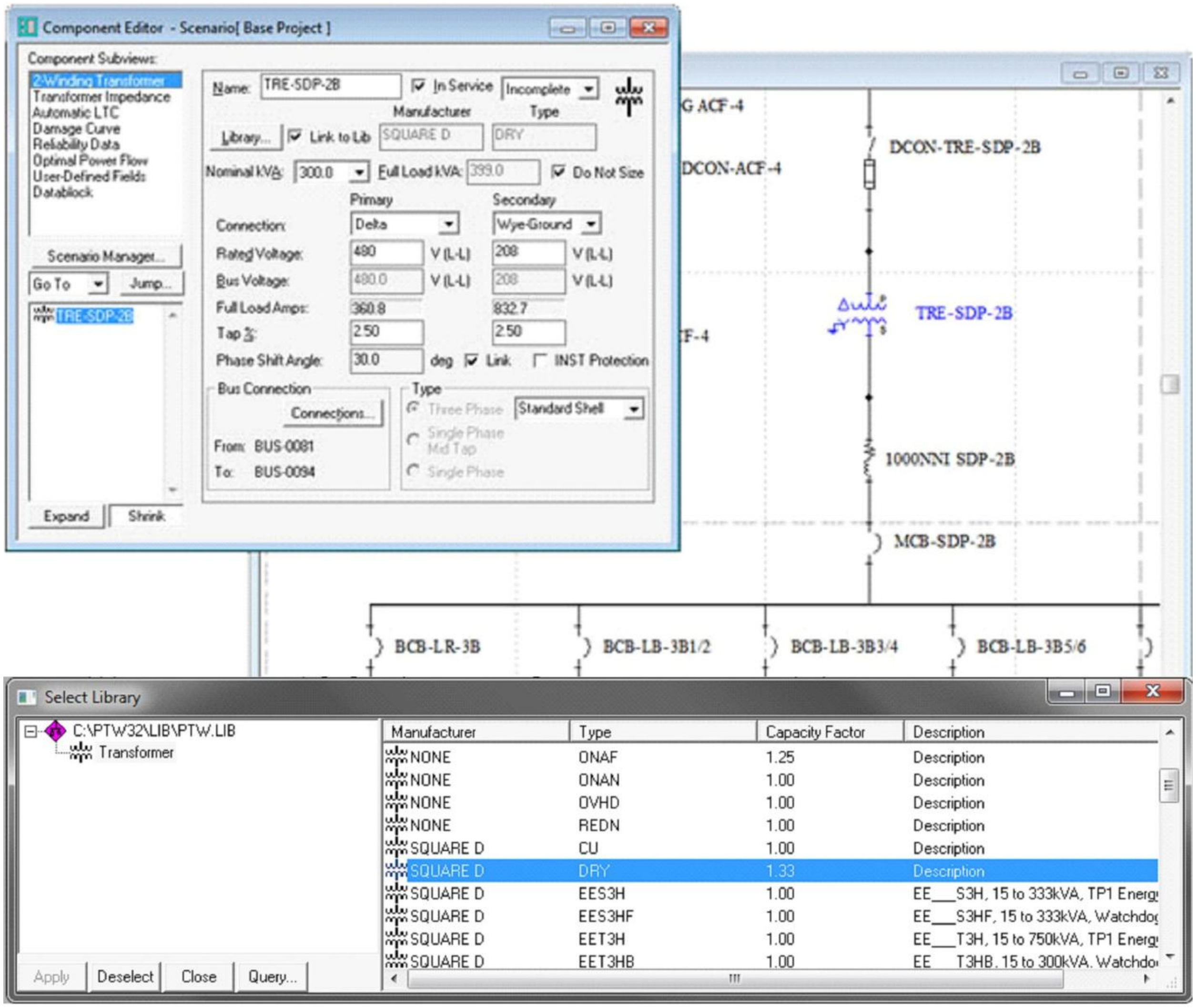



Figure 129: Transformer Inputs in SKM.

The ends of circuits in SKM cannot be left open. Therefore, each circuit must either end at a bus (panelboard, switchboard, switchgear, etc.) or at a load. These loads can be synchronous motors, induction motors (squirrel cage by NEC), or a non-motor panel load. Again, the engineer can specify detailed information about each piece of equipment through the component editor. Figure 130 and Figure 131below illustrate the inclusion of an induction motor load and non-motor panelboard load for the third floor of the Millennium Science Complex.

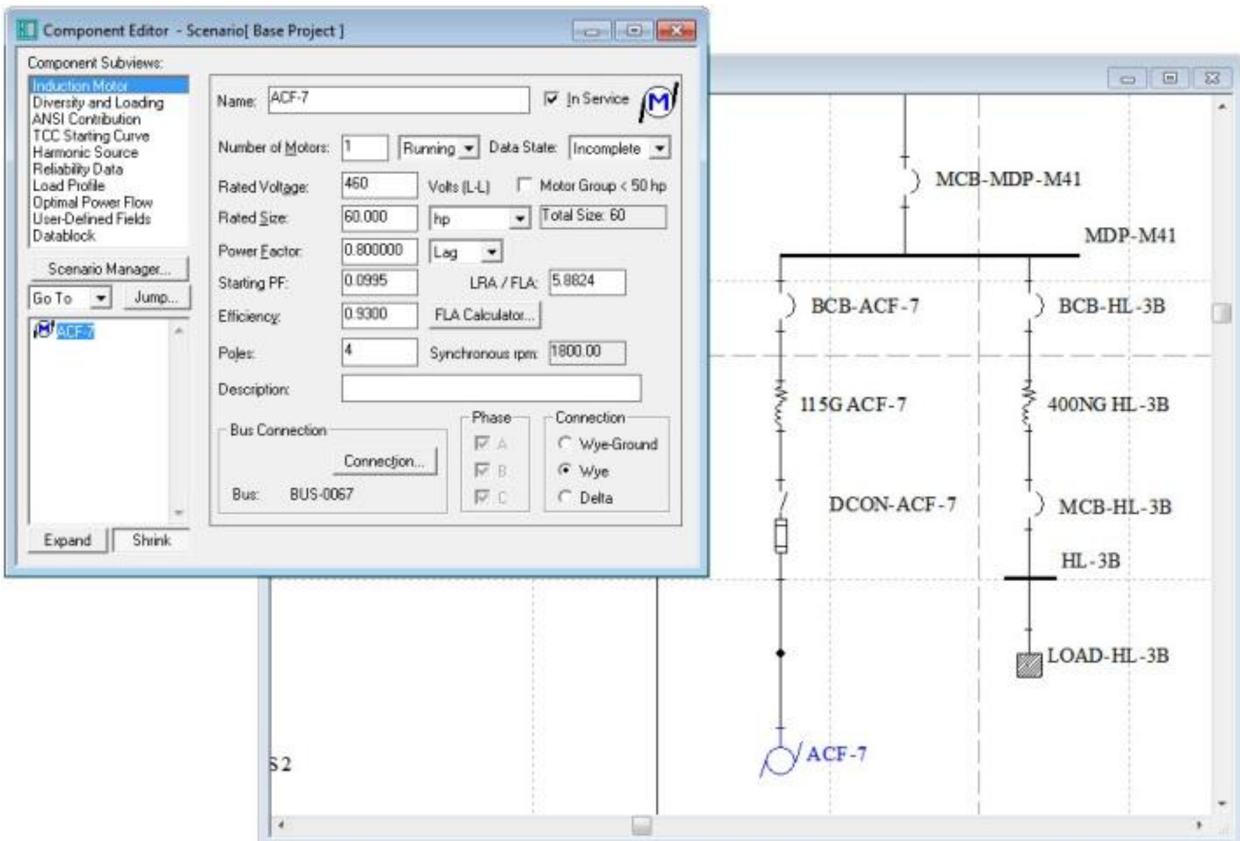



Figure 130: Induction Motor Inputs in SKM.

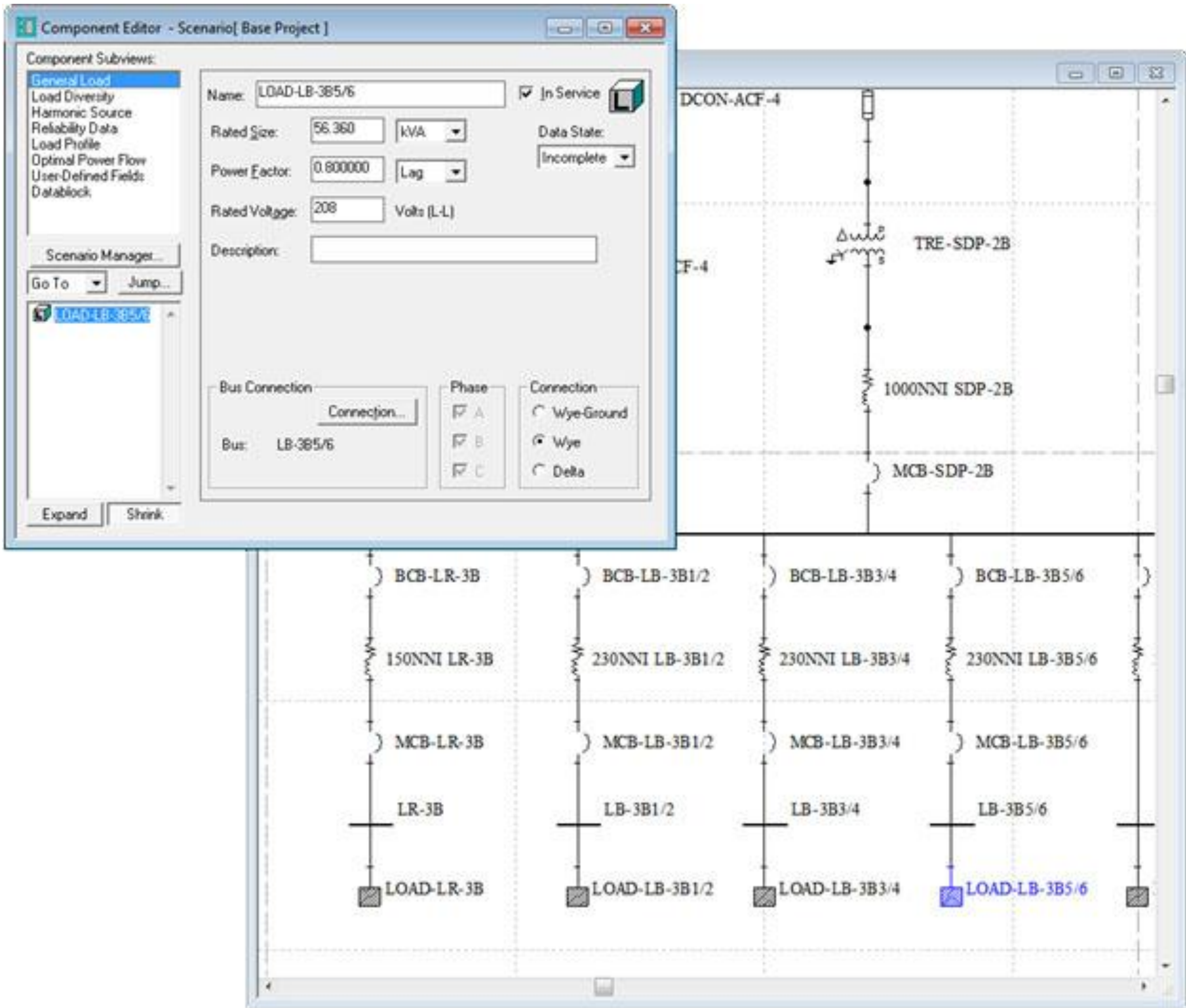



Figure 131: Non-Motor Load Inputs in SKM.

The following figures illustrate the distribution equipment servicing the third floor of the Millennium Science Complex, beginning with the overall one-line diagram:

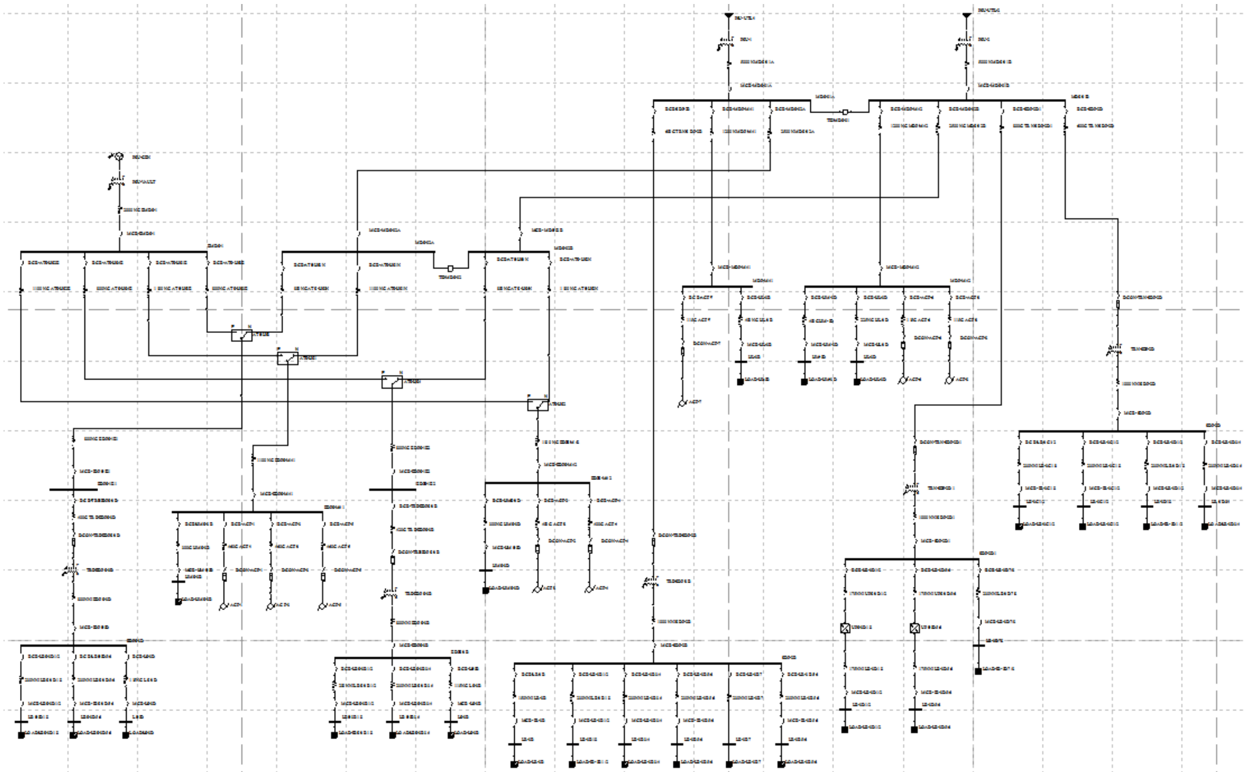


Figure 132: Millennium Science Complex third floor service equipment one-line diagram.

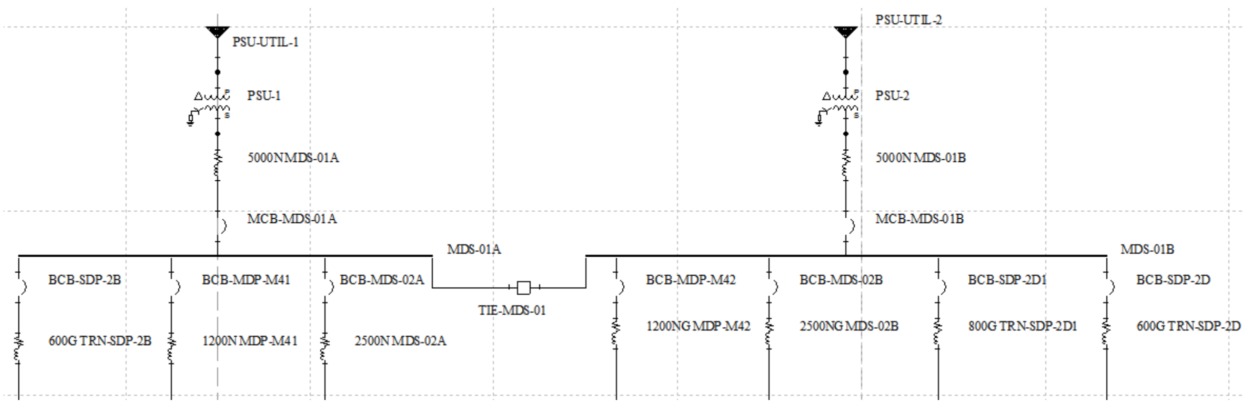



Figure 133: MDS-01A and MDS-01B one-line diagram.

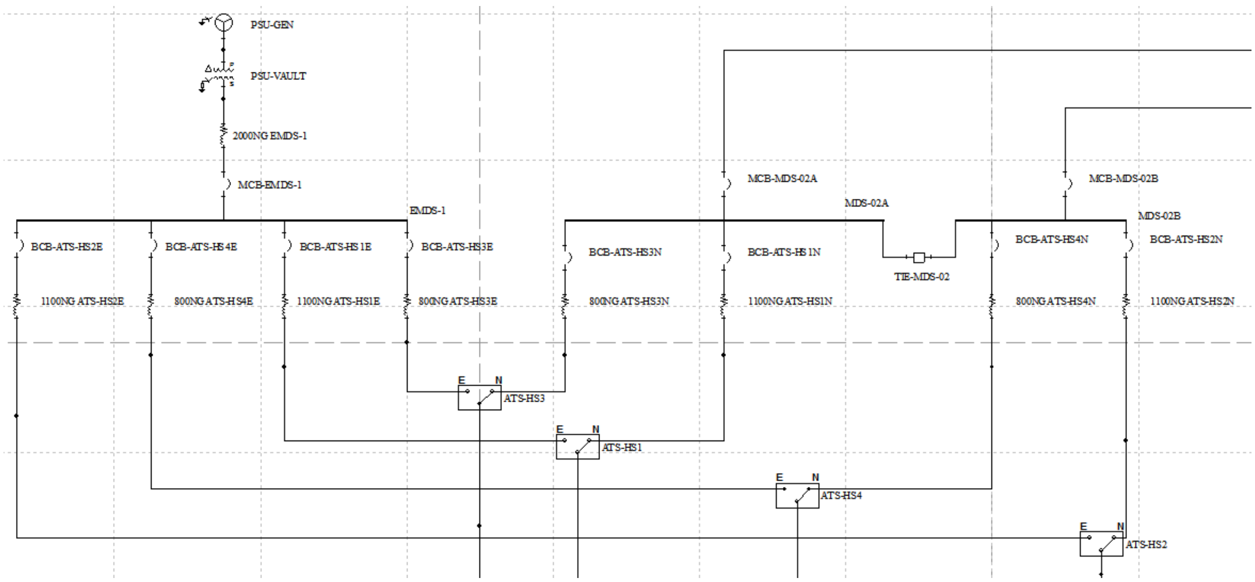



Figure 134: EMDS-1, MDS-02A, MDS-02B, and ATSs one-line diagram.

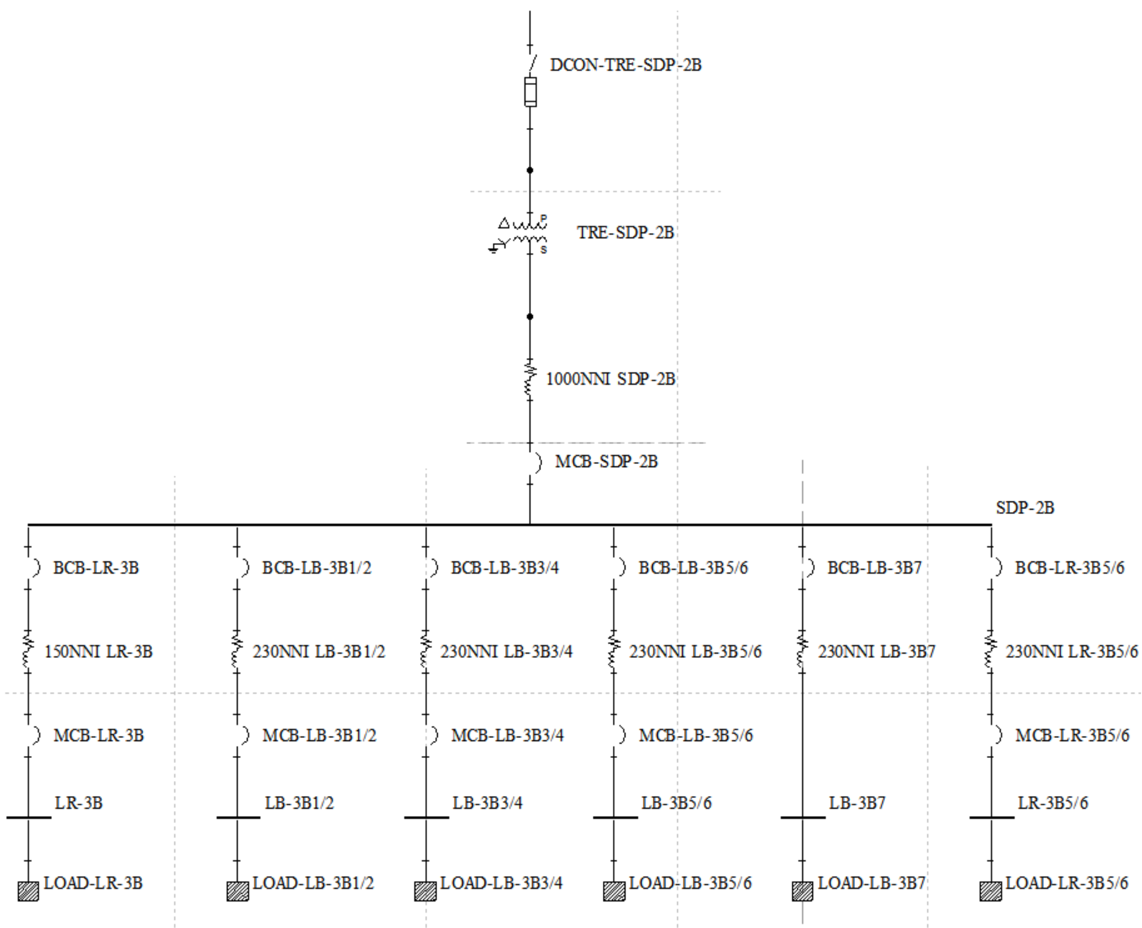



Figure 135: SDP-2B and loads one-line diagram.

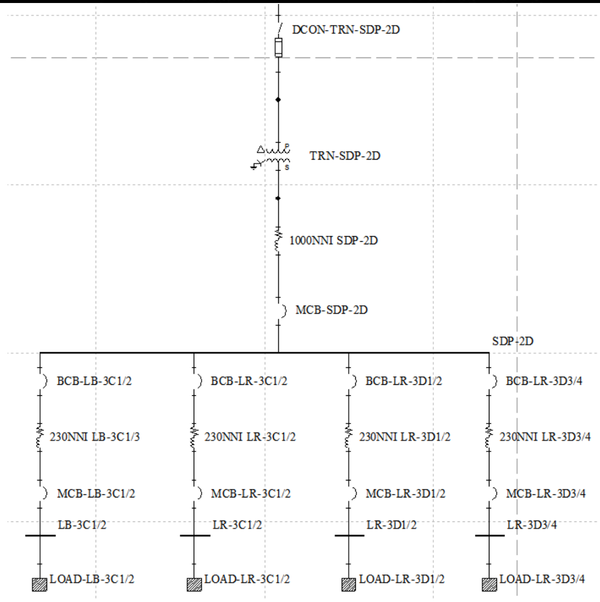



Figure 136: SDP-2D and loads one-line diagram.

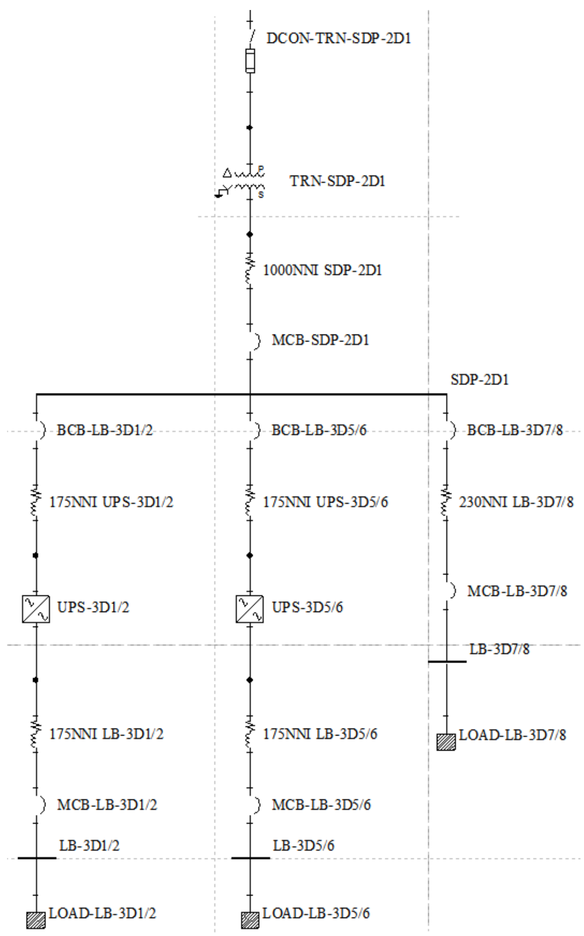



Figure 137: SDP-2D1 and loads one-line diagram.

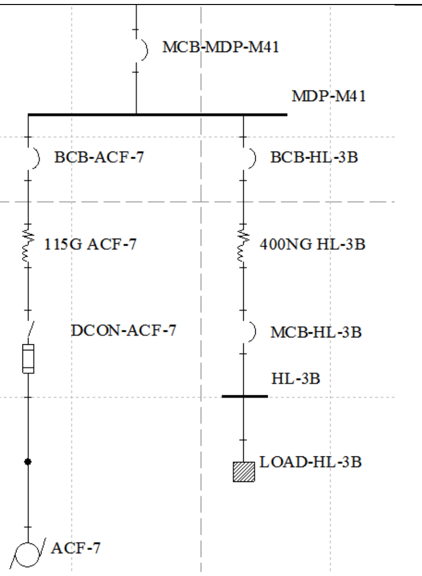



Figure 138: MDP-M41 and loads one-line diagram.

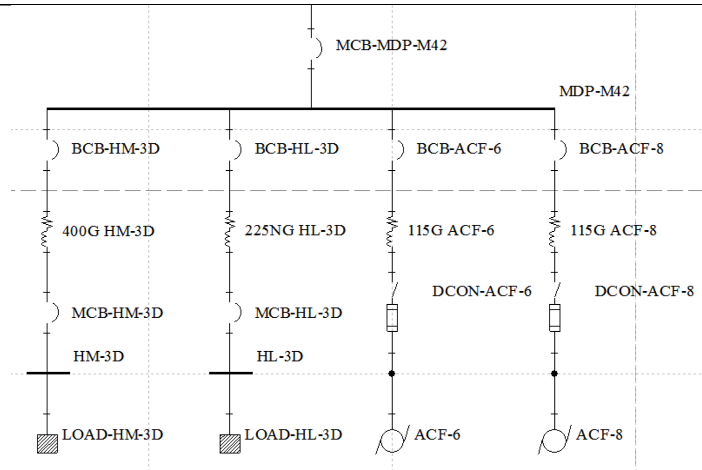



Figure 139: MDP-M42 and loads one-line diagram.

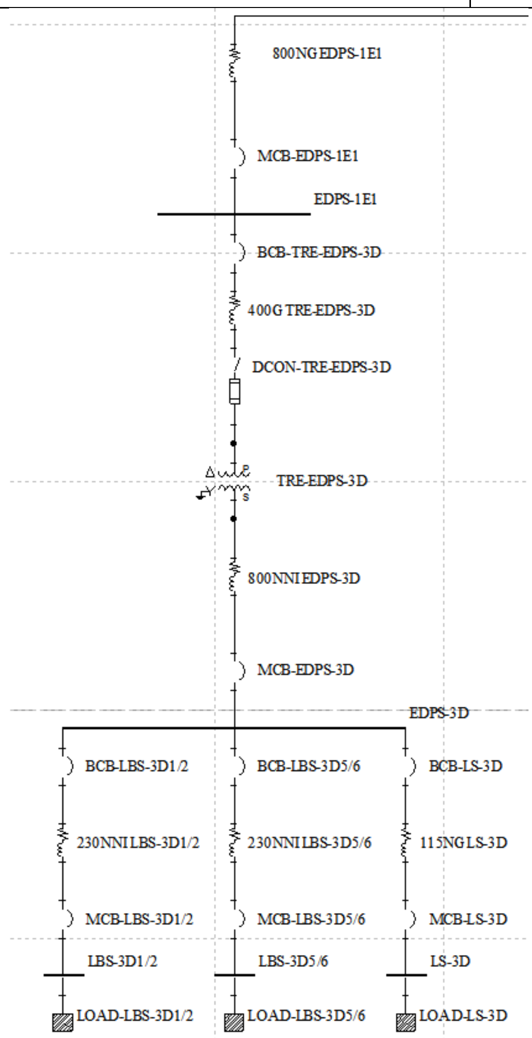



Figure 140: EDPS-1E1 and loads one-line diagram.

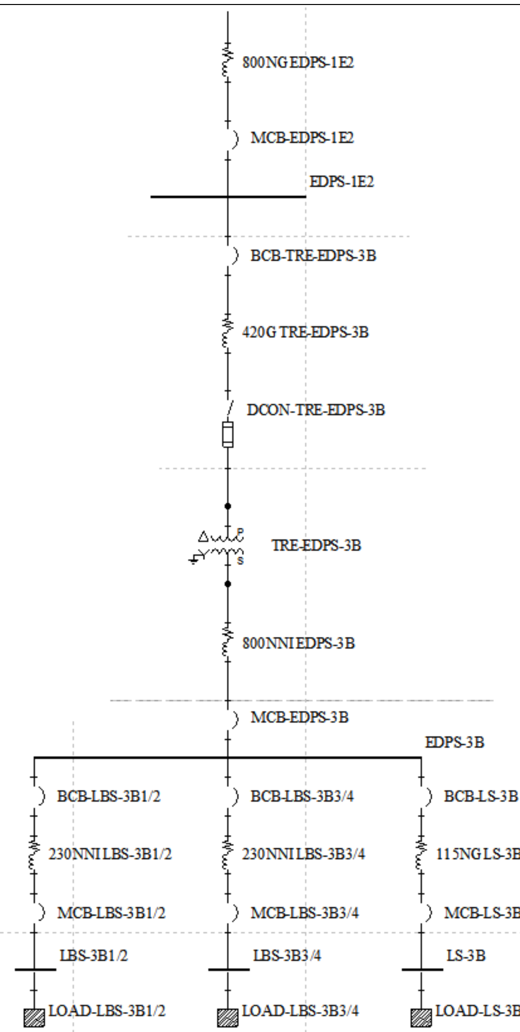



Figure 141: EDPS-3B and loads one-line diagram.

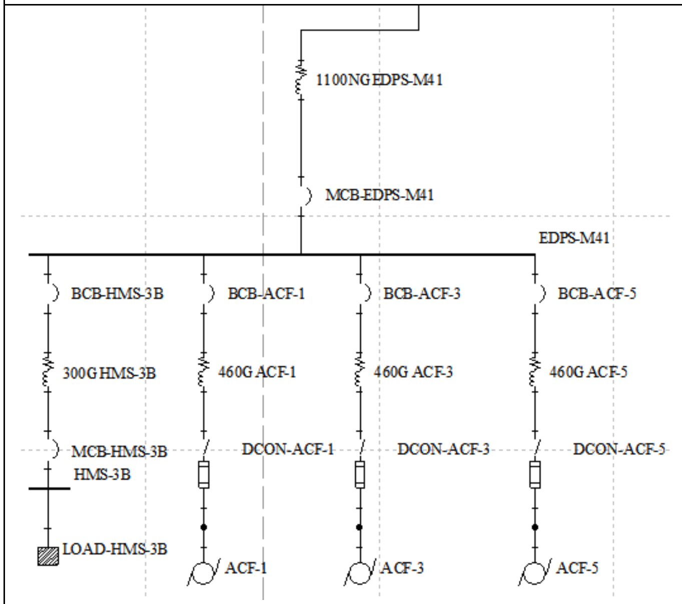



Figure 142: EDPS-M41 and loads one-line diagram.

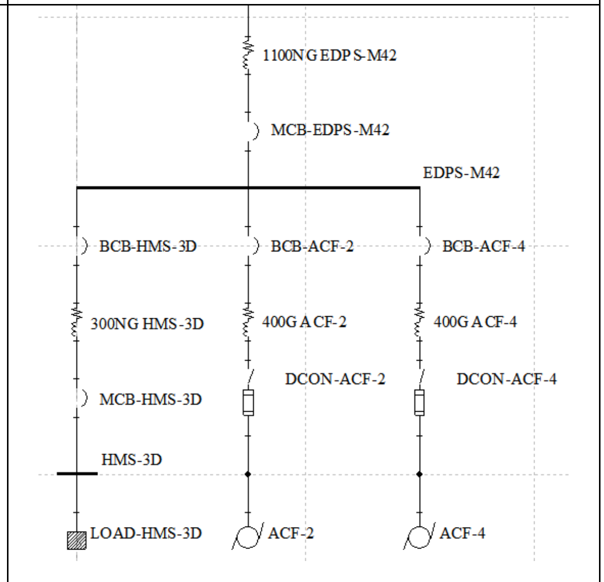



Figure 143: EDPS-M41 and loads one-line diagram.

Once the one-line diagram is finalized and all components will run through the analysis software without fatal errors or warnings, it is possible to run a report on arc flash, short circuit, equipment sizing, etc. Utility available fault current for this depth topic is courtesy of Penn State OPP. The two main utility feeds for the Millennium Science Complex contribute 37,246A (PSU1) and 34,372A (PSU-2). Results from the SKM analysis can be seen in Table 46 below.

Table 46: Transformer Impedance Summary.

| Transformer Impedance Summary | | | | |
|---|---|---|---|---|
| Tag | Primary Voltage | Secondary Voltage | %R | %X |
| PSU-1 | 12.47kV Delta | 480Y/277V | 0.4775 | 5.73 |
| PSU-2 | 12.47kV Delta | 480Y/277V | 0.4775 | 5.73 |
| PSU-VAULT | 4160V Delta | 480Y/277V | 1.05 | 5.65 |
| TRN-SDP-2D | 480V Delta | 208Y/120V | 2.07 | 4.00 |
| TRN-SDP-2D1 | 480V Delta | 208Y/120V | 2.07 | 4.00 |
| TRE-SDP-2B | 480V Delta | 208Y/120V | 2.07 | 4.00 |
| TRE-EDPS-3B | 480V Delta | 208Y/120V | 2.36 | 3.83 |
| TRE-EDPS-3D | 480V Delta | 208Y/120V | 2.36 | 3.83 |

As stated in the introduction to this analysis, knowing arc flash and short circuit characteristics of equipment can help engineers prevent loss of live in worst-case-scenario events. Ideally, each piece of equipment should have an interrupting rating greater than the analysis results in the SKM output. The highlighted values in Table 47 on the following page are pieces of equipment that can be deemed in violation of their interrupting rating or are close to violating their interrupting rating. The higher voltage panelboard (H- prefix) are currently rated for 14,000 AIC. The two HMS panel boards above can now be seen to be unsafe for the event of a short circuit – given the manner in which this system was modeled. Similarly, panelboard LR-3B is close to its maximum interrupting current rating. On panelboard schedules, a *minimum* value for interrupting current is written in. After viewing this results table, designs can be adjusted to account for dangers such as panelboard failures and arc flashes.

Table 47: SKM Short Circuit Report Summary.

| Fault Analysis Summary | | | | | |
|---|---|---|---|---|---|
| Bus Name | Voltage | Available Fault Current | | | |
| | L-L | 3-Phase | X/R | LINE/GRND | X/R |
| EDPS-1E1 | 480 | 39353.3 | 3 | 8391.63 | 0.2 |
| EDPS-1E2 | 480 | 38449.6 | 2.9 | 8364.93 | 0.2 |
| EDPS-3B | 208 | 8147.9 | 1.6 | 9238.12 | 1.6 |
| EDPS-3D | 208 | 9963.3 | 1.6 | 10713.51 | 1.6 |
| EDPS-M41 | 480 | 26611.3 | 2.1 | 7238.23 | 0.3 |
| EDPS-M42 | 480 | 32169.3 | 2.4 | 7817.41 | 0.3 |
| EMDS-1 | 480 | 10039.0 | 4.9 | 1621.01 | 0.1 |
| HL-3B | 480 | 13108.6 | 1.6 | 5383.71 | 0.5 |
| HL-3D | 480 | 11810.3 | 1.2 | 4971.80 | 0.5 |
| HM-3D | 480 | 13304.3 | 1.6 | 5406.24 | 0.5 |
| HMS-3B | 480 | 15707.0 | 1.4 | 5858.97 | 0.4 |
| HMS-3D | 480 | 17537.7 | 1.4 | 6259.26 | 0.4 |
| LB-3B1/2 | 208 | 7593.2 | 1.1 | 6792.20 | 1.2 |
| LB-3B3/4 | 208 | 7756.9 | 1.1 | 6964.21 | 1.2 |
| LB-3B5/6 | 208 | 7756.9 | 1.1 | 6964.21 | 1.2 |
| LB-3B7 | 208 | 8104.7 | 1.2 | 7334.45 | 1.2 |
| LB-3C1/2 | 208 | 4502.6 | 0.9 | 4019.60 | 1 |
| LB-3D1/2 | 208 | 138.7 | 7.9 | 134.64 | 8.1 |
| LB-3D5/6 | 208 | 138.7 | 7.9 | 134.64 | 8.1 |
| LB-3D7/8 | 208 | 4508.2 | 0.9 | 4021.00 | 1 |
| LBS-3B1/2 | 208 | 6467.5 | 1.2 | 6633.94 | 1.2 |
| LBS-3B3/4 | 208 | 6467.5 | 1.2 | 6633.94 | 1.2 |
| LBS-3D1/2 | 208 | 7560.1 | 1.2 | 7361.22 | 1.2 |
| LBS-3D5/6 | 208 | 7560.1 | 1.2 | 7361.22 | 1.2 |
| LR-3B | 208 | 9213.2 | 1.2 | 8620.65 | 1.2 |
| LR-3B5/6 | 208 | 7756.9 | 1.1 | 6964.21 | 1.2 |
| LR-3C1/2 | 208 | 3773.0 | 0.8 | 3288.52 | 0.9 |
| LR-3D1/2 | 208 | 6503.1 | 1.1 | 6244.65 | 1.2 |
| LR-3D3/4 | 208 | 6503.1 | 1.1 | 6244.65 | 1.2 |
| LS-3B | 208 | 6746.9 | 1.1 | 7098.78 | 1 |
| LS-3D | 208 | 7936.7 | 1.1 | 7928.46 | 1 |
| MDP-M41 | 480 | 18646.1 | 1.9 | 6337.24 | 0.4 |
| MDP-M42 | 480 | 19033.2 | 1.9 | 6367.69 | 0.4 |
| MDS-01A | 480 | 57411.7 | 5.7 | 9248.60 | 0.1 |
| MDS-01B | 480 | 57406.8 | 5.7 | 9248.52 | 0.1 |
| MDS-02A | 480 | 44453.2 | 3.5 | 8669.88 | 0.2 |
| MDS-02B | 480 | 44450.1 | 3.5 | 8669.80 | 0.2 |
| SDP-2B | 208 | 10951.5 | 1.6 | 10647.34 | 1.7 |
| SPD-2D | 208 | 8645.7 | 1.4 | 9083.76 | 1.5 |
| SDP-2D1 | 208 | 8574.7 | 1.3 | 9026.44 | 1.6 |

## Short Circuit Hand Calculation

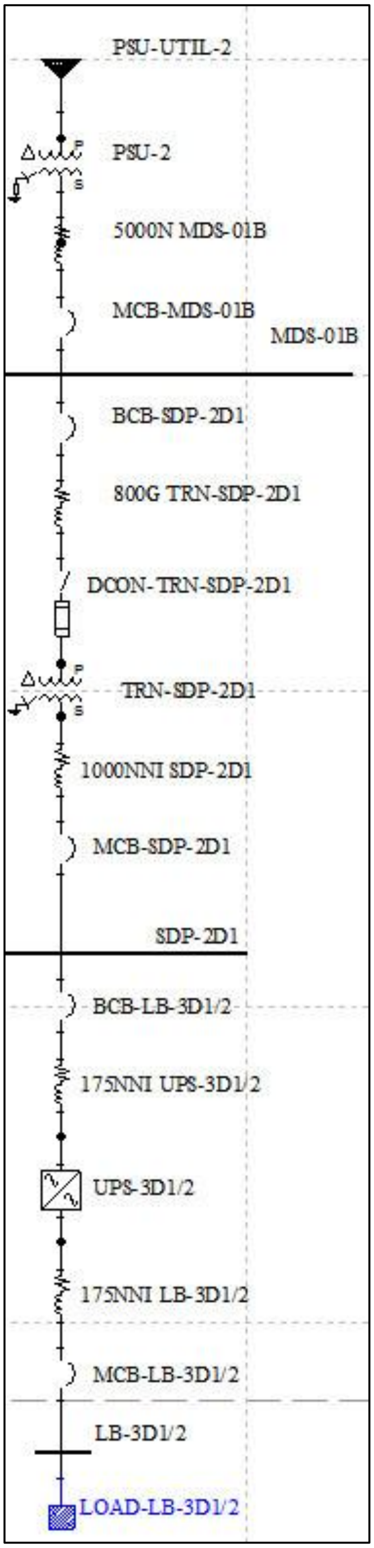



Figure 144: Short Circuit Analysis Path.

A short circuit analysis of the follow sting of electrical components was completed using the per-unit method:

- PSU Utility
- TRN-PSU-2
    - (12) Sets of 750
- MDS-01B
    - (2) Sets of 600
- TRN-SDP-2D1
    - (3) Sets of 400
- SDP-2D1
    - (1) Set of 2/0
- UPS-3D1/2
    - (1) Set of 2/0
- LB-3D1/2

The one-line view of this run can be seen to the left in Figure 144: Short Circuit Analysis Path. The results are found on the following page in Table 48: Short Circuit Analysis Calculation Table.

**Table 48: Short Circuit Analysis Calculation Table.**

| Short Circuit Aalysis (Per Unit Method) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equipment Characteristics | | | | | | | | | | | Per-Unit Value | | | | |
| Mark | %X | %R | %Z | kVA | X/1000ft | R/1000ft | Z/1000ft | Length (ft) | No. Sets | 3ph Voltage (V) | Mark | $X_u$ | $R_u$ | $Z_u$ | $I_{sc}$ |
| Utility | 0.235 | | | 42563.55 | | | | | | 12470 | Utility | 0.2349 | | 0.2349 | |
| | | | | | | | | | | | | | | | 1970.656 |
| TRN-PSU-2 | 5.730 | 0.478 | 5.750 | 5000 | | | | | | 480 | PSU-2 | 0.1146 | 0.0096 | 0.1150 | |
| | | | | | | | | | | | | | | | 34371.90 |
| FEEDER MDS-01B (750) | | | | | 0.0445 | 0.0216 | 0.0495 | 30 | 12 | 480 | FEEDER MDS-01B | 0.0048 | 0.0023 | 0.0054 | |
| | | | | | | | | | | | | | | | 33852.67 |
| MDS-01B | | | | | | | | | | 480 | MDS-01B | | | | |
| | | | | | | | | | | | | | | | 33852.67 |
| FEEDER TRN-SDP-2D1 (600) | | | | | 0.0257 | 0.0463 | 0.0530 | 1000 | 2 | 480 | FEEDER TRN-SDP-2D1 | 0.5577 | 1.0048 | 1.1492 | |
| | | | | | | | | | | | | | | | 7994.798 |
| TRN-SDP-2D1 | 2.070 | 4.000 | 4.504 | 300 | | | | | | 480 | TRN-SDP-2D1 | 0.6900 | 1.3333 | 1.5013 | |
| | | | | | | | | | | | | | | | 4001.658 |
| FEEDER SDP-2D1 (400) | | | | | 0.0490 | 0.0356 | 0.0606 | 154 | 3 | 208 | FEEDER SDP-2D1 | 0.5814 | 0.4224 | 0.7186 | |
| | | | | | | | | | | | | | | | 7452.76 |
| SDP-2D1 | | | | | | | | | | | SDP-2D1 | | | | |
| | | | | | | | | | | | | | | | 7452.76 |
| FEEDER UPS-3D1/2 (2/0) | | | | | 0.0553 | 0.1020 | 0.1150 | 200 | 1 | 208 | FEEDER UPS-3D1/2 | 2.5564 | 4.7152 | 5.3636 | |
| | | | | | | | | | | | | | | | 3054.251 |
| UPS-3D1/2 | 0.992 | 0.012 | 0.992 | 50 | | | | | | 208 | UPS-3D1/2 | 1.9840 | 0.0240 | 1.9841 | |
| | | | | | | | | | | | | | | | 2506.928 |
| FEEDER-LB-3D1/2 (2/0) | | | | | 0.0553 | 0.1020 | 0.1150 | 10 | 1 | 208 | FEEDER-LB-3D1/2 | 0.1278 | 0.2358 | 0.2682 | |
| | | | | | | | | | | | | | | | 2447.643 |
| LB-3D1/2 | | | | | | | | | | | LB-3D1/2 | | | | |

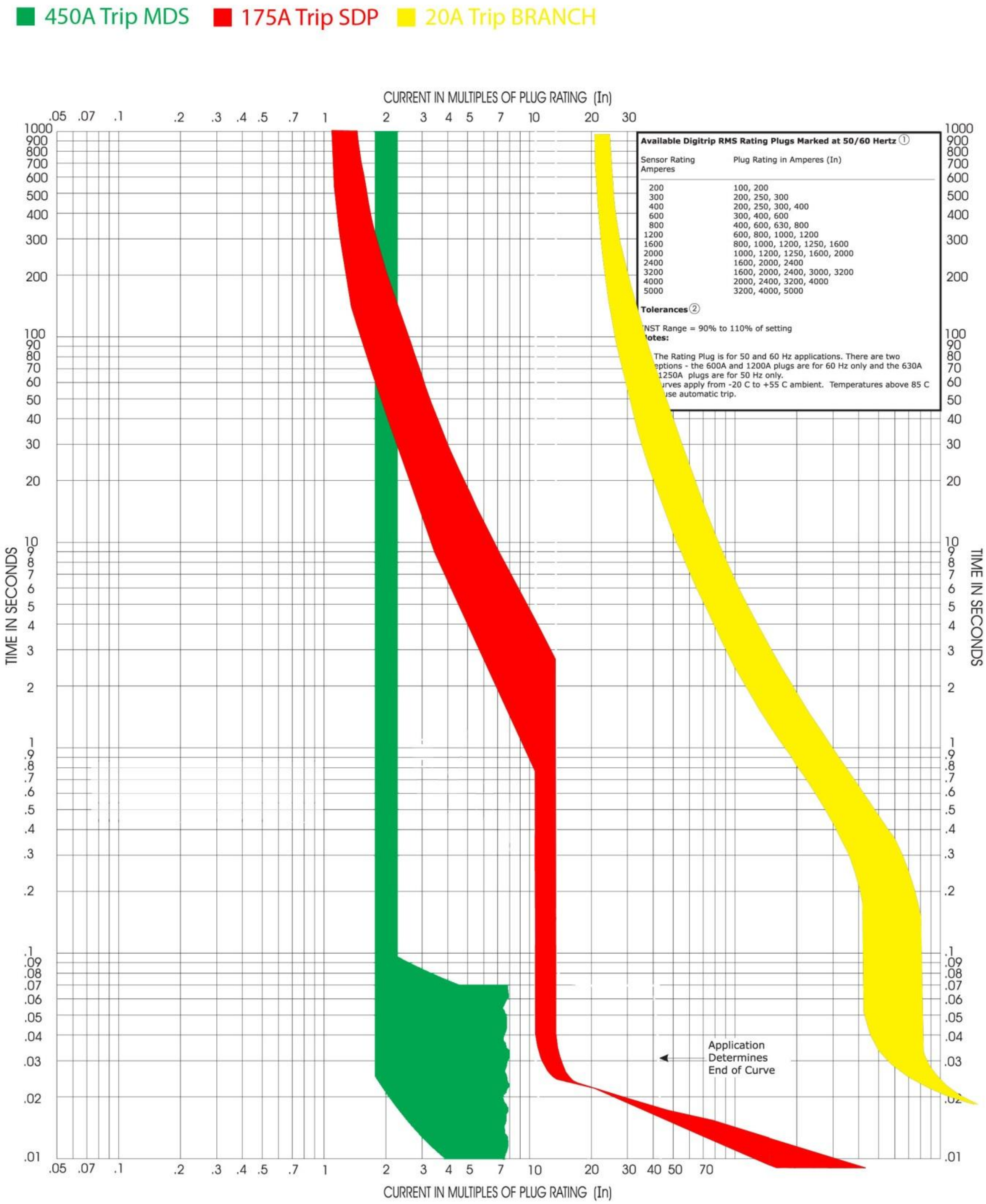



**Figure 145: Short Circuit Device Coordination.**

# Revit MEP Modeling

## Summary

The use of an in depth program such as Revit MEP allows for quick integration between disciplines. Specifically, Mechanical and Electrical designers can exchange accurate design loads almost instantaneously. The process of setting up a Revit MEP Model can be intensive up front, yet allow for easy changes to systems and designs closer to the end of the design timeline.

The Millennium Science Complex is an intensive research lab with extensive electrical plug loads and research equipment throughout. The use of ASHRAE suggested electrical design load watts/SF according to the type of room in question would be an underestimation for mechanical equipment sizing. The use of Revit MEP while designing an electrical system can allow the designer to provide each room with an actual connected load and W/SF.

The Building Stimulus took the opportunity to explore the use of Revit MEP as both an electrical design tool and a BIM/IPD design tool. In the following sections the topics of using Revit MEP as an electrical design tool, a building information modeling tool, and an integration tool between disciplines.

## Revit MEP as a Lighting Design Tool

### Entering Material Properties

Professionals who have used platforms of AutoDesk Revit are usually familiar with the materials editing process, but not to the level of detail that can be fully achieved with the programs. With respect to lighting design, the generic material types in Revit MEP simply are not enough to provide detailed renderings of spaces, which keep lighting design out of BIM. Embedded within the material properties of Revit Architecture are custom materials. In order to appropriately model surfaces such as "painted gypsum wall board with [manufacturer] cool gray paint," the designer should use a custom wall.

When going deeper into the wall construction and materials, the user will notice that there is not much room for customization in the generic Revit material types. For example, the standard gypsum wall board acts like a painted surface (Figure 42). There are pre-loaded properties of finishes in the following combinations of color, finish, and application:

| Color | Finish | Application |
|---|---|---|
| Customizable | Flat/Matte | Brush |
| | Eggshell | Roller |
| | Platinum | Spray |
| | Pearl | |
| | Semi-gloss | |
| | Gloss | |

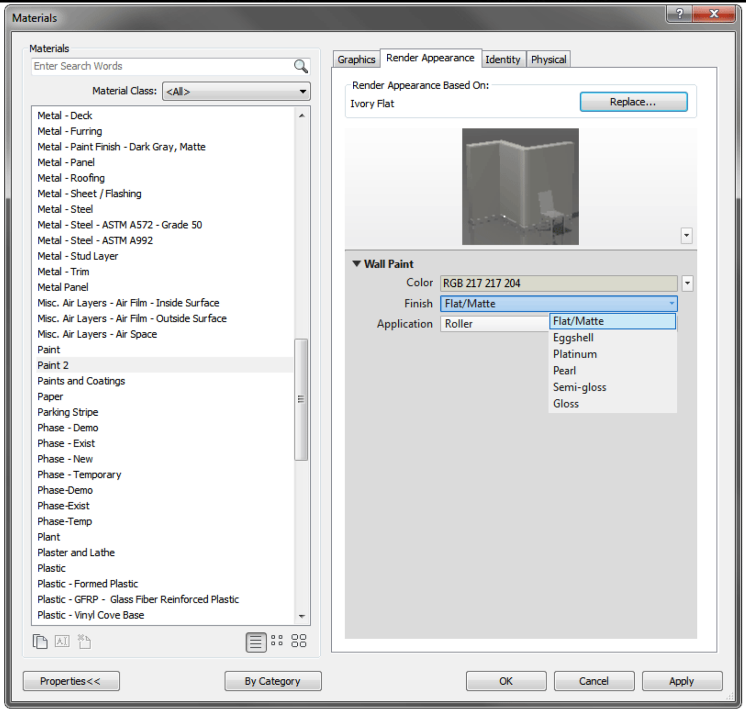



Figure 146: Material Properties - Finishes.

Each of these finishes and applications has properties of reflectance, specularity, roughness, etc. that cannot be accessed by the designer. A good way to make the surface somewhat custom to the design is to begin with a "Generic" material and adjust colors and reflectivity (Figure 43).

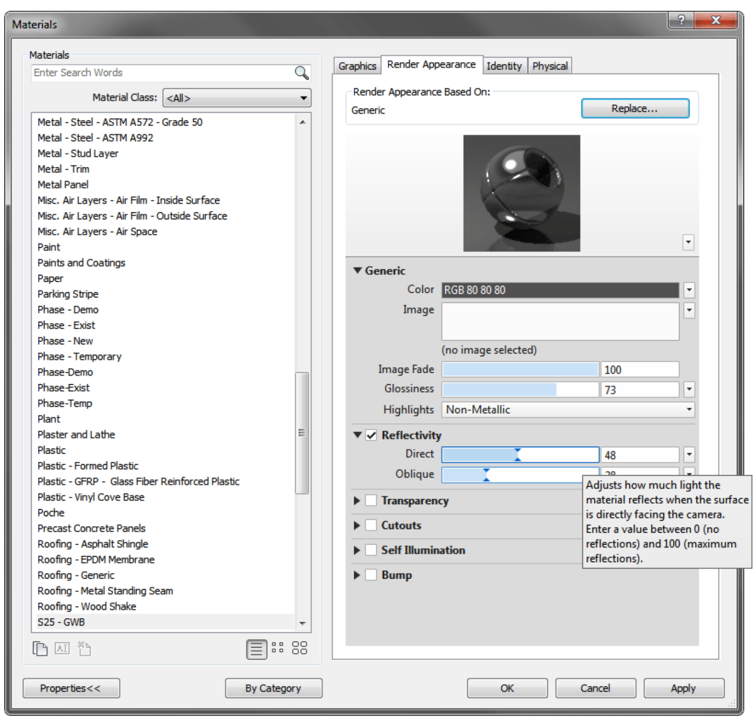



Figure 147: Material Properties – Custom Finishes.

These properties, however, are not exactly the inputs lighting designers wish to be able to control. The direct reflectivity and oblique reflectivity are defined by Revit Architecture as follows:

> Direct Reflectivity: Measurement of how much light the material reflects when the surface is directly facing the camera. Enter a value between 0 (no reflections) and 1 (maximum reflections).

> Oblique Reflectivity: Measurement of how much light the material reflects when the surface is at an angle to the camera. Enter a value between 0 (no reflections) and 1 (maximum reflections).

This means that designers must perform a calculation to find the relative reflectivity of their surfaces, or guess and hope that their inputs are somewhat accurate. On the positive end, there are materials that do have relative inputs. Glass types allow the designer to input reflectance and number of sheets in the panel. Glass types do not, however, allow for specification of transmittance. Without usable inputs such as reflectance, instead of reflectivity, and transmittance, instead of transparency, lighting design in platforms of Revit is simply too time consuming and not worth the input relative to programs such as AGI32.

## Setting Design Criteria

One of the largest challenges of lighting designers is establishing appropriate design criteria for spaces. The discussion up to this section has been design criteria for three spaces in the Millennium Science Complex. With the advent of Building Information Modeling, lighting design has an opportunity to merge into a larger world than lighting software. In its current state, building information modeling lacks in ultimate usefulness of design criteria such as design illuminance and other measurable quantities such as uniformity gradient, coefficient of variance, and luminance ratios. However, this observation is only applicable to Revit MEP 2011 as it is the primary software for IPD/BIM Thesis 2010-2011.

Revit MEP allows for specialized space criteria once a schedule is created. It is possible to add custom parameters, but it is not possible to edit pre-loaded templates (Figure 44). Other information, such as power densities (similar to ASHRAE 90.1) is already embedded into space types. It is possible to add custom parameters through schedules (Figure 45).

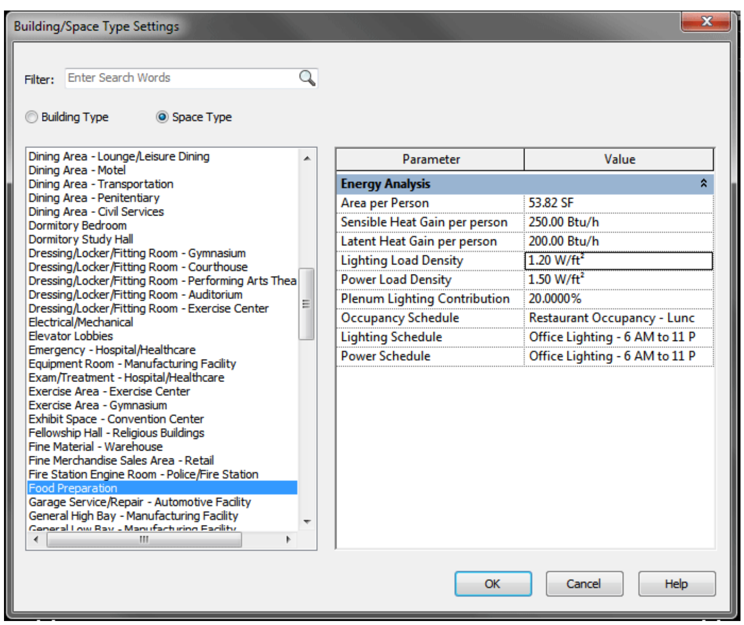



Figure 148: Space Type.

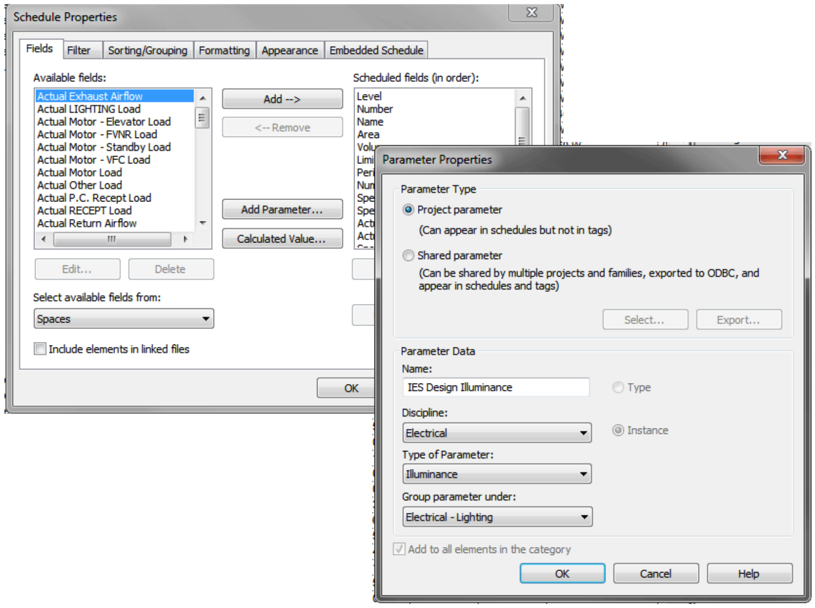



Figure 149: Parameter Properties.

For the inputs above, the parameter "IES Design Illuminance" will appear under the "Electrical – Lighting" properties of the space and be in "Illuminance" parameters (i.e. footcandles). Now that this parameter has been created, each space can be edited to have its IES recommended illumination value within its properties. These new parameters can be drawn out of the BIM model in a schedule, but are arbitrary to space type. Not being associated with a pre-specified space type creates a labor-intensive chore to assign design criteria to spaces.

If IES values and parameters can be associated in the base space types, then it will be possible to have a visual check on initial space design compliance. Discussed in the next section will be how Revit calculates average illuminance values and their comparison to actual hand calculations.

## Calculation Process Revit MEP

Embedded in space types as discussed in "Setting Design Criteria" of this document are calculated statistics applicable to lighting design. Parameters for these calculations include:

| <u>Variable Inputs</u> | <u>Outputs</u> |
|---|---|
| Lighting Calculation Workplane | Average Estimated Illumination (AEI) |
| Ceiling Reflectance | Room Cavity Ratio (RCR) |
| Wall Reflectance | |
| Floor Reflectance | |

These inputs are separate from the "reflectivity" parameters discussed in the previous topic. The reflectances in this topic are applied to the space. The space is essentially an imaginary box that fills a room to its extents. The reflectance values apply to the ceiling, walls, and floor of the space box and are not associated with the materials in the room whatsoever. Each reflectance can be thought of as an area average for the entire area it is analogous to in the space.

The room cavity ratio is automatically calculated from the "lighting calculation workplane" and the mounting height of the luminaire. All calculations are used in a basic Lumen Method for the space. This inherently cannot take criteria such as vertical illuminance, actual uniformity, or luminance ratios as discussed in the last topic. Other inputs are available that affect the calculation such as customizable light loss factors and initial intensity (by efficacy, flux, luminous intensity, or illuminance at a distance). The image from Revit MEP's help site below shows these inputs (Figures 46 and 47). These all are combined into a total light loss factor for the calculation.

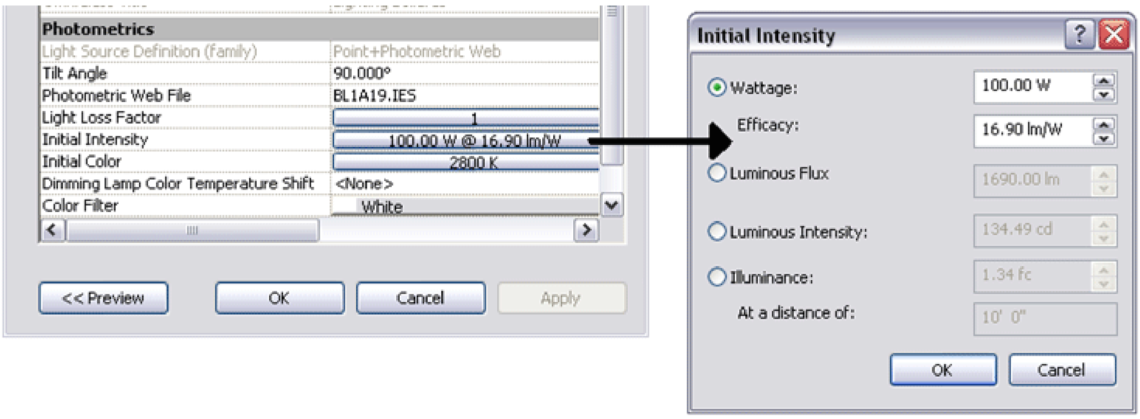



Figure 150: Initial Intensity.

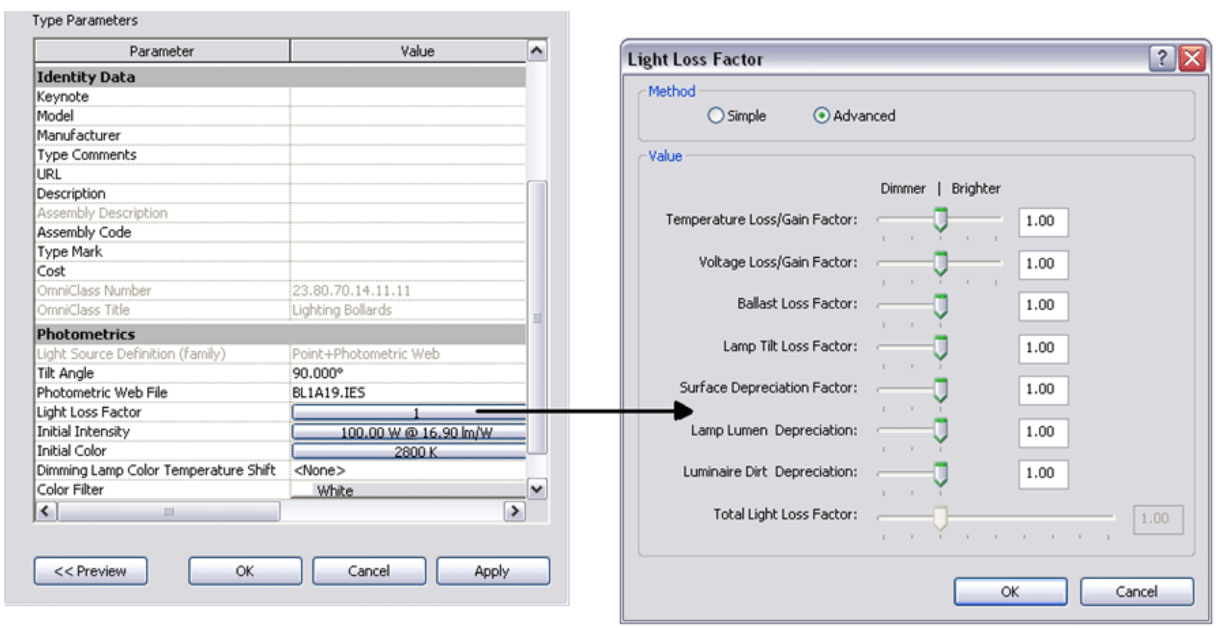



Figure 151: Light Loss Factors.

Revit's calculation process incorporates all of the input factors from each luminaire and adds them individually. Regardless of luminaire position, orientation, and distribution, a simple addition of flux is the only equation used to calculate total illuminance:

$$AEI = \sum_{i=1}^{n} \frac{Lumens\ at\ Workplane_i}{Area}$$

The quantity of lumens at the work plane is a peculiar calculation also. It is a product of the "initial intensity" from the properties seen in the image above, total light loss factors, and the coefficient of utilization of the luminaire. It is unclear in the Revit MEP help page how the coefficient of utilization is actually calculated and used and CU does not appear in an output in the properties box of a space. What the total calculation boils down to is the following:

$$AEI = \sum_{i=1}^{n} \frac{(II * LLF * CU)_i}{Space\ Area}$$

Where: II = Initial Intensity in lumens
LLF = total light loss factors
CU = Coefficient of Utilization

As the equation turns out, room reflectance values should have direct bearing on the average estimated illumination of the space, as should the task plane height. In reality, the user cannot determine how CU and RCR are used in these calculations. In normal lighting calculations, a room cavity ratio, wall reflectance, and ceiling cavity reflectance are used to interpolate on a chart for the luminaire. In the example below (Figure 48), reflectance values are changed from ceiling/wall/floor of 0.8/0.6/0.2 (standard) to other values.

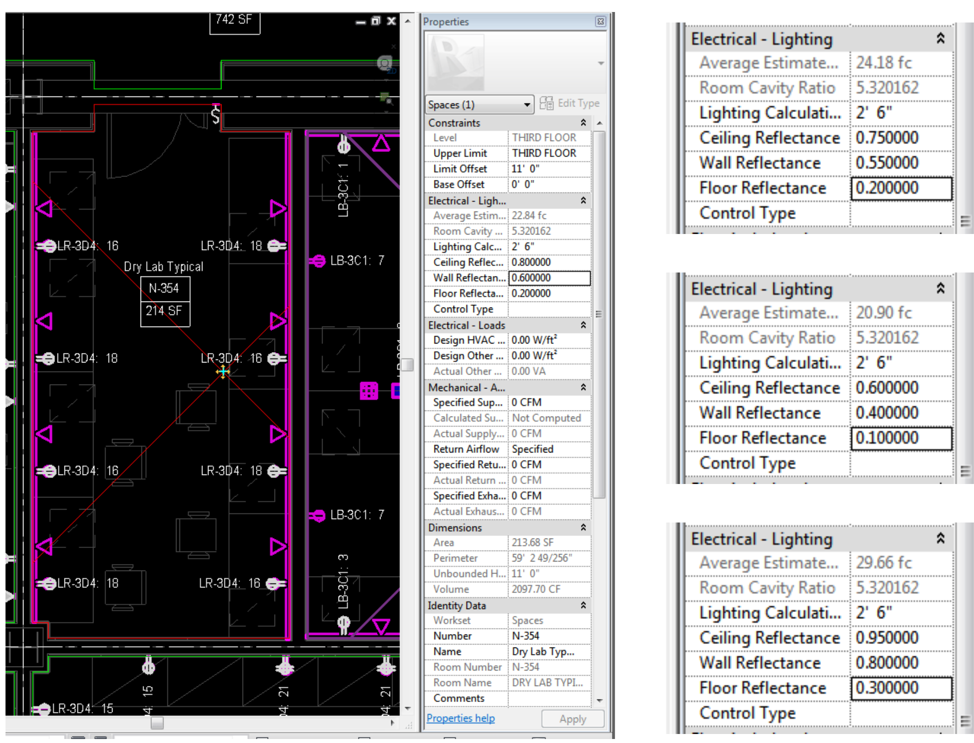



Figure 152: Changing Reflectance Values.

Notice the inconsistent change in the calculated illuminance and RCR relative to the given equation. If this calculation were a true Lumen Method, the equations would depend on CU as in the IESNA Handbook shown here:

$$Illuminance = \frac{(\#\ of\ Luminaires)(\varphi\ per\ Luminaire)(CU)(LLF)}{Workplane\ Area}$$

$$Where: \quad CU \propto \quad F(\rho_{CC}, \rho_W, RCR)$$

Upon examining luminaires and spaces, it is possible that the "Room Cavity Ratio" report in the properties dialog is actually a product of RCR and CU. Upon further investigation, this is not true. If reflectances are changed in a space, the coefficient of utilization is automatically changed per luminaire, provided that the "Calculate Coefficient of Utilization" box is checked in the luminaire properties. Using flux transfer, a coefficient of utilization can be obtained that is similar to the value calculated in Revit MEP:

$$\begin{bmatrix} -1 & \rho_1 F_{1-2} & \rho_1 F_{1-3} \\ \rho_2 F_{2-1} & -1 & \rho_2 F_{2-3} \\ \rho_3 F_{3-1} & \rho_3 F_{3-2} & (\rho_3 F_{3-3}) - 1 \end{bmatrix} \begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix} = \begin{bmatrix} -M_{01} \\ -M_{02} \\ -M_{03} \end{bmatrix}$$

$$CU = \frac{M_{FC} * A_{FC}}{\varphi_{LAMP} * \rho_{FC}}$$

Using the flux balance method, this room has a coefficient of utilization of 0.507 as opposed to a Revit MEP calculated value of 0.518. "Room Cavity Ratio" in Revit MEP is still unclear as to how to achieve this value. For the same room, Revit MEP's output RCR has a value of 5.320. The actual RCR as calculated by the IESNA Handbook has a value of 5.698. When hand-calculated RCR and CU are combined in the Lumen Method equation discussed previously, this room should be calculated to be between 24.80 fc and 30.03 fc depending upon efficiency of the light fixture. Revit MEP calculates the average estimated illumination for this space to be 24.95 fc, which is analogous to an efficiency of 72.7% in the Lumen Method calculation.

In conclusion, Revit MEP's calculation of "average estimated illuminance" can be a good starting point for lighting design, but is not clear enough communicating how these values are calculated. If a more extensive demonstration of how Revit MEP calculates average estimated illuminance can be written into the program, there could be more use for lighting design estimation in Revit.

## Electrical Impacts from Lighting Design

Building Stimulus has focused on the third floor for the primary zone for redesign. Because of this, lighting designs of the third floor typical spaces have been extrapolated throughout the third floor for electrical analysis.

Panel HL-3B feeds the normal system lighting in the Life Science wing, while HLE-3B feeds the normal/emergency system lighting in the Life Science wing. Similarly, Panel HL-3D feeds the normal system lighting in the Material Science wing, while HLE-3B feeds the normal/emergency system lighting in the Material Science wing.

There are 23 typical offices as well as two distinguished offices on the 3$^{rd}$ floor of the Material Science wing which are circuited to panel HL-3D.The corridor lighting design will affect 4384SF of circulation space in the Material Science wing, where normal system lighting will be fed from HL-3D and normal/emergency system lighting is fed from HLE-3D. Room N308A/B is a conference room totaling 846SF which is circuited to HL-3D. The Life Science wing also contains three student study areas, two are 780SF and the other is 313SF – all three of which are fed from panel HL-3D.

There are 15 typical offices as well as a single distinguished office on the 3$^{rd}$ floor of the Life Science wing which are circuited panel HL-3B. The corridor lighting design affects 4270SF of circulation space in the Life Science wing, where normal system lighting is fed from HL-3B and normal/emergency system lighting is fed from HLE-3B. The Life Science wing also has a conference room, totaling 846SF which is circuited to HL-3B.

Site and lobby lighting is fed from panels LCP-1 and LCPE-1. LCP-1 feeds the normal lighting system while LCPE-1 feeds the normal/emergency lighting systems. These panels have been adjusted to work with the exterior plaza lighting design.

**Table 49: Lighting Design Panel Schedules**

| Lighting Design Impacted Panelboards | | | | | | | |
|---|---|---|---|---|---|---|---|
| Panel Tag | Voltage | System | Exterior Plaza | Conference Room | Student Study Area | Corridor | Office |
| LCP-1 | 277/480V, 3P, 4W | N | X | | | | |
| LCPE-1 | 277/480V, 3P, 4W | N/E | X | | | | |
| HL-3B | 277/480V, 3P, 4W | N | | X | | X | X |
| HL-3D | 277/480V, 3P, 4W | N | | X | X | X | X |
| HLE-3D | 277/480V, 3P, 4W | N/E | | | | X | |
| HLE-3B | 277/480V, 3P, 4W | N/E | | | | X | |

## Existing Panel Schedules

### LCP-1

| BRANCH CIRCUIT PANELBOARD SCHEDULE | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Panel Name: LCP-1** | | Mounting: Surface: | X | | | Main Lugs Only: | . | | Amp Main CB | | | | . |
| 277/480V, 3 Phase, 4 Wire | | Flush: | . | | | Shunt Trip Main: | . | | Amp Bus | | | | 225 |
| 14,000MIN A.I.C. SYM | | In MCC | . | | | Feed Through: | . | | Ground Bus | | | | . |
| Neutral: 100% | | Number of Poles: | 42 | | | TVSS: | . | | Isolated Ground Bus | | | | . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Zone 1 LS Lobby Lighting | 20 | 0.42 | | | 1 | 2 | 0.00 | | | 20 | Spare | 2 |
| 3 | Spare | 20 | | 0.00 | | 3 | 4 | | 0.24 | | 20 | Zone 19 Site Lighting | 4 |
| 5 | Zone 3 Exterior Lighting | 20 | | | 1.40 | 5 | 6 | | | 0.24 | 20 | Zone 20 Site Lighting | 6 |
| 7 | Zone 4 LS Lobby Lighting | 20 | 0.31 | | | 7 | 8 | 0.36 | | | 20 | Zone 21 Site Lighting | 8 |
| 9 | Zone 5 LS Lobby Lighting | 20 | | 0.56 | | 9 | 10 | | 0.70 | | 20 | Zone 22 Site Lighting | 10 |
| 11 | Zone 6 Exterior Lighting | 20 | | | 1.25 | 11 | 12 | | | 0.00 | 20 | Spare | 12 |
| 13 | Zone 7 ML Lobby Lighting | 20 | 0.84 | | | 13 | 14 | 0.38 | | | 20 | Zone 24 Site Lighting | 14 |
| 15 | Zone 8 ML Lobby Lighting | 20 | | 0.56 | | 15 | 16 | | 0.00 | | 20 | Spare | 16 |
| 17 | Zone 9 LS Exterior Lighting | 20 | | | 1.40 | 17 | 18 | | | 0.40 | 20 | Zone 26 Site Lighting | 18 |
| 19 | Spare | 20 | 0.00 | | | 19 | 20 | 0.05 | | | 20 | Zone 27 Site Lighting | 20 |
| 21 | Zone 11 Exterior Lighting | 20 | | 1.25 | | 21 | 22 | | 0.40 | | 20 | Zone 28 Site Lighitng | 22 |
| 23 | Zone 12 ML Lobby Lighting | 20 | | | 0.31 | 23 | 24 | | | 0.27 | 20 | Zone 29 Exterior Lighting | 24 |
| 25 | Zone 13 Exterior Lighting | 20 | 0.63 | | | 25 | 26 | 0.27 | | | 20 | Zone 30 Exterior Lighting | 26 |
| 27 | Zone 14 Exterior Lighting | 20 | | 0.84 | | 27 | 28 | | 0.23 | | 20 | Zone 31 Exterior Lighting | 28 |
| 29 | Zone 15 Site Lighting | 20 | | | 2.10 | 29 | 30 | | | 0.20 | 20 | Zone 32 Exterior Lighting | 30 |
| 31 | Zone 16 Site Lighting | 20 | 2.10 | | | 31 | 32 | 0.23 | | | 20 | Zone 33 Exterior Lighting | 32 |
| 33 | Zone 17 Site Lighting | 20 | | 1.90 | | 33 | 34 | | 0.27 | | 20 | Zone 34 Exterior Lighting | 34 |
| 35 | Zone 35 ML Lobby Lighting | 20 | | | 0.46 | 35 | 36 | | | 0.42 | 20 | Zone 36 LS Lobby Lighting | 36 |
| 37 | Spare | 20 | 0.00 | | | 37 | 38 | 0.00 | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | 0.00 | | 39 | 40 | | 0.00 | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | 0.00 | 41 | 42 | | | 0.00 | 20 | Spare | 42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 4.30 | 5.11 | 6.92 | 1.29 | 1.84 | 1.53 | Subtotals (kVA) |
| Total Loads: | Phase A: | 5.59 kVA | | | 80 % | | | Demand Factor |
| | Phase B: | 6.95 kVA | | | 16.79 kVA | | | Demand Load |
| | Phase C: | 8.45 kVA | | | 20.99 kVA | | | Load x 1.25 |
| Total Connected Load: | | 20.99 kVA | | | 25.28 A | | | Demand Amps |

*Denotes Programmable Remote Control Breaker

**Figure 153: Existing Panel Schedule LCP-1.**

## LCPE-1

### BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Panel Name: LCPE-1** | Mounting: | Surface: | X | Main Lugs Only: | . | Amp Main CB | 90 |
| 277/480V, 3 Phase, 4 Wire | | Flush: | . | Shunt Trip Main: | . | Amp Bus | 100 |
| 14,000MIN A.I.C. SYM | | In MCC | . | Feed Through: | . | Ground Bus | . |
| Neutral: 100% | Number of Poles: | | 42 | TVSS: | . | Isolated Ground Bus | . |

| | CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | Spare | 20 | 0.00 | | | 1 | 2 | 0.22 | | | 20 | Zone 42 Exterior Lighting | 2 | * |
| | 3 | Spare | 20 | | 0.00 | | 3 | 4 | | 0.23 | | 20 | Zone 41 M. Lobby Lighting | 4 | * |
| * | 5 | Zone 37 LS Lobby Lighting | 20 | | | 0.23 | 5 | 6 | | | 0.17 | 20 | Zone 43 Exterior Lighting | 6 | * |
| * | 7 | Zone 38 Exterior Lighting | 20 | 0.70 | | | 7 | 8 | 0.77 | | | 20 | Loading Dock | 8 | * |
| * | 9 | Zone 39 Exterior Lighting | 20 | | 0.70 | | 9 | 10 | | 0.00 | | 20 | Spare | 10 | |
| * | 11 | Zone 40 Exterior Lighting | 20 | | | 0.70 | 11 | 12 | | | 0.00 | 20 | Spare | 12 | |
| | 13 | Spare | 20 | 0.00 | | | 13 | 14 | 0.00 | | | 20 | Spare | 14 | |
| | 15 | Spare | 20 | | 0.00 | | 15 | 16 | | 0.00 | | 20 | Spare | 16 | |
| | 17 | Spare | 20 | | | 0.00 | 17 | 18 | | | 0.00 | 20 | Spare | 18 | |
| | 19 | Spare | 20 | 0.00 | | | 19 | 20 | 0.00 | | | 20 | Spare | 20 | |
| | 21 | Spare | 20 | | 0.00 | | 21 | 22 | | 0.00 | | 20 | Spare | 22 | |
| | 23 | Spare | 20 | | | 0.00 | 23 | 24 | | | 0.00 | 20 | Spare | 24 | |
| | 25 | Spare | 20 | 0.00 | | | 25 | 26 | 0.00 | | | 20 | Spare | 26 | |
| | 27 | Spare | 20 | | 0.00 | | 27 | 28 | | 0.00 | | 20 | Spare | 28 | |
| | 29 | Spare | 20 | | | 0.00 | 29 | 30 | | | 0.00 | 20 | Spare | 30 | |
| | 31 | Spare | 20 | 0.00 | | | 31 | 32 | 0.00 | | | 20 | Spare | 32 | |
| | 33 | Spare | 20 | | 0.00 | | 33 | 34 | | 0.00 | | 20 | Spare | 34 | |
| | 35 | Spare | 20 | | | 0.00 | 35 | 36 | | | 0.00 | 20 | Spare | 36 | |
| | 37 | Spare | 20 | 0.00 | | | 37 | 38 | 0.00 | | | 20 | Spare | 38 | |
| | 39 | Spare | 20 | | 0.00 | | 39 | 40 | | 0.00 | | 20 | Spare | 40 | |
| | 41 | Spare | 20 | | | 0.00 | 41 | 42 | | | 0.00 | 20 | Spare | 42 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 0.70 | 0.70 | 0.93 | 0.99 | 0.23 | 0.17 | Subtotals (kVA) |
| Total Loads: | Phase A: | 1.69 kVA | | | 80 % | | | Demand Factor |
| | Phase B: | 0.93 kVA | | | 2.98 kVA | | | Demand Load |
| | Phase C: | 1.10 kVA | | | 3.72 kVA | | | Load x 1.25 |
| Total Connected Load: | | 3.72 kVA | | | 4.48 A | | | Demand Amps |

*Denotes Programmable Remote Control Breaker

**Figure 154: Existing Panel Schedule LCPE-1.**

## HL-3B

### BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Panel Name: HL-3B** | Mounting: | Surface: | X | Main Lugs Only: | . | Amp Main CB | 200 |
| 277/480V, 3 Phase, 4 Wire | | Flush: | . | Shunt Trip Main: | . | Amp Bus | 225 |
| 14,000MIN A.I.C. SYM | | In MCC | . | Feed Through: | . | Ground Bus | X |
| Neutral: 100% | Number of Poles: | | 42 | TVSS: | . | Isolated Ground Bus | . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | KVA/Phase B | KVA/Phase C | CKT No. | CKT No. | KVA/Phase A | KVA/Phase B | KVA/Phase C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Nuerophts-Invitro Lighting | 20 | 2.21 | | | 1 | 2 | 2.21 | | | 20 | Nuerophts-Invitro Lighting | 2 |
| 3 | Nuerophts-Invitro Lighting | 20 | | 1.83 | | 3 | 4 | | 1.83 | | 20 | Nuerophts-Invitro Lighting | 4 |
| 5 | Optical Imagimg Lighting | 20 | | | 2.58 | 5 | 6 | | | 2.40 | 20 | Fumehood, Tissue Culture Lighting | 6 |
| 7 | Fumehood Procedure, Hot Room | 20 | 2.18 | | | 7 | 8 | 1.72 | | | 20 | Toilet, Equip Corr. Lighting | 8 |
| 9 | Faculty, Grad Student Lighting | 20 | | 2.07 | | 9 | 10 | | 1.76 | | 20 | Faculty GMAD Hudson Lighting | 10 |
| 11 | Elec. Equipment, Post Doc & Light | 20 | | | 1.74 | 11 | 12 | | | 1.74 | 20 | BCI Teaching, GMAD, Post Doc Lighting | 12 |
| 13 | Conference Library Lighting | 20 | 1.32 | | | 13 | 14 | 1.82 | | | 20 | Office, Staff, Kitchen Lighting | 14 |
| 15 | Conference Library Lighting | 20 | | 1.79 | | 15 | 16 | | 2.27 | | 20 | Corridor Lighting | 16 |
| 17 | Terrace Lighting | 20 | | | 1.00 | 17 | 18 | | | 1.69 | 20 | Corridor Lighting | 18 |
| 19 | Motorized Shades | 20 | 0.50 | | | 19 | 20 | 1.93 | | | 20 | Café/Common Lighting | 20 |
| 21 | Motorized Shades | 20 | | 0.50 | | 21 | 22 | | 1.67 | | 20 | Café/Common Lighting | 22 |
| 23 | Motorized Shades | 20 | | | 0.50 | 23 | 24 | | | 0.60 | 20 | Track Lighitng | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | 2.40 | | | 20 | Track Lighting | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | Spare | 20 | | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 6.21 | 6.19 | 5.82 | 10.08 | 7.53 | 6.43 | Subtotals (kVA) |
| Total Loads: | Phase A: | 16.29 kVA | | | 90 % | | | Demand Factor |
| | Phase B: | 13.72 kVA | | | 38.03 kVA | | | Demand Load |
| | Phase C: | 12.25 kVA | | | 47.54 kVA | | | Load x 1.25 |
| Total Connected Load: | | 42.26 kVA | | | 57.25 A | | | Demand Amps |

Figure 155: Existing Panel Schedule HL-3B.

HL-3D

## BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| **Panel Name: HL-3D** | Mounting: Surface: | X | Main Lugs Only: | . | Amp Main CB 200 |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus 225 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | . | Ground Bus X |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | KVA/Phase B | KVA/Phase C | CKT No. | CKT No. | KVA/Phase A | KVA/Phase B | KVA/Phase C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Student Lighting | 20 | 0.83 | | | 1 | 2 | 1.70 | | | 20 | Staff &Faculty Lighting | 2 |
| 3 | Electroactive Poly Lighting | 20 | | 1.60 | | 3 | 4 | | 1.90 | | 20 | Student Lighting | 4 |
| 5 | Organic Elec & Pho Lighting | 20 | | | 1.60 | 5 | 6 | | | 1.90 | 20 | Student Lighting | 6 |
| 7 | Dry Lab A&B, Staff Lighting | 20 | 1.41 | | | 7 | 8 | 2.20 | | | 20 | Staff Lighting | 8 |
| 9 | Staff Admin, Kitchen Lighitng | 20 | | 1.23 | | 9 | 10 | | 1.32 | | 20 | Conference Room Lighting | 10 |
| 11 | Dry Lab, Misc. Comp. Lighting | 20 | | | 1.28 | 11 | 12 | | | 1.52 | 20 | Conference Room Lighting | 12 |
| 13 | Corridor Lighting | 20 | 1.60 | | | 13 | 14 | | | | 20 | Spare | 14 |
| 15 | Corridor Lighitng | 20 | | 1.54 | | 15 | 16 | | | | 20 | Spare | 16 |
| 17 | Corridor Lighitng | 20 | | | 1.68 | 17 | 18 | | | | 20 | Spare | 18 |
| 19 | Spare | 20 | | | | 19 | 20 | | | | 20 | Spare | 20 |
| 21 | Spare | 20 | | | | 21 | 22 | | | | 20 | Spare | 22 |
| 23 | Spare | 20 | | | | 23 | 24 | | | | 20 | Spare | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | | | | 20 | Spare | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | Spare | 20 | | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 3.84 | 4.37 | 4.56 | 3.90 3.22 3.42 | | Subtotals (kVA) |
| Total Loads: | Phase A: | 7.74 kVA | | | 80 % | | Demand Factor |
| | Phase B: | 7.59 kVA | | | 18.65 kVA | | Demand Load |
| | Phase C: | 7.98 kVA | | | 23.31 kVA | | Load x 1.25 |
| Total Connected Load: | | 23.31 kVA | | | 28.07 A | | Demand Amps |

Figure 156: Existing Panel Schedule HL-3D

## HLE-3B

### BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | |
|---|---|---|---|---|---|---|
| **Panel Name: HLE-3B** | Mounting: Surface: | X | Main Lugs Only: | . | Amp Main CB | 100 |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus | 100 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | . | Ground Bus | X |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus | . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Stair W1 Lighting | 20 | 1.02 | | | 1 | 2 | 2.27 | | | 20 | Toilet & Corridor Lighting | 2 |
| 3 | Stair W1 Lighting | 20 | | 1.45 | | 3 | 4 | | 0.90 | | 20 | Exit Sign | 4 |
| 5 | Stair W2 Lighting | 20 | | | 0.58 | 5 | 6 | | | 0.28 | 20 | Warning Light | 6 |
| 7 | Stair W2 Lighting | 20 | 0.29 | | | 7 | 8 | | | | 20 | Spare | 8 |
| 9 | Café/Commons Lighting | 20 | | 0.70 | | 9 | 10 | | | | 20 | Spare | 10 |
| 11 | Spare | 20 | | | | 11 | 12 | | | | 20 | Spare | 12 |
| 13 | Spare | 20 | | | | 13 | 14 | | | | 20 | Spare | 14 |
| 15 | Spare | 20 | | | | 15 | 16 | | | | 20 | Spare | 16 |
| 17 | Spare | 20 | | | | 17 | 18 | | | | 20 | Spare | 18 |
| 19 | Spare | 20 | | | | 19 | 20 | | | | 20 | Spare | 20 |
| 21 | Spare | 20 | | | | 21 | 22 | | | | 20 | Spare | 22 |
| 23 | Spare | 20 | | | | 23 | 24 | | | | 20 | Spare | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | | | | 20 | Spare | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | Spare | 20 | | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | |
|---|---|---|---|---|
| Subtotals (kVA): | | 1.31 | 2.15 | 0.58 |
| Total Loads: | Phase A: | 3.58 kVA | | |
| | Phase B: | 3.05 kVA | | |
| | Phase C: | 0.86 kVA | | |
| Total Connected Load: | | 7.49 kVA | | |

| | | | |
|---|---|---|---|
| 2.27 | 0.90 | 0.28 | Subtotals (kVA) |
| 60 % | | | Demand Factor |
| 4.494 kVA | | | Demand Load |
| 5.618 kVA | | | Load x 1.25 |
| 6.765 A | | | Demand Amps |

**Figure 157: Existing Panel Schedule HLE-3B.**

## HLE-3D

# BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| **Panel Name: HLE-3D** | Mounting: Surface: | X | Main Lugs Only: | . | Amp Main CB 100 |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus 225 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | . | Ground Bus X |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Exit Sign | 20 | 0.10 | | | 1 | 2 | 1.02 | | | 20 | Stair N-1 Lighting | 2 |
| 3 | Toilet & Corridor Lighting | 20 | | 2.16 | | 3 | 4 | | 1.46 | | 20 | Stair N-1 Lighting | 4 |
| 5 | Organic Elec & Pho, Lab Lighting | 20 | | | 2.30 | 5 | 6 | | | | 20 | Spare | 6 |
| 7 | Spare | 20 | | | | 7 | 8 | | | | 20 | Spare | 8 |
| 9 | Spare | 20 | | | | 9 | 10 | | | | 20 | Spare | 10 |
| 11 | Spare | 20 | | | | 11 | 12 | | | | 20 | Spare | 12 |
| 13 | Spare | 20 | | | | 13 | 14 | | | | 20 | Spare | 14 |
| 15 | Spare | 20 | | | | 15 | 16 | | | | 20 | Spare | 16 |
| 17 | Spare | 20 | | | | 17 | 18 | | | | 20 | Spare | 18 |
| 19 | Spare | 20 | | | | 19 | 20 | | | | 20 | Spare | 20 |
| 21 | Spare | 20 | | | | 21 | 22 | | | | 20 | Spare | 22 |
| 23 | Spare | 20 | | | | 23 | 24 | | | | 20 | Spare | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | | | | 20 | Spare | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | | | 4.94 | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Panel LE-3D Via XFMR 'TRE-LE-3D' | 50 | | 3.80 | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | | | | | 3.80 | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | 5.04 | 5.96 | 6.1 | | 1.02 | 1.46 | 0 | Subtotals (kVA) |
| Total Loads: | Phase A: | 6.06 kVA | | | 60 % | | | Demand Factor |
| | Phase B: | 7.42 kVA | | | 11.75 kVA | | | Demand Load |
| | Phase C: | 6.10 kVA | | | 14.69 kVA | | | Load x 1.25 |
| Total Connected Load: | 19.58 kVA | | | | 17.68 A | | | Demand Amps |

Figure 158: Existing Panel Schedule HLE-3D.

## Panel Redesigns

The Millennium Science Complex has an electrical system designed for expansion. Over 60% of the circuits throughout the building are spare loads. The calculation from the panelboard worksheets that were provided has been altered to account for the inevitable expansion of the building. The panelboard worksheets have been primarily altered to design feeders and main circuit breakers (if applicable) for the redesigned panels.

Spare capacity has been addressed in a "worst-case scenario" situation. All lighting panels are at 277V, leaving the calculation for 20A spare loads as follows:

- 20A x 0.8 (NEC max loading of current protection device) = 16A Max connected load
- 16A x 0.8 (Good Engineering Practice) = 12.8A Max connected load
- 12.8A * 277V = 3546.6VA
- 3.5kVA will be used as spare loads in panelboard worksheets for sizing MCB's and feeder sizes.

**Table 50: Panelboard Redesign Summary.**

| Panelboard | Original Design Load (A) | Calculated Design Load (kVA) | Calculated DF | Calculated Design Load (A) |
|---|---|---|---|---|
| LCP-1 | 25.28 | 20.65 | 0.82 | 25.51 |
| LCPE-1 | 4.48 | 3.50 | 0.80 | 4.21 |
| HL-3B | 57.25 | 38.19 | 0.90 | 51.96 |
| HLE-3B | 9.02 | 6.37 | 0.91 | 8.75 |
| HL-3D | 28.07 | 16.65 | 0.92 | 23.14 |
| HLE-3D | 17.68 | 18.56 | 0.84 | 25.50 |

## LCP-1

**PANELBOARD SIZING WORKSHEET**

| | | | |
|---|---|---|---|
| Panel Tag-------------------------> | LCP-1 | Panel Location: | N-P052 |
| Nominal Phase to Neutral Voltage-------> | 277 | Phase: | 3 |
| Nominal Phase to Phase Voltage--------> | 480 | Wires: | 4 |

| Pos | Ph. | Load Type | Cat. | Location | Load | Units | I. PF | Watts | VA | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Zone 1 LS Lobby Lighting | 3 | | 0.42 | kva | 0.80 | 336 | 420 | |
| 2 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 3 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 4 | B | Zone 19 Site Lighting | 4 | | 0.94 | kva | 0.90 | 850 | 944 | Site Post Lighting |
| 5 | C | L.S. Sidewalk Lighting | 4 | L.S. | 0.55 | kva | 0.90 | 499 | 554 | |
| 6 | C | Zone 20 Site Lighitng | 4 | | 1.06 | kva | 0.90 | 956 | 1062 | Site Post Lighting |
| 7 | A | Zoen 4 LS Lobby Lighting | 3 | | 0.31 | kva | 0.80 | 248 | 310 | |
| 8 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | Removed Circuit |
| 9 | B | Zone 5 LS Lobby Lighting | 3 | | 0.56 | kva | 0.80 | 448 | 560 | |
| 10 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 11 | C | L.S. Uplighting | 4 | L.S. | 0.95 | kva | 0.90 | 856 | 951 | |
| 12 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 13 | A | Zone 7 ML Lobby Lighting | 3 | | 0.84 | kva | 0.80 | 672 | 840 | |
| 14 | A | West Octulous | 3 | | 0.71 | kva | 0.90 | 643 | 715 | |
| 15 | B | Zone 8 ML Lobby Lighitng | 3 | | 0.56 | kva | 0.80 | 448 | 560 | |
| 16 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 17 | C | L.S. Entry Wall Washing | 4 | L.S. | 0.62 | kva | 0.80 | 492 | 616 | |
| 18 | C | North Octulous | 3 | | 0.66 | kva | 0.80 | 524 | 655 | |
| 19 | A | Spare | 9 | | 0.00 | kva | 0.80 | 0 | 0 | |
| 20 | A | Zone 27 Site Lighting | 3 | | 0.05 | kva | 0.80 | 40 | 50 | |
| 21 | B | L.S. Entry Downlighting | 4 | L.S. | 0.43 | kva | 0.80 | 341 | 427 | |
| 22 | B | Zone 28 Site Lighting | 3 | | 0.40 | kva | 0.80 | 320 | 400 | |
| 23 | C | Zone 12 ML Lobby Lighting | 3 | | 0.31 | kva | 0.80 | 248 | 310 | |
| 24 | C | M.S. Entry Downlighting | 4 | M.S. | 0.43 | kva | 0.80 | 341 | 427 | |
| 25 | A | South Octulous | 3 | | 0.66 | kva | 0.80 | 524 | 655 | |
| 26 | A | M.S. Entry Wall Washing | 4 | M.S. | 0.43 | kva | 0.80 | 341 | 427 | |
| 27 | B | East Octulous | 3 | | 0.71 | kva | 0.80 | 572 | 715 | |
| 28 | B | M.S. Uplighting | 4 | M.S. | 1.06 | kva | 0.80 | 845 | 1057 | |
| 29 | C | Zone 15 Site Lighting | 3 | | 2.10 | kva | 0.80 | 1680 | 2100 | |
| 30 | C | M.S. Sidewalk | 4 | M.S. | 0.62 | kva | 0.80 | 492 | 616 | |
| 31 | A | Zone 16 Site Lighting | 3 | | 2.10 | kva | 0.80 | 1680 | 2100 | |
| 32 | A | Bridge Downlighting | 3 | | 0.32 | kva | 0.80 | 256 | 320 | |
| 33 | B | Zone 17 Site Lighting | 3 | | 1.90 | kva | 0.80 | 1520 | 1900 | |
| 34 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | Removed Circuit |
| 35 | C | Zone 35 ML Lobby Lighting | 3 | | 0.46 | kva | 0.80 | 368 | 460 | |
| 36 | C | Zone 36 LS Lobby Lighting | 3 | | 0.42 | kva | 0.80 | 336 | 420 | |
| 37 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 38 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 39 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 40 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 41 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| 42 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | |
| PANEL TOTAL | | | | | | | | 53.3 | 66.1 | Amps= 79.5 |

| PHASE LOADING | | kW | kVA | % | Amps |
|---|---|---|---|---|---|
| PHASE TOTAL | A | 15.9 | 19.8 | 31% | 71.6 |
| PHASE TOTAL | B | 22.1 | 27.6 | 43% | 99.5 |
| PHASE TOTAL | C | 15.2 | 17.3 | 27% | 62.3 |

| LOAD CATAGORIES | | Connected kW | Connected kVA | DF | Demand kW | Demand kVA | PF | | Ver. 104 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | receptacles | 0.0 | 0.0 | | 0.0 | 0.0 | | | |
| 2 | computers | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 3 | fluorescent lighting | 10.9 | 13.5 | 1.00 | 10.9 | 13.5 | 0.81 | | |
| 4 | Metal Halide lighting | 6.0 | 7.1 | 1.00 | 6.0 | 7.1 | 0.85 | | |
| 5 | incandescent lighting | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 6 | HVAC fans | 0.0 | 0.0 | 0.80 | 0.0 | 0.0 | | | |
| 7 | heating | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 8 | kitchen equipment | 0.0 | 0.0 | 0.60 | 0.0 | 0.0 | | | |
| 9 | Spare Load | 36.4 | 45.5 | 0.60 | 21.8 | 27.3 | 0.80 | | |
| | Total Demand Loads | | | | 38.7 | 47.9 | | | |
| | Spare Capacity | 0% | | | 0.0 | 0.0 | | | |
| | Total Design Loads | | | | 38.7 | 47.9 | 0.81 | Amps= | 57.60 |

| | |
|---|---|
| **Default Power Factor =** | 0.80 |
| **Default Demand Factor =** | 100 % |

**Figure 159: LCP-1 Panelboard Worksheet.**

Building Stimulus

## BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | |
|---|---|---|---|---|---|---|
| **Panel Name: LCP-1** | Mounting: Surface: | X | Main Lugs Only: | X | Amp Main CB | . |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus | 225 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | X | Ground Bus | . |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus | . |

| | CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * | 1 | Zone 1 LS Lobby Lighting | 20 | 0.42 | | | 1 | 2 | 0.00 | | | 20 | Spare | 2 | |
| | 3 | Spare | 20 | | 0.00 | | 3 | 4 | | 1.05 | | 20 | Zone 19 Site Lighting | 4 | * |
| * | 5 | L.S. Sidewalk Lighting | 20 | | | 0.62 | 5 | 6 | | | 1.18 | 20 | Zone 20 Site Lighting | 6 | * |
| * | 7 | Zone 4 LS Lobby Lighting | 20 | 0.31 | | | 7 | 8 | 0.00 | | | 20 | Spare | 8 | |
| * | 9 | Zone 5 LS Lobby Lighting | 20 | | 0.56 | | 9 | 10 | | 0.00 | | 20 | Spare | 10 | |
| * | 11 | L.S. Uplighting | 20 | | | 1.06 | 11 | 12 | | | 0.00 | 20 | Spare | 12 | |
| * | 13 | Zone 7 ML Lobby Lighting | 20 | 0.84 | | | 13 | 14 | 0.71 | | | 20 | West Octulous | 14 | * |
| * | 15 | Zone 8 ML Lobby Lighting | 20 | | 0.56 | | 15 | 16 | | 0.00 | | 20 | Spare | 16 | |
| * | 17 | L.S. Entry Wall Washing | 20 | | | 0.31 | 17 | 18 | | | 0.66 | 20 | North Octulous | 18 | * |
| | 19 | Spare | 20 | 0.00 | | | 19 | 20 | 0.05 | | | 20 | Zone 27 Site Lighting | 20 | * |
| * | 21 | L.S. Entry Downlighting | 20 | | 0.43 | | 21 | 22 | | 0.40 | | 20 | Zone 28 Site Lighitng | 22 | * |
| * | 23 | Zone 12 ML Lobby Lighting | 20 | | | 0.31 | 23 | 24 | | | 0.43 | 20 | M.S. Entry Downlighting | 24 | * |
| * | 25 | South Octulous | 20 | 0.66 | | | 25 | 26 | 0.43 | | | 20 | M.S. Entry Wall Washing | 26 | * |
| * | 27 | East Octulous | 20 | | 0.71 | | 27 | 28 | | 1.06 | | 20 | M.S. Uplighting | 28 | * |
| * | 29 | Zone 15 Site Lighting | 20 | | | 2.10 | 29 | 30 | | | 0.62 | 20 | M.S. Sidewalk | 30 | * |
| * | 31 | Zone 16 Site Lighting | 20 | 2.10 | | | 31 | 32 | 0.32 | | | 20 | Bridge Downlighting | 32 | * |
| * | 33 | Zone 17 Site Lighting | 20 | | 1.90 | | 33 | 34 | | 0.00 | | 20 | Spare | 34 | |
| * | 35 | Zone 35 ML Lobby Lighting | 20 | | | 0.46 | 35 | 36 | | | 0.42 | 20 | Zone 36 LS Lobby Lighting | 36 | * |
| | 37 | Spare | 20 | 0.00 | | | 37 | 38 | 0.00 | | | 20 | Spare | 38 | |
| | 39 | Spare | 20 | | 0.00 | | 39 | 40 | | 0.00 | | 20 | Spare | 40 | |
| | 41 | Spare | 20 | | | 0.00 | 41 | 42 | | | 0.00 | 20 | Spare | 42 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | 4.33 | 4.16 | 4.85 | | 1.51 | 2.51 | 3.30 | Subtotals (kVA) |
| Total Loads: | Phase A: | 5.84 kVA | | | 82.05 % | | | Demand Factor |
| | Phase B: | 6.67 kVA | | | 16.95 kVA | | | Demand Load |
| | Phase C: | 8.15 kVA | | | 21.18 kVA | | | Load x 1.25 |
| Total Connected Load: | 20.65 kVA | | | | 25.51 A | | | Demand Amps |

*Denotes Programmable Remote Control Breaker

**Figure 160: Redesigned Panel LCP-1.**

| LCP-1 | | |
|---|---|---|
| Tag | | LCP-1 |
| Feed From | | MDP-1E1 |
| Voltage System | | 277/480V |
| Calculated Design Load (kW) | | 38.72 |
| Calculated Power Factor | | 0.81 |
| Calculated Design Load (kVA) | | 47.87 |
| Calculated Design Load (A) | | 57.60 |
| Feeder Protection Size | | 75 |
| | Phase | (3) #4 |
| | Neutral | #4 |
| | Ground | #8 |
| Wire Area (Sq. in.) | | |
| | Each Phase | 0.0824 |
| | Total - All Phases | 0.2472 |
| | Nuetral | 0.0824 |
| | Ground | 0.0366 |
| | Total - All Wires | 0.3662 |
| Minimum Conduit Area (Sq. In.) (Above x 2.5) | | 0.9155 |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Feeder Length | | 10 |
| Final Voltage Drop (V) | | 0.4 |
| Final Voltage Drop (%) | | 0.1 |
| Feeder Re-sizing | | No |

**Figure 161: LCP-1 Feeder Worksheet.**

LCPE-1

**PANELBOARD SIZING WORKSHEET**

| | | | |
|---|---|---|---|
| Panel Tag-------------------------> | LCPE-1 | Panel Location: | N-P052 |
| Nominal Phase to Neutral Voltage-------> | 277 | Phase: | 3 |
| Nominal Phase to Phase Voltage--------> | 480 | Wires: | 4 |

| Pos | Ph. | Load Type | Cat. | Location | Load | Units | I. PF | Watts | VA | Remarks | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 2 | A | Zone 42 Exterior Lighting | 3 | | 0.22 | kva | 0.80 | 176 | 220 | | |
| 3 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 4 | B | Zone 41 M. Lobby Lighting | 3 | | 0.23 | kva | 0.80 | 184 | 230 | | |
| 5 | C | Zone 37 LS Lobby Lighting | 3 | | 0.23 | kva | 0.80 | 184 | 230 | | |
| 6 | C | Zone 43 Exterior Lighting | 3 | | 0.17 | kva | 0.80 | 136 | 170 | | |
| 7 | A | Sidewalk Downlighting | 3 | | 0.48 | kva | 0.80 | 384 | 480 | | |
| 8 | A | Loading Dock | 3 | | 0.77 | kva | 0.80 | 616 | 770 | | |
| 9 | B | Zone 39 Exterior Lighting | 3 | | 0.70 | kva | 0.80 | 560 | 700 | | |
| 10 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 11 | C | Zone 40 Exterior Lighting | 3 | | 0.70 | kva | 0.80 | 560 | 700 | | |
| 12 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 13 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 14 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 15 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 16 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 17 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 18 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 19 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 20 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 21 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 22 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 23 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 24 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 25 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 26 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 27 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 28 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 29 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 30 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 31 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 32 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 33 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 34 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 35 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 36 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 37 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 38 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 39 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 40 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 41 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 42 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| PANEL TOTAL | | | | | | | | 98.0 | 122.5 | Amps= | 147.4 |

| PHASE LOADING | | kW | kVA | % | Amps |
|---|---|---|---|---|---|
| PHASE TOTAL | A | 32.0 | 40.0 | 33% | 144.3 |
| PHASE TOTAL | B | 34.3 | 42.9 | 35% | 155.0 |
| PHASE TOTAL | C | 31.7 | 38.2 | 32% | 137.9 |

| LOAD CATAGORIES | | Connected | | | Demand | | | | Ver. 104 |
|---|---|---|---|---|---|---|---|---|---|
| | | kW | kVA | DF | kW | kVA | PF | | |
| 1 | receptacles | 0.0 | 0.0 | | 0.0 | 0.0 | | | |
| 2 | computers | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 3 | Metal Halide Lighitng | 2.8 | 3.5 | 1.00 | 2.8 | 3.5 | 0.80 | | |
| 4 | HID lighting | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 5 | incandescent lighting | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 6 | HVAC fans | 0.0 | 0.0 | 0.80 | 0.0 | 0.0 | | | |
| 7 | heating | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 8 | kitchen equipment | 0.0 | 0.0 | 0.60 | 0.0 | 0.0 | | | |
| 9 | Spare Load | 95.2 | 119.0 | 0.60 | 57.1 | 71.4 | 0.80 | | |
| | Total Demand Loads | | | | 59.9 | 74.9 | | | |
| | Spare Capacity | | | | 0.0 | 0.0 | | | |
| | Total Design Loads | | | | 59.9 | 74.9 | 0.80 | Amps= | 90.1 |

| | |
|---|---|
| **Default Power Factor =** | 0.80 |
| **Default Demand Factor =** | 100 % |

**Figure 162: LCPE-1 Panel Worksheet.**

## BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | |
|---|---|---|---|---|---|---|
| **Panel Name: LCPE-1** | Mounting: Surface: | X | Main Lugs Only: | . | Amp Main CB | 100 |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus | 100 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | . | Ground Bus | . |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus | . |

| | CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | Spare | 20 | 0.00 | | | 1 | 2 | 0.22 | | | 20 | Zone 42 Exterior Lighting | 2 | * |
| | 3 | Spare | 20 | | 0.00 | | 3 | 4 | | 0.23 | | 20 | Zone 41 M. Lobby Lighting | 4 | * |
| * | 5 | Zone 37 LS Lobby Lighting | 20 | | | 0.23 | 5 | 6 | | | 0.17 | 20 | Zone 43 Exterior Lighting | 6 | * |
| * | 7 | Sidewalk Downlighting | 20 | 0.48 | | | 7 | 8 | 0.77 | | | 20 | Loading Dock | 8 | * |
| * | 9 | Zone 39 Exterior Lighting | 20 | | 0.70 | | 9 | 10 | | 0.00 | | 20 | Spare | 10 | |
| * | 11 | Zone 40 Exterior Lighting | 20 | | | 0.70 | 11 | 12 | | | 0.00 | 20 | Spare | 12 | |
| | 13 | Spare | 20 | 0.00 | | | 13 | 14 | 0.00 | | | 20 | Spare | 14 | |
| | 15 | Spare | 20 | | 0.00 | | 15 | 16 | | 0.00 | | 20 | Spare | 16 | |
| | 17 | Spare | 20 | | | 0.00 | 17 | 18 | | | 0.00 | 20 | Spare | 18 | |
| | 19 | Spare | 20 | 0.00 | | | 19 | 20 | 0.00 | | | 20 | Spare | 20 | |
| | 21 | Spare | 20 | | 0.00 | | 21 | 22 | | 0.00 | | 20 | Spare | 22 | |
| | 23 | Spare | 20 | | | 0.00 | 23 | 24 | | | 0.00 | 20 | Spare | 24 | |
| | 25 | Spare | 20 | 0.00 | | | 25 | 26 | 0.00 | | | 20 | Spare | 26 | |
| | 27 | Spare | 20 | | 0.00 | | 27 | 28 | | 0.00 | | 20 | Spare | 28 | |
| | 29 | Spare | 20 | | | 0.00 | 29 | 30 | | | 0.00 | 20 | Spare | 30 | |
| | 31 | Spare | 20 | 0.00 | | | 31 | 32 | 0.00 | | | 20 | Spare | 32 | |
| | 33 | Spare | 20 | | 0.00 | | 33 | 34 | | 0.00 | | 20 | Spare | 34 | |
| | 35 | Spare | 20 | | | 0.00 | 35 | 36 | | | 0.00 | 20 | Spare | 36 | |
| | 37 | Spare | 20 | 0.00 | | | 37 | 38 | 0.00 | | | 20 | Spare | 38 | |
| | 39 | Spare | 20 | | 0.00 | | 39 | 40 | | 0.00 | | 20 | Spare | 40 | |
| | 41 | Spare | 20 | | | 0.00 | 41 | 42 | | | 0.00 | 20 | Spare | 42 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 0.48 | 0.70 | 0.93 | 0.99 | 0.23 | 0.17 | Subtotals (kVA) |
| Total Loads: | Phase A: | 1.47 kVA | | | 80.00 % | | | Demand Factor |
| | Phase B: | 0.93 kVA | | | 2.80 kVA | | | Demand Load |
| | Phase C: | 1.10 kVA | | | 3.5 kVA | | | Load x 1.25 |
| Total Connected Load: | 3.5 kVA | | | | 4.215 A | | | Demand Amps |

*Denotes Programmable Remote Control Breaker

**Figure 163: Redesigned LCPE-1 Panel.**

| LCPE-1 | | |
|---|---|---|
| Tag | | LCPE-1 |
| Feed From | | HLE-0D |
| Voltage System | | 277/480V |
| Calculated Design Load (kW) | | 59.92 |
| Calculated Power Factor | | 0.80 |
| Calculated Design Load (kVA) | | 74.90 |
| Calculated Design Load (A) | | 90.13 |
| Feeder Protection Size | | 100 |
| | Phase | (3) #3 |
| | Neutral | #3 |
| | Ground | #8 |
| Wire Area (Sq. in.) | | |
| | Each Phase | 0.0973 |
| | Total - All Phases | 0.2919 |
| | Nuetral | 0.0973 |
| | Ground | 0.0366 |
| | Total - All Wires | 0.4258 |
| Minimum Conduit Area (Sq. In.) (Above x 2.5) | | 1.0645 |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Feeder Length | | 10 |
| Final Voltage Drop (V) | | 0.3 |
| Final Voltage Drop (%) | | 0.1 |
| Feeder Re-sizing | | No |

**Figure 164: LCPE-1 Feeder Worksheet.**

## HL-3B

| PANELBOARD SIZING WORKSHEET | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Panel Tag-------------------------> | | | HL-3B | Panel Location: | | W-P338 | | | |
| | | Nominal Phase to Neutral Voltage-------> | | | 277 | Phase: | | | 3 | | |
| | | Nominal Phase to Phase Voltage--------> | | | 480 | Wires: | | | 4 | | |
| Pos | Ph. | Load Type | Cat. | Location | Load | Units | I. PF | Watts | VA | Remarks | |
| 1 | A | Neurophts-Invitro Lighting | 3 | | 2.21 | kva | 0.90 | 1989 | 2210 | | |
| 2 | A | Neurophts-Invitro Lighting | 3 | | 2.21 | kva | 0.90 | 1989 | 2210 | | |
| 3 | B | Neurophts-Invitro Lighting | 3 | | 1.83 | kva | 0.90 | 1647 | 1830 | | |
| 4 | B | Neurophts-Invitro Lighting | 3 | | 1.83 | kva | 0.90 | 1647 | 1830 | | |
| 5 | C | Optical Imaging Lighting | 3 | | 2.58 | kva | 0.90 | 2322 | 2580 | | |
| 6 | C | Fumehood, Tissue Culture Lighting | 3 | | 2.40 | kva | 0.90 | 2160 | 2400 | | |
| 7 | A | Fumehood, Procedure, Hot Room | 3 | | 2.18 | kva | 0.90 | 1962 | 2180 | | |
| 8 | A | Toilet, Equip Corr. Lighting | 3 | | 1.72 | kva | 0.90 | 1548 | 1720 | | |
| 9 | B | Faculty, Grad Student Lighting | 3 | | 0.50 | kva | 0.90 | 450 | 499 | Office Redesign | |
| 10 | B | Faculty, GMAD Hudson Lighting | 3 | | 1.27 | kva | 0.90 | 1150 | 1274 | Office Redesign | |
| 11 | C | Elec. Equip, Post Doc Lighting | 3 | | 1.74 | kva | 0.90 | 1566 | 1740 | | |
| 12 | C | BCI Treaching, GMAD, Post Doc LTG | 3 | | 1.74 | kva | 0.90 | 1566 | 1740 | | |
| 13 | A | Conference Library Lighitng | 3 | | 1.32 | kva | 0.90 | 1188 | 1320 | | |
| 14 | A | Office, Staff, Kitchen Lighting | 3 | | 1.82 | kva | 0.90 | 1638 | 1820 | | |
| 15 | B | Conference Library Lighting | 3 | | 1.35 | kva | 0.95 | 1278 | 1352 | Conference Room Redesign | |
| 16 | B | Corridor Lighting | 3 | | 1.37 | kva | 0.93 | 1282 | 1372 | Corridor Redesign | |
| 17 | C | Terrace Lighting | 3 | | 1.00 | kva | 0.90 | 900 | 1000 | | |
| 18 | C | Corridor Lighitng | 3 | | 1.02 | kva | 0.94 | 950 | 1015 | Corridor Redesign | |
| 19 | A | Motorized Shades | 3 | | 0.50 | kva | 0.90 | 450 | 500 | | |
| 20 | A | Café/Common Lighitng | 3 | | 1.93 | kva | 0.90 | 1737 | 1930 | | |
| 21 | B | Motorized Shades | 3 | | 0.50 | kva | 0.90 | 450 | 500 | | |
| 22 | B | Café/Common Lighitng | 3 | | 1.67 | kva | 0.90 | 1503 | 1670 | | |
| 23 | C | Motorized Shades | 3 | | 0.50 | kva | 0.90 | 450 | 500 | | |
| 24 | C | Track Lighting | 3 | | 0.60 | kva | 0.90 | 540 | 600 | | |
| 25 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 26 | A | Track Lighting | 3 | | 2.40 | kva | 0.90 | 2160 | 2400 | | |
| 27 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 28 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 29 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 30 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 31 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 32 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 33 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 34 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 35 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 36 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 37 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 38 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 39 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 40 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 41 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 42 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| PANEL TOTAL | | | | | | | | 82.1 | 97.7 | Amps= | 117.6 |
| PHASE LOADING | | | | | | | | kW | kVA | % | Amps |
| | | PHASE TOTAL | A | | | | | 28.7 | 33.8 | 35% | 122.0 |
| | | PHASE TOTAL | B | | | | | 26.2 | 31.3 | 33% | 113.1 |
| | | PHASE TOTAL | C | | | | | 27.3 | 31.2 | 32% | 112.5 |
| LOAD CATAGORIES | | | | Connected | | | Demand | | | | Ver. 104 |
| | | | | kW | kVA | DF | kW | kVA | PF | | |
| 1 | receptacles | | | 0.0 | 0.0 | | 0.0 | 0.0 | | | |
| 2 | computers | | | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 3 | fluorescent lighting | | | 34.5 | 38.2 | 1.00 | 34.5 | 38.2 | 0.90 | | |
| 4 | HID lighting | | | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 5 | incandescent lighting | | | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 6 | HVAC fans | | | 0.0 | 0.0 | 0.80 | 0.0 | 0.0 | | | |
| 7 | heating | | | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 8 | kitchen equipment | | | 0.0 | 0.0 | 0.60 | 0.0 | 0.0 | | | |
| 9 | Spare Load | | | 47.6 | 59.5 | 0.60 | 28.6 | 35.7 | 0.80 | | |
| | | Total Demand Loads | | | | | 63.1 | 73.9 | | | |
| | | Spare Capacity | | 0% | | | 0.0 | 0.0 | | | |
| | | Total Design Loads | | | | | 63.1 | 73.9 | 0.85 | Amps= | 88.9 |

| | |
|---|---|
| **Default Power Factor =** | 0.80 |
| **Default Demand Factor =** | 100 % |

**Figure 165: HL-3B Panelboard Worksheet.**

## BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Panel Name: HL-3B** | Mounting: | Surface: | X | Main Lugs Only: | . | Amp Main CB | 100 |
| 277/480V, 3 Phase, 4 Wire | | Flush: | . | Shunt Trip Main: | . | Amp Bus | 225 |
| 14,000MIN A.I.C. SYM | | In MCC | . | Feed Through: | . | Ground Bus | X |
| Neutral: 100% | Number of Poles: | | 42 | TVSS: | . | Isolated Ground Bus | . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | KVA/Phase B | KVA/Phase C | CKT No. | CKT No. | KVA/Phase A | KVA/Phase B | KVA/Phase C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Nuerophts-Invitro Lighting | 20 | 2.21 | | | 1 | 2 | 2.21 | | | 20 | Nuerophts-Invitro Lighting | 2 |
| 3 | Nuerophts-Invitro Lighting | 20 | | 1.83 | | 3 | 4 | | 1.83 | | 20 | Nuerophts-Invitro Lighting | 4 |
| 5 | Optical Imagimg Lighting | 20 | | | 2.58 | 5 | 6 | | | 2.40 | 20 | Fumehood, Tissue Culture Lighting | 6 |
| 7 | Fumehood Procedure, Hot Room | 20 | 2.18 | | | 7 | 8 | 1.72 | | | 20 | Toilet, Equip Corr. Lighting | 8 |
| 9 | Faculty, Grad Student Lighting | 20 | | 0.50 | | 9 | 10 | | 1.27 | | 20 | Faculty GMAD Hudson Lighting | 10 |
| 11 | Elec. Equipment, Post Doc & Light | 20 | | | 1.74 | 11 | 12 | | | 1.74 | 20 | BCI Teaching, GMAD, Post Doc Lighting | 12 |
| 13 | Conference Library Lighting | 20 | 1.32 | | | 13 | 14 | 1.82 | | | 20 | Office, Staff, Kitchen Lighting | 14 |
| 15 | Conference Library Lighting | 20 | | 1.35 | | 15 | 16 | | 1.37 | | 20 | Corridor Lighting | 16 |
| 17 | Terrace Lighting | 20 | | | 1.00 | 17 | 18 | | | 1.02 | 20 | Corridor Lighting | 18 |
| 19 | Motorized Shades | 20 | 0.50 | | | 19 | 20 | 1.93 | | | 20 | Café/Common Lighting | 20 |
| 21 | Motorized Shades | 20 | | 0.50 | | 21 | 22 | | 1.67 | | 20 | Café/Common Lighting | 22 |
| 23 | Motorized Shades | 20 | | | 0.50 | 23 | 24 | | | 0.60 | 20 | Track Lighitng | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | 2.40 | | | 20 | Track Lighting | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | Spare | 20 | | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | |
|---|---|---|---|---|---|
| Subtotals (kVA): | | 6.21 | 4.18 | 5.82 | |
| Total Loads: | Phase A: | 16.29 kVA | | | |
| | Phase B: | 10.33 kVA | | | |
| | Phase C: | 11.58 kVA | | | |
| Total Connected Load: | | 38.19 kVA | | | |

| | | | | |
|---|---|---|---|---|
| 10.08 | 6.146 | 5.755 | | Subtotals (kVA) |
| 90.39 % | | | | Demand Factor |
| 34.52 kVA | | | | Demand Load |
| 43.15 kVA | | | | Load x 1.25 |
| 51.96 A | | | | Demand Amps |

**Figure 166: Redesigned Panel HL-3B.**

| HL-3B | | |
|---|---|---|
| Tag | | HL-3B |
| Feed From | | MDP-M41 |
| Voltage System | | 277/480V |
| Calculated Design Load (kW) | | 63.08 |
| Calculated Power Factor | | 0.85 |
| Calculated Design Load (kVA) | | 73.89 |
| Calculated Design Load (A) | | 88.92 |
| Feeder Protection Size | | 100 |
| | Phase | (3) #3 |
| | Neutral | #3 |
| | Ground | #8 |
| Wire Area (Sq. in.) | | |
| | Each Phase | 0.0973 |
| | Total - All Phases | 0.2919 |
| | Nuetral | 0.0973 |
| | Ground | 0.0366 |
| | Total - All Wires | 0.4258 |
| Minimum Conduit Area (Sq. In.) (Above x 2.5) | | 1.0645 |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Feeder Length | | 207 ft |
| Final Voltage Drop (V) | | 5.6 |
| Final Voltage Drop (%) | | 2.0 |
| Feeder Re-sizing | | No |

**Figure 167: HL-3B Feeder Worksheet.**

## HLE-3B

### PANELBOARD SIZING WORKSHEET

| Pos | Ph. | Load Type | Cat. | Location | Load | Units | I. PF | Watts | VA | Remarks | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Panel Tag-------------------------> | | | HLE-3B | Panel Location: | | | W-P338 | | |
| | | Nominal Phase to Neutral Voltage-------> | | | 277 | Phase: | | | 3 | | |
| | | Nominal Phase to Phase Voltage--------> | | | 480 | Wires: | | | 4 | | |
| 1 | A | Stair W1 Lighting | 3 | | 1.02 | kva | 0.90 | 918 | 1020 | | |
| 2 | A | Toilet & Corridor Lighting | 3 | | 1.15 | kva | 0.97 | 1114 | 1150 | Corridor Redesign | |
| 3 | B | Stair W1 Lighting | 3 | | 1.45 | kva | 0.90 | 1305 | 1450 | | |
| 4 | B | Exit Sign | 3 | | 0.90 | kva | 0.90 | 810 | 900 | | |
| 5 | C | Stair W2 Lighting | 3 | | 0.58 | kva | 0.90 | 522 | 580 | | |
| 6 | C | Warning Light | 3 | | 0.28 | kva | 0.90 | 252 | 280 | | |
| 7 | A | Stair W2 Lighting | 3 | | 0.29 | kva | 0.90 | 261 | 290 | | |
| 8 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 9 | B | Café/Commons Lighting | 3 | | 0.70 | kva | 0.90 | 630 | 700 | | |
| 10 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 11 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 12 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 13 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 14 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 15 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 16 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 17 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 18 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 19 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 20 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 21 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 22 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 23 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 24 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 25 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 26 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 27 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 28 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 29 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 30 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 31 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 32 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 33 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 34 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 35 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 36 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 37 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 38 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 39 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 40 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 41 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 42 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| PANEL TOTAL | | | | | | | | 101.0 | 125.4 | Amps= | 150.9 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PHASE LOADING | | | | | | | kW | kVA | % | Amps |
| PHASE TOTAL | | A | | | | | 33.1 | 41.0 | 33% | 147.9 |
| PHASE TOTAL | | B | | | | | 33.5 | 41.6 | 34% | 150.0 |
| PHASE TOTAL | | C | | | | | 34.4 | 41.5 | 33% | 149.7 |
| LOAD CATAGORIES | | | Connected | | | Demand | | | | Ver. 104 |
| | | | kW | kVA | DF | kW | kVA | PF | | |
| 1 | receptacles | | 0.0 | 0.0 | | 0.0 | 0.0 | | | |
| 2 | computers | | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 3 | fluorescent lighting | | 5.8 | 6.4 | 1.00 | 5.8 | 6.4 | 0.91 | | |
| 4 | HID lighting | | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 5 | incandescent lighting | | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 6 | HVAC fans | | 0.0 | 0.0 | 0.80 | 0.0 | 0.0 | | | |
| 7 | heating | | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 8 | kitchen equipment | | 0.0 | 0.0 | 0.60 | 0.0 | 0.0 | | | |
| 9 | Spare Load | | 95.2 | 119.0 | 0.80 | 76.2 | 95.2 | 0.80 | | |
| | Total Demand Loads | | | | | 82.0 | 101.6 | | | |
| | Spare Capacity | | 0% | | | 0.0 | 0.0 | | | |
| | Total Design Loads | | | | | 82.0 | 101.6 | 0.81 | Amps= | 122.23 |

| | |
|---|---|
| **Default Power Factor =** | 0.80 |
| **Default Demand Factor =** | 100 % |

**Figure 168: HLE-3B Panelboard Worksheet.**

## BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| **Panel Name: HLE-3B** | Mounting: Surface: | X | Main Lugs Only: | . | Amp Main CB 125 |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus 125 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | . | Ground Bus X |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Stair W1 Lighting | 20 | 1.02 | | | 1 | 2 | 1.15 | | | 20 | Toilet & Corridor Lighting | 2 |
| 3 | Stair W1 Lighting | 20 | | 1.45 | | 3 | 4 | | 0.90 | | 20 | Exit Sign | 4 |
| 5 | Stair W2 Lighting | 20 | | | 0.58 | 5 | 6 | | | 0.28 | 20 | Warning Light | 6 |
| 7 | Stair W2 Lighting | 20 | 0.29 | | | 7 | 8 | | | | 20 | Spare | 8 |
| 9 | Café/Commons Lighting | 20 | | 0.70 | | 9 | 10 | | | | 20 | Spare | 10 |
| 11 | Spare | 20 | | | | 11 | 12 | | | | 20 | Spare | 12 |
| 13 | Spare | 20 | | | | 13 | 14 | | | | 20 | Spare | 14 |
| 15 | Spare | 20 | | | | 15 | 16 | | | | 20 | Spare | 16 |
| 17 | Spare | 20 | | | | 17 | 18 | | | | 20 | Spare | 18 |
| 19 | Spare | 20 | | | | 19 | 20 | | | | 20 | Spare | 20 |
| 21 | Spare | 20 | | | | 21 | 22 | | | | 20 | Spare | 22 |
| 23 | Spare | 20 | | | | 23 | 24 | | | | 20 | Spare | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | | | | 20 | Spare | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | Spare | 20 | | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 1.31 | 2.15 | 0.58 | | 1.15 | 0.90 | 0.28 | Subtotals (kVA) |
| Total Loads: | Phase A: | 2.46 kVA | | | | 91.24 % | | | Demand Factor |
| | Phase B: | 3.05 kVA | | | | 5.812 kVA | | | Demand Load |
| | Phase C: | 0.86 kVA | | | | 7.265 kVA | | | Load x 1.25 |
| Total Connected Load: | | 6.37 kVA | | | | 8.749 A | | | Demand Amps |

Figure 169: Redesigned Panel HLE-3B.

| HLE-3B | | |
|---|---|---|
| Tag | | HLE-3B |
| Feed From | | EDP-L0B |
| Voltage System | | 277/480V |
| Calculated Design Load (kW) | | 81.97 |
| Calculated Power Factor | | 0.81 |
| Calculated Design Load (kVA) | | 101.57 |
| Calculated Design Load (A) | | 122.23 |
| Feeder Protection Size | | 125 |
| | Phase | (3) 3/0 |
| | Neutral | 3/0 |
| | Ground | #4 |
| Wire Area (Sq. in.) | | |
| | Each Phase | 0.2223 |
| | Total - All Phases | 0.6669 |
| | Nuetral | 0.2223 |
| | Ground | 0.0366 |
| | Total - All Wires | 0.9258 |
| Minimum Conduit Area (Sq. In.) (Above x 2.5) | | 2.3145 |
| Conduit Size (NEC Chapter 9, Table 4) | | 2.00" EMT |
| Conduit Size (NEC Chapter 9, Table 4) | | 2.00" EMT |
| Feeder Length | | 290 |
| Final Voltage Drop (V) | | 5.5 |
| Final Voltage Drop (%) | | 2.0 |
| Feeder Re-sizing | | Yes |

Figure 170: HLE-3B feeder worksheet.

## HL-3D

| PANELBOARD SIZING WORKSHEET | | | |
|---|---|---|---|
| Panel Tag-------------------------> | HL-3D | Panel Location: | N-P347 |
| Nominal Phase to Neutral Voltage-------> | 277 | Phase: | 3 |
| Nominal Phase to Phase Voltage--------> | 480 | Wires: | 4 |

| Pos | Ph. | Load Type | Cat. | Location | Load | Units | I. PF | Watts | VA | Remarks | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Student Lighting | 3 | | 0.54 | kva | 1.00 | 537 | 537 | Student Redesign | |
| 2 | A | Staff & Faculty Lighting | 3 | | 1.63 | kva | 0.90 | 1467 | 1626 | Office Redesign | |
| 3 | B | Electroactive Poly Lighting | 3 | | 1.60 | kva | 0.90 | 1440 | 1600 | | |
| 4 | B | Student Lighting | 3 | | 1.18 | kva | 0.94 | 1110 | 1177 | Student Redesign | |
| 5 | C | Organix Elec & Pho Lighting | 3 | | 1.60 | kva | 0.90 | 1440 | 1600 | | |
| 6 | C | Student Lighting | 3 | | 1.18 | kva | 0.90 | 1059 | 1177 | Student Redesign | |
| 7 | A | Dry Lab A&B, Staff Lighting | 3 | | 1.41 | kva | 0.94 | 1330 | 1410 | | |
| 8 | A | Staff Lighting | 3 | | 1.66 | kva | 0.90 | 1496 | 1662 | Office Redesign | |
| 9 | B | Staff Admin, Kitchen Lighting | 3 | | 1.23 | kva | 0.90 | 1107 | 1230 | | |
| 10 | B | Conference Room Lighting | 3 | | 1.35 | kva | 0.95 | 1278 | 1352 | Conference Room Redesign | |
| 11 | C | Dry Lab, Misc. Comp. Lighting | 3 | | 1.28 | kva | 0.90 | 1152 | 1280 | | |
| 12 | C | Conference Room Lighitng | 3 | | 1.52 | kva | 0.90 | 1368 | 1520 | | |
| 13 | A | Corridor Lighitng | 3 | | 0.50 | kva | 1.00 | 504 | 504 | Corridor Redesign | |
| 14 | A | Spare | 9 | | 3.50 | kva | 0.90 | 3150 | 3500 | | |
| 15 | B | Corridor Lighitng | 3 | | 0.90 | kva | 0.93 | 842 | 904 | Corridor Redesign | |
| 16 | B | Spare | 9 | | 3.50 | kva | 0.90 | 3150 | 3500 | | |
| 17 | C | Corridor Lighitng | 3 | | 1.14 | kva | 0.93 | 1060 | 1142 | Corridor Redesign | |
| 18 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 19 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 20 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 21 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 22 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 23 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 24 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 25 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 26 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 27 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 28 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 29 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 30 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 31 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 32 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 33 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 34 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 35 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 36 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 37 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 38 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 39 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 40 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 41 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 42 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| PANEL TOTAL | | | | | | | | 93.5 | 113.2 | Amps= | 136.2 |

| PHASE LOADING | | kW | kVA | % | Amps |
|---|---|---|---|---|---|
| PHASE TOTAL | A | 30.9 | 37.2 | 33% | 134.4 |
| PHASE TOTAL | B | 31.3 | 37.8 | 34% | 136.3 |
| PHASE TOTAL | C | 31.3 | 36.8 | 33% | 132.9 |

| LOAD CATAGORIES | | Connected | | | Demand | | | | Ver. 104 |
|---|---|---|---|---|---|---|---|---|---|
| | | kW | kVA | DF | kW | kVA | PF | | |
| 1 | receptacles | 0.0 | 0.0 | | 0.0 | 0.0 | | | |
| 2 | computers | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 3 | fluorescent lighting | 17.2 | 18.72 | 1.00 | 17.2 | 18.7 | 0.92 | | |
| 4 | HID lighting | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 5 | incandescent lighting | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 6 | HVAC fans | 0.0 | 0.0 | 0.80 | 0.0 | 0.0 | | | |
| 7 | heating | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 8 | kitchen equipment | 0.0 | 0.0 | 0.60 | 0.0 | 0.0 | | | |
| 9 | Spare Load | 76.3 | 94.5 | 0.60 | 45.8 | 56.7 | 0.81 | | |
| | Total Demand Loads | | | | 63.0 | 75.4 | | | |
| | Spare Capacity | 0% | | | 0.0 | 0.0 | | | |
| | Total Design Loads | | | | 63.0 | 75.4 | 0.83 | Amps= | 90.8 |

| | |
|---|---|
| **Default Power Factor =** | 0.80 |
| **Default Demand Factor =** | 100 % |

Figure 171: HL-3D Panelboard Worksheet.

# BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| **Panel Name: HL-3D** | Mounting: Surface: | X | Main Lugs Only: | . | Amp Main CB 100 |
| 277/480V, 3 Phase, 4 Wire | Flush: | . | Shunt Trip Main: | . | Amp Bus 225 |
| 14,000MIN A.I.C. SYM | In MCC | . | Feed Through: | . | Ground Bus X |
| Neutral: 100% | Number of Poles: | 42 | TVSS: | . | Isolated Ground Bus . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | KVA/Phase B | KVA/Phase C | CKT No. | CKT No. | KVA/Phase A | KVA/Phase B | KVA/Phase C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Student Lighting | 20 | 0.39 | | | 1 | 2 | 1.05 | | | 20 | Staff &Faculty Lighting | 2 |
| 3 | Electroactive Poly Lighting | 20 | | 1.60 | | 3 | 4 | | 0.88 | | 20 | Student Lighting | 4 |
| 5 | Organic Elec & Pho Lighting | 20 | | | 1.60 | 5 | 6 | | | 0.88 | 20 | Student Lighting | 6 |
| 7 | Dry Lab A&B, Staff Lghting | 20 | 1.41 | | | 7 | 8 | 0.91 | | | 20 | Staff Lighting | 8 |
| 9 | Staff Admin, Kitchen Lighitng | 20 | | 1.23 | | 9 | 10 | | 1.35 | | 20 | Conference Room Lighting | 10 |
| 11 | Dry Lab, Misc. Comp. Lighting | 20 | | | 1.28 | 11 | 12 | | | 1.52 | 20 | Conference Room Lighting | 12 |
| 13 | Corridor Lighting | 20 | 0.50 | | | 13 | 14 | | | | 20 | Spare | 14 |
| 15 | Corridor Lighitng | 20 | | 0.90 | | 15 | 16 | | | | 20 | Spare | 16 |
| 17 | Corridor Lighitng | 20 | | | 1.14 | 17 | 18 | | | | 20 | Spare | 18 |
| 19 | Spare | 20 | | | | 19 | 20 | | | | 20 | Spare | 20 |
| 21 | Spare | 20 | | | | 21 | 22 | | | | 20 | Spare | 22 |
| 23 | Spare | 20 | | | | 23 | 24 | | | | 20 | Spare | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | | | | 20 | Spare | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | Spare | 20 | | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Spare | 20 | | | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | Spare | 20 | | | | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | 2.30 | 3.73 | 4.02 | 1.97 | 2.23 | 2.40 | Subtotals (kVA) |
| Total Loads: | Phase A: | 4.27 kVA | | 92.33 % | | | Demand Factor |
| | Phase B: | 5.96 kVA | | 15.38 kVA | | | Demand Load |
| | Phase C: | 6.42 kVA | | 19.22 kVA | | | Load x 1.25 |
| Total Connected Load: | | 16.65 kVA | | 23.14 A | | | Demand Amps |

Figure 172: Revised Panel Schedule HL-3D.

| HL-3D | | |
|---|---|---|
| Tag | | HL-3D |
| Feed From | | MDP-M42 |
| Voltage System | | 277/480V |
| Calculated Design Load (kW) | | 62.97 |
| Calculated Power Factor | | 0.83 |
| Calculated Design Load (kVA) | | 75.42 |
| Calculated Design Load (A) | | 90.76 |
| Feeder Protection Size | | 100 |
| | Phase | (3) #3 |
| | Neutral | #3 |
| | Ground | #8 |
| Wire Area (Sq. in.) | | |
| | Each Phase | 0.0973 |
| | Total - All Phases | 0.2919 |
| | Nuetral | 0.0973 |
| | Ground | 0.0366 |
| | Total - All Wires | 0.4258 |
| Minimum Conduit Area (Sq. In.) (Above x 2.5) | | 1.0645 |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Conduit Size (NEC Chapter 9, Table 4) | | 1.25" RMC |
| Feeder Length | | 207 ft |
| Final Voltage Drop (V) | | 5.6 |
| Final Voltage Drop (%) | | 2.0 |
| Feeder Re-sizing | | No |

Figure 173: HL-3D Feeder Worksheet.

## HLE-3D

| PANELBOARD SIZING WORKSHEET | | | |
|---|---|---|---|
| Panel Tag--------------------------> | HLE-3D | Panel Location: | N-P347 |
| Nominal Phase to Neutral Voltage-------> | 277 | Phase: | 3 |
| Nominal Phase to Phase Voltage--------> | 480 | Wires: | 4 |

| Pos | Ph. | Load Type | Cat. | Location | Load | Units | I. PF | Watts | VA | Remarks | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | Exit Sign | 3 | | 0.10 | kva | 0.90 | 90 | 100 | | |
| 2 | A | Stair N-1 Lighting | 3 | | 1.02 | kva | 0.90 | 918 | 1020 | | |
| 3 | B | Toilet & Corridor Lighting | 3 | | 1.10 | kva | 0.97 | 1066 | 1100 | Corridor Redesign | |
| 4 | B | Stair N-1 Lighting | 3 | | 1.45 | kva | 0.90 | 1305 | 1450 | | |
| 5 | C | Office Lighting | 3 | | 2.30 | kva | 0.90 | 2070 | 2300 | *Typo, no offices on this circuit | |
| 6 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 7 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 8 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 9 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 10 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 11 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 12 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 13 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 14 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 15 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 16 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 17 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 18 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 19 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 20 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 21 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 22 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 23 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 24 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 25 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 26 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 27 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 28 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 29 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 30 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 31 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 32 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 33 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 34 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 35 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 36 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 37 | A | Panel LE-3D | 8 | 3 Pole | 4.94 | kva | 1.00 | 4940 | 4940 | | |
| 38 | A | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 39 | B | Panel LE-3D | 8 | 3 Pole | 3.80 | kva | 1.00 | 3800 | 3800 | | |
| 40 | B | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| 41 | C | Panel LE-3D | 8 | 3 Pole | 3.80 | kva | 1.00 | 3800 | 3800 | | |
| 42 | C | Spare | 9 | | 3.50 | kva | 0.80 | 2800 | 3500 | | |
| PANEL TOTAL | | | | | | | | 113.2 | 137.5 | Amps= | 165.5 |
| PHASE LOADING | | | | | | | | kW | kVA | % | Amps |
| | | PHASE TOTAL | A | | | | | 36.7 | 44.6 | 33% | 160.9 |
| | | PHASE TOTAL | B | | | | | 37.0 | 44.9 | 33% | 161.9 |
| | | PHASE TOTAL | C | | | | | 39.5 | 47.4 | 35% | 171.1 |
| LOAD CATAGORIES | | | | Connected | | | Demand | | | | Ver. 104 |
| | | | | kW | kVA | DF | kW | kVA | PF | | |
| 1 | | receptacles | | 0.0 | 0.0 | | 0.0 | 0.0 | | | |
| 2 | | computers | | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 3 | | fluorescent lighting | | 5.4 | 6.0 | 1.00 | 5.4 | 6.0 | 0.91 | | |
| 4 | | HID lighting | | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 5 | | incandescent lighting | | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 | | | |
| 6 | | HVAC fans | | 0.0 | 0.0 | 0.80 | 0.0 | 0.0 | | | |
| 7 | | heating | | 0.0 | 0.0 | 0.70 | 0.0 | 0.0 | | | |
| 8 | | Distribution Panel | | 12.5 | 12.5 | 1.00 | 12.5 | 12.5 | 0.80 | | |
| 9 | | Spare Load | | 95.2 | 119.0 | 0.60 | 57.1 | 71.4 | 0.80 | | |
| | | Total Demand Loads | | | | | 75.1 | 89.9 | | | |
| | | Spare Capacity | | 0% | | | 0.0 | 0.0 | | | |
| | | Total Design Loads | | | | | 75.1 | 89.9 | 0.84 | Amps= | 108.2 |

| | |
|---|---|
| **Default Power Factor =** | 0.80 |
| **Default Demand Factor =** | 100 % |

**Figure 174: Panelboard HLE-3D Worksheet.**

## BRANCH CIRCUIT PANELBOARD SCHEDULE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Panel Name: HLE-3D** | Mounting: | Surface: | X | Main Lugs Only: | . | Amp Main CB | 125 |
| 277/480V, 3 Phase, 4 Wire | | Flush: | . | Shunt Trip Main: | . | Amp Bus | 225 |
| 14,000MIN A.I.C. SYM | | In MCC | . | Feed Through: | . | Ground Bus | X |
| Neutral: 100% | Number of Poles: | | 42 | TVSS: | . | Isolated Ground Bus | . |

| CKT No. | Load | TRIP (Amp) | KVA/Phase A | B | C | CKT No. | CKT No. | KVA/Phase A | B | C | TRIP (Amp) | Load | CKT No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Exit Sign | 20 | 0.10 | | | 1 | 2 | 1.02 | | | 20 | Stair N-1 Lighting | 2 |
| 3 | Toilet & Corridor Lighting | 20 | | 1.14 | | 3 | 4 | | 1.46 | | 20 | Stair N-1 Lighting | 4 |
| 5 | Organic Elec & Pho, Lab Lighting | 20 | | | 2.30 | 5 | 6 | | | | 20 | Spare | 6 |
| 7 | Spare | 20 | | | | 7 | 8 | | | | 20 | Spare | 8 |
| 9 | Spare | 20 | | | | 9 | 10 | | | | 20 | Spare | 10 |
| 11 | Spare | 20 | | | | 11 | 12 | | | | 20 | Spare | 12 |
| 13 | Spare | 20 | | | | 13 | 14 | | | | 20 | Spare | 14 |
| 15 | Spare | 20 | | | | 15 | 16 | | | | 20 | Spare | 16 |
| 17 | Spare | 20 | | | | 17 | 18 | | | | 20 | Spare | 18 |
| 19 | Spare | 20 | | | | 19 | 20 | | | | 20 | Spare | 20 |
| 21 | Spare | 20 | | | | 21 | 22 | | | | 20 | Spare | 22 |
| 23 | Spare | 20 | | | | 23 | 24 | | | | 20 | Spare | 24 |
| 25 | Spare | 20 | | | | 25 | 26 | | | | 20 | Spare | 26 |
| 27 | Spare | 20 | | | | 27 | 28 | | | | 20 | Spare | 28 |
| 29 | Spare | 20 | | | | 29 | 30 | | | | 20 | Spare | 30 |
| 31 | Spare | 20 | | | | 31 | 32 | | | | 20 | Spare | 32 |
| 33 | Spare | 20 | | | | 33 | 34 | | | | 20 | Spare | 34 |
| 35 | Spare | 20 | | | | 35 | 36 | | | | 20 | Spare | 36 |
| 37 | | | 4.94 | | | 37 | 38 | | | | 20 | Spare | 38 |
| 39 | Panel LE-3D Via XFMR 'TRE-LE-3D' | 50 | | 3.80 | | 39 | 40 | | | | 20 | Spare | 40 |
| 41 | | | | | 3.80 | 41 | 42 | | | | 20 | Spare | 42 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subtotals (kVA): | | 5.04 | 4.94 | 6.1 | | 1.02 | 1.46 | 0 | Subtotals (kVA) |
| Total Loads: | Phase A: | 6.06 kVA | | | | 91.26 % | | | Demand Factor |
| | Phase B: | 6.40 kVA | | | | 16.94 kVA | | | Demand Load |
| | Phase C: | 6.10 kVA | | | | 21.17 kVA | | | Load x 1.25 |
| Total Connected Load: | | 18.56 kVA | | | | 25.5 A | | | Demand Amps |

Figure 175: Revised Panel Schedule HLE-3D.

| HLE-3D | | |
|---|---|---|
| Tag | | HLE-3D |
| Feed From | | EDP-L0B |
| Voltage System | | 277/480V |
| Calculated Design Load (kW) | | 75.11 |
| Calculated Power Factor | | 0.84 |
| Calculated Design Load (kVA) | | 89.91 |
| Calculated Design Load (A) | | 108.20 |
| Feeder Protection Size | | 125 |
| | Phase | (3) 300 MCM |
| | Neutral | #300 MCM |
| | Ground | #4 |
| Wire Area (Sq. in.) | | |
| | Each Phase | 0.2679 |
| | Total - All Phases | 0.8037 |
| | Nuetral | 0.2679 |
| | Ground | 0.0366 |
| | Total - All Wires | 1.1082 |
| Minimum Conduit Area (Sq. In.) (Above x 2.5) | | 2.7705 |
| Conduit Size (NEC Chapter 9, Table 4) | | 2" RMC |
| Conduit Size (NEC Table C.1) | | 2" RMC |
| Feeder Length | | 500 |
| Final Voltage Drop (V) | | 4.9 |
| Final Voltage Drop (%) | | 1.8 |
| Feeder Re-sizing | | Yes |

Figure 176: HLE-3D Feeder Worksheet.

## Mechanical

### MAE Course Related Study

As part of Building Stimulus' goal to improve the overall efficiency performance of the Millennium Science Complex, sustainability and energy conservation were a large focus throughout the redesign process. The iconic stature of the MSC yields itself to being a beacon for energy and sustainability use in buildings. This is why a decrease in the dependence of fossil fuel consumption and reduced carbon emissions produced by the Millennium Science Complex was sought after during redesign. After investigating several alternative energy sources, rooftop mounted wind turbines were selected to be utilized for the Complex. It is one of the tallest buildings on campus and is capable of acquiring higher wind speeds due to this height.

Several wind turbine manufacturers were investigated for their applicability with respect to aesthetics and performance. Two companies were narrowed down based on the aforementioned criteria. Those companies were AeroVironment and Cascade Renewable Energy. AeroVironment's Architectural Wind offers a building integrated wind turbine that is attached along the roof line of the building. The ingenuity of the design is that the turbine takes advantage of the wind's acceleration that occurs as it passes over the building's parapet. Based on this special design, the company has received 3 utility patents. According to the manufacturer, this accelerated wind can increase the turbine's electrical power generation by more than 50% compared to locations outside of the acceleration zone. Figure 177 illustrates how the Architectural Wind turbine can be applied to a building's rooftop. This turbine requires at least 2.2 m/s wind velocity to start up the turbine and its rated power is 1000 watts at speeds of 11 m/s or higher.

Figure 177: AeroVironment's Architectural Wind.

Figure 178: Cascade Renewable Energy Swift Wind Turbine.

The Swift wind turbine provided by Cascade Renewable Energy is a more traditional design. While this turbine may not be as aesthetically designed as the architectural wind, it is capable of achieving higher power production outputs. Figure 178 illustrates a typical Swift wind turbine building application. It is a horizontal axis turbine that is capable of being mounted to the structure as well. The turbine requires a wind velocity of 3.58 m/s for start-up, which is slightly higher than Architectural Wind. The peak production for this particular turbine is also higher than Architectural Wind, in which it can attain power outputs of over 1.5 kW at peak production and has a similar power output of 1.0 kW at 11 m/s. Cascade's technical specifications for the turbine estimates an annual energy production of approximately 1200 kWh for 5 m/s annual average wind speed and 1900 kWh for 6 m/s annual average wind speed. This power output is based on just one wind turbine's production.

Based on typical meteorological year (TMY) data for State College, as measured from the University Park Airport from 1991 to 2005, the prevailing wind for the site was determined to be 3.6 m/s measured 250$^{o}$ from North (where North is considered to be 360$^{o}$). This leads to the prevailing wind to be from the westerly direction, which aligns with the apex of the building where the two wings meet: life science and material science. Based on this prevailing wind speed, this site is capable of generating enough velocity to start up both AeroVironment's and Cascade's wind turbines. In order to attain more accurate wind velocity profiles for the Millennium Science Complex, based on flow patterns caused by the structure and surrounding buildings, a computational fluid dynamics (CFD) model was used to determine the profiles. Knowledge from the Master's course, AE 559: Computational Fluid Dynamics was utilized extensively during this analysis to develop the model.

For the analysis, the CFD software, Phoenics, was used to model both the Millennium Science Complex and its surrounding buildings on campus. Developing the physical model for the CFD simulation provided a great opportunity for the inclusion of BIM techniques. Using AutoCad 3D and Revit, the massings for the surrounding buildings and MSC were developed as three dimensional objects, which were then exported as .stl files into

Phoenics. By creating the objects in AutoCad using the existing site plan and utilizing the model developed for MSC in Revit, it saved time during the model development phase. The size and locations were specified in the AutoCad file. Exporting the site and buildings as an .stl allowed attached properties (size and location) to be maintained once it was imported into Phoenics with a domain size of (900, 900, 100). Once the model was setup in Phoenics, the prevailing wind data was included for the boundary conditions, where the reference height was assumed to be 10.0 meters and the ground plane was modeled as a friction boundary. The properties for the simulation were set to be isothermal since the analyzed property of interest is outdoor wind velocity. The turbulence model used during the simulation process was the standard K-ε Chen model. This model was selected based on its reliability and widespread acceptance for the accuracy of the results attained. The numerical scheme set for the simulation was the hybrid scheme.

Several simulations were run to develop the velocity profiles around the Millennium Science Complex. After continuous refinement of the mesh for a grid size of (107, 108, 20), numerical schemes and relaxation factors for the simulation model, the simulation was able to attain a percent mass residual of 0.096%, which is less than 0.1%. This indicates that the solution was able to reach convergence and therefor is can be assumed that the outflow model of the site represents approximate performance of the windflow over the buildings.

Figure 179 and Figure 180 show the Z-plane velocity profiles at heights of 24 m and ground plane, respectively. Based on these profiles, the optimal location for wind turbines for the Millennium Science Complex should be along the buiding’s north and west rooflines.

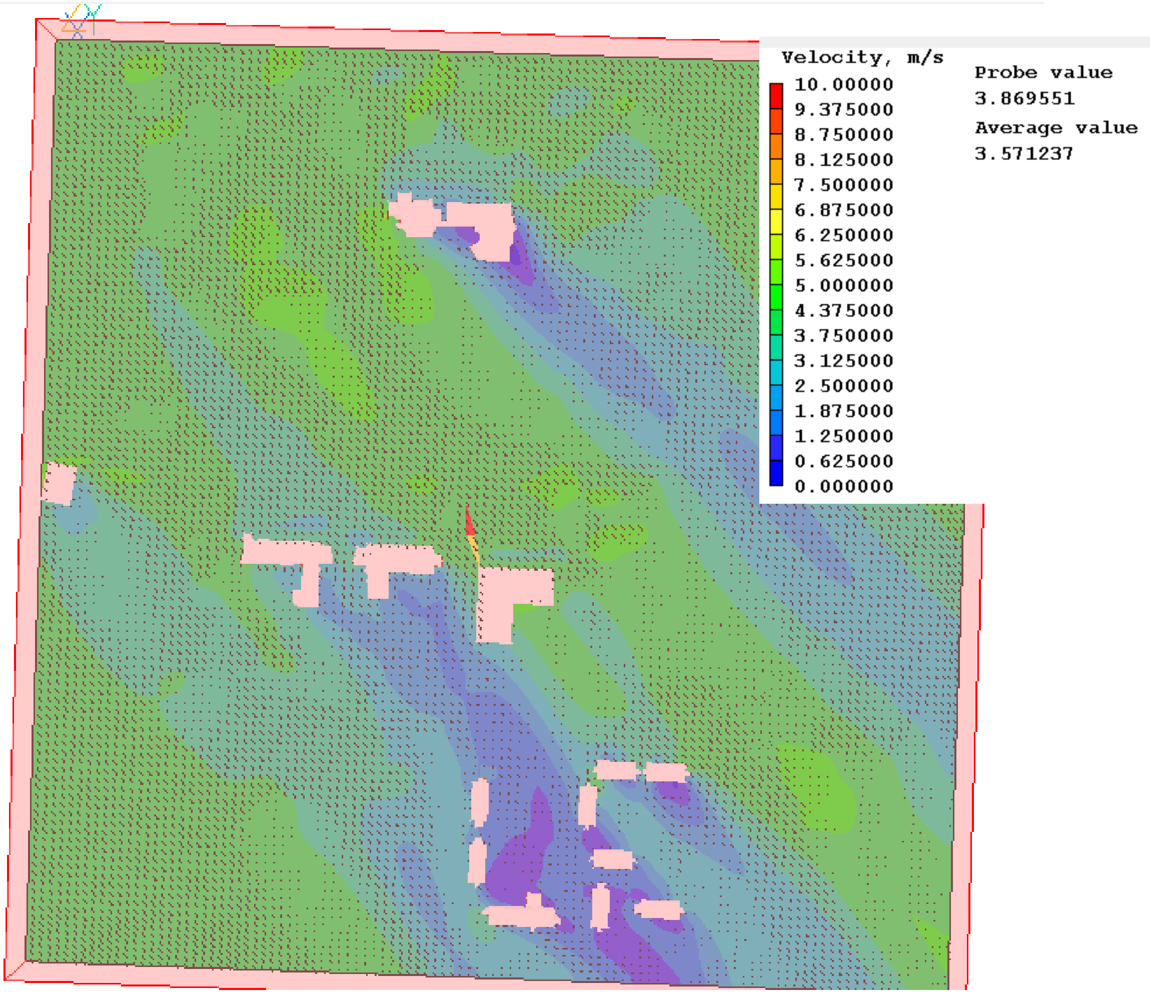



Figure 179: Z-Plane Velocity Profile: Z=24 m, Probe Position: (500, 430, 24)

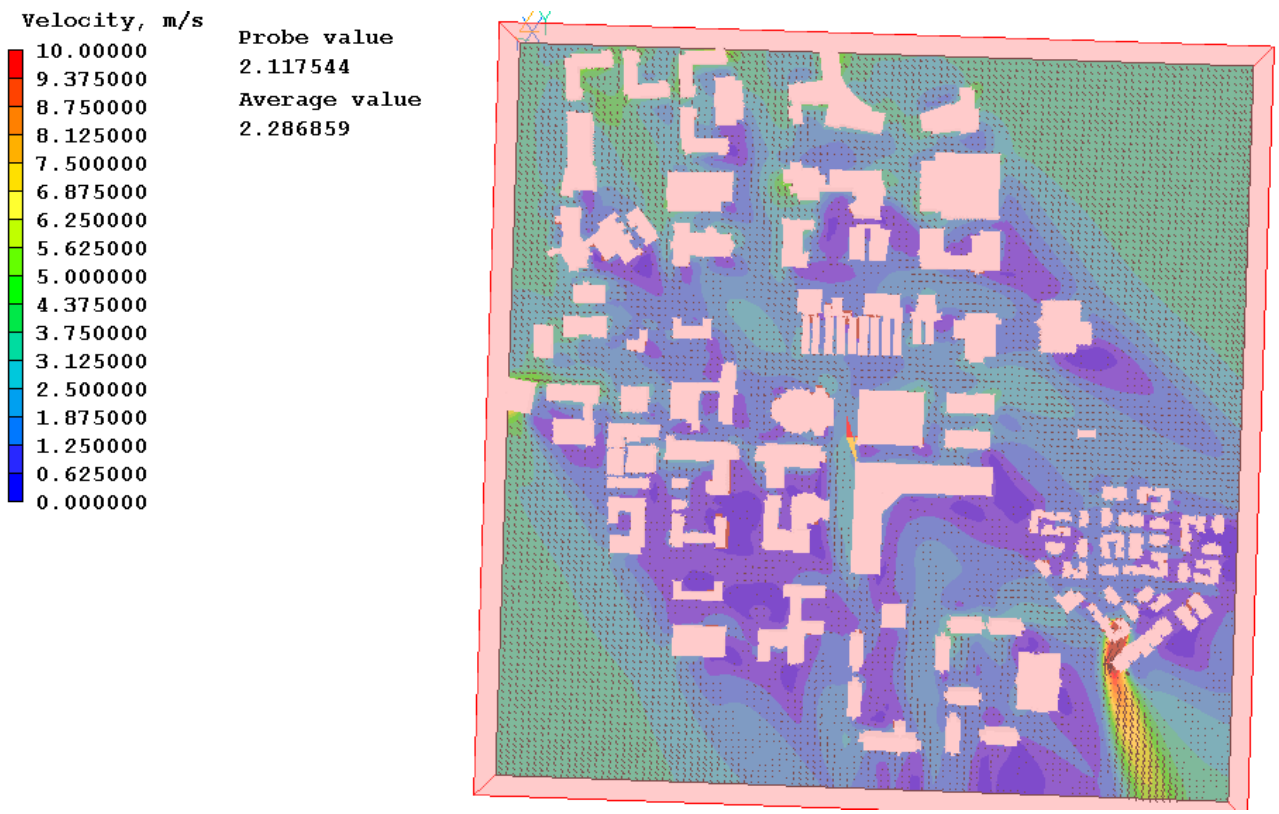



Figure 180: Z-Plane Velocity Profile: ground plane, Probe Position: (500, 430, 0.5)

The Y and X-plane velocity profiles for the wind around the building of interest, Millennium Science Complex, are shown Figure 181 and Figure 182, respectively. They both show higher wind speeds at the top of the building, which indicates that this location would be more appropriate for the location of wind turbines. Based on these profiles, the optimal location for the wind turbines was along the top of the cantilever.

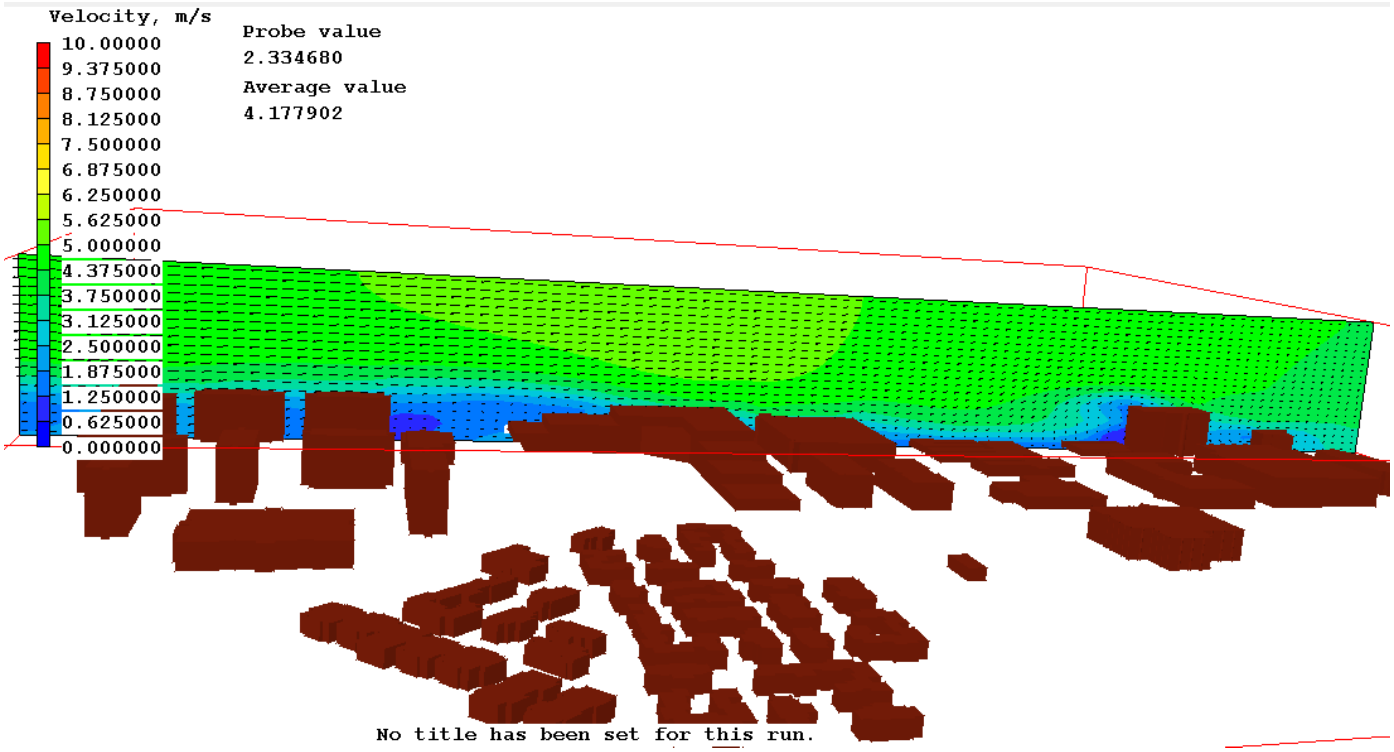



Figure 181: Y-Plane Velocity Profile, Probe Location (500, 430, 10)

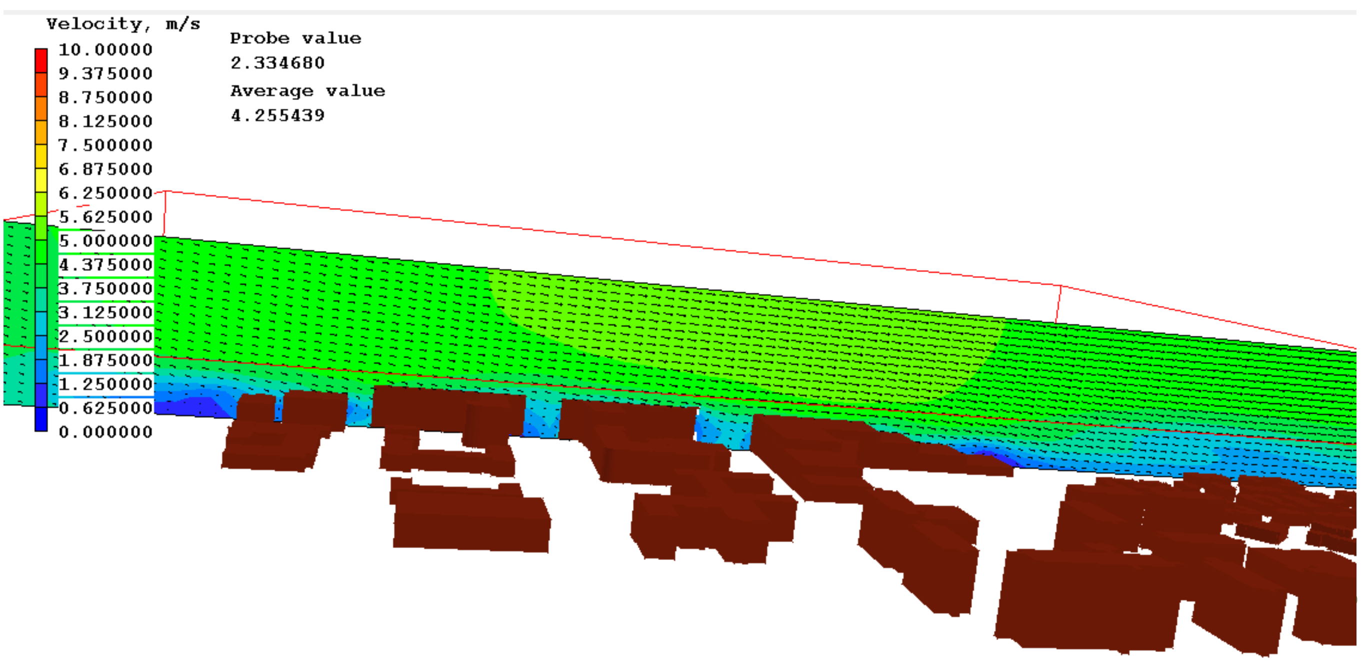



Figure 182: X-Plane Velocity Profile, Probe Location (500, 430, 10)

The additions of wind turbines were then added to the simulation to determine the face velocities. These results can be seen in Appendix C: Energy Analysis. Incorporating the wind turbines to the top of the cantilever impacts the architecture of MSC since they will be noticeable from the ground view by pedestrians and other onlookers. Figure 183 shows how the added Architectural Wind turbines impact the architecture.

Figure 183: AeroVironment Architectural Wind Building Integration.

While these turbines are more aesthetically pleasing as compared to other wind turbines, the addition impacts the feel of linearity that the architect Raphael Vinoly desired in his vision. However, by placing the wind turbines in a prominent location, it adds to MSC's profile as an iconic building on campus as a beacon for energy use and sustainability. This public display helps educate the others about clean energy and how it can be successfully utilized.

Figure 184shows the designed layout for the wind turbines along the roof of the cantilever. As per the spacing requirements for Swift wind turbine, one turbine is allowed to be placed at every column line, which is every 22 feet. This results in 18 turbines to be mounted to the structure. Using the prevailing wind speed of 3.6 m/s, the average maximum velocity that occurs at the Millennium Science Complex is approximately 4.9 m/s, according to the CFD results.

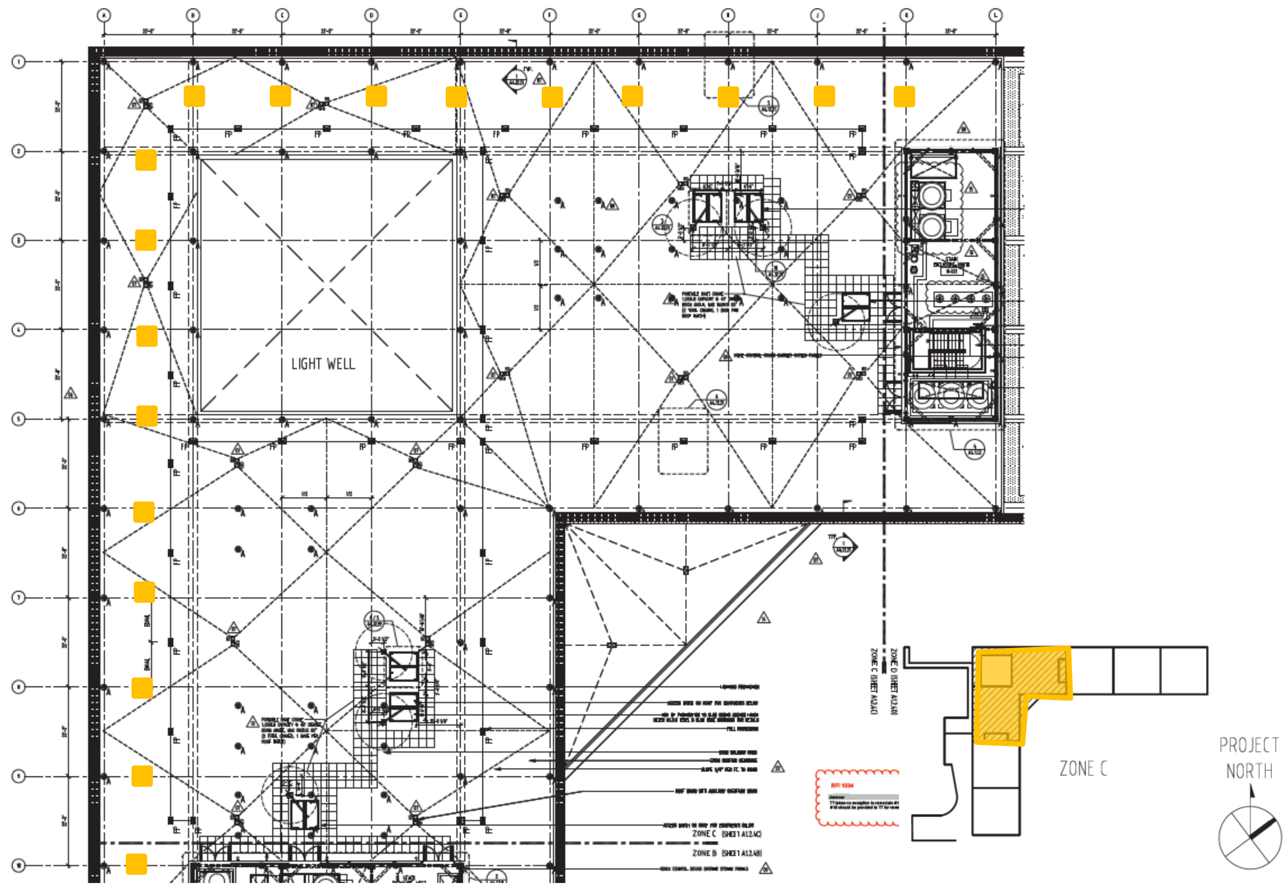



Figure 184: Wind Turbine Location.

According to the manufacturer's data for both the Cascade wind turbines and AeroVironment Architectural Wind, this results in an expected annual energy production power output of approximately 1200 kWh per turbine, which is a total 21,600 kWh for the total rooftop array. These production values are based on Cascade's values for 5.0 m/s average wind speed. This contributes to approximately 3% of the Millennium Science Complex's total energy consumption on the third floor alone, which results in an annual savings of $1,624 based on Penn State's utility data for electricity cost. For a rooftop array of this size, the total initial cost is $153,000 at $8,500 per unit, based on Cascade's data. For a simple payback period, it would require 94 years for return on investment and the lifetime expectancy for the array is only 20 years. Based on the size of the building and the energy consumption, it was determined by Building Stimulus to not be advantageous to the lifecycle cost of the building.

Due to its impact on the architecture and the small energy actually provided by the turbines for the building's energy use, Building Stimulus determined that these qualities outweighed the benefits provided from raising awareness to the campus by putting the wind turbines on a public display. Therefore, the wind turbines were not part of the final recommended design by Building Stimulus for Millennium Science Complex.

## Structural

### Gravity System Check

The gravity system of the MSC was not the main focus of Building Stimulus' building redesign. However, a sample calculation of the gravity system was performed to check the adequacy of the existing structure. These calculations and a chart of the applicable gravity loads on the structure can be found in Appendix A: Structural Analysis. A sample beam, girder, and column were chosen to be checked at the bay between grid lines 12-13 and B-C, shown in the figure below.

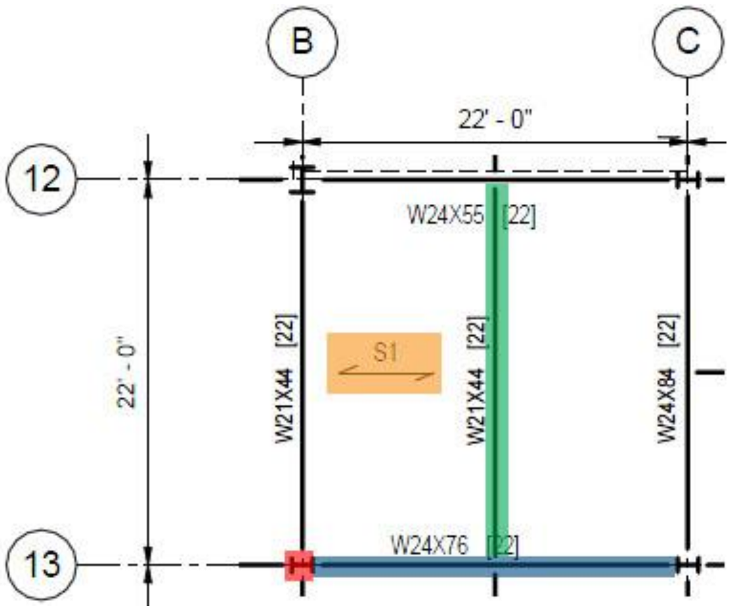



**Figure 185: Gravity System Callout.**

It was noticed that the beam was upsized from a minimum size of W14x22 to a W21x44 this could possibly be due to the vibration requirements of this sensitive laboratory building. A thorough vibrational analysis would be needed to confirm this claim but as this was not involved in the goals of the group this was not performed. This claim is not without validity however, the increase in beam section results in an increase in I from 199 $in^4$ to 843 $in^4$ and an increase in weight of 22 plf. Both of these factors contribute to the vibration reduction of the floor system. Specifically the floor system had to be upsized to limit the max velocity of the floor system with respect to impulse loading due to human activity. Design guidelines were defined as 4000 ui/s for the life science wing for example, these limits are defined by AISC Design Guide 11.

## Lateral System Check

The lateral system of the Millennium Science Complex was not the main focus of the structural investigation of this thesis report. However, a lateral analysis was conducted on the existing lateral system and a series of resisting elements were checked for shear capacity. As seen in Figure 186 a lateral system model was generated in ETABS and the applicable lateral loads were applied to determine a controlling load case. Lateral loads for both earthquake and wind were calculated using ASCE7-05, and detailed calculations can be found in Appendix A: .

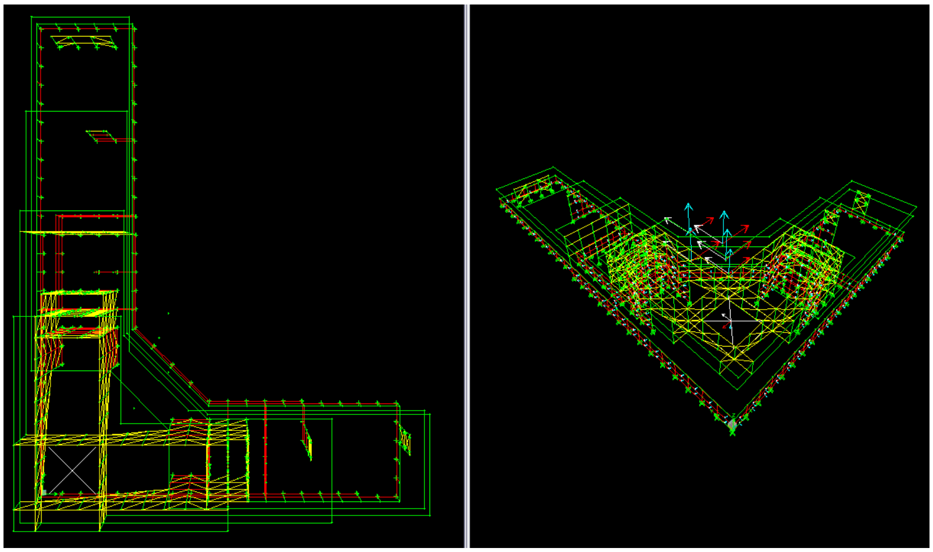


Figure 186: ETABS Lateral Model.

Earthquake loads were applied with a 5% accidental torsion in accordance with section 12.8.4.2. The effect of the amplification factor designated in section 12.8.4.3 was considered because of the presence of a building torsional irregularity of type 1a, however, section 12.8.4.3 indicates that the amplification factor only applies to structures assigned to Seismic Design Category C, D, E, or F. Therefore, because the MSC is under SDC: B, section 12.8.4.3 does not apply. Wind loads were applied using Figure 6-9 of Method 2 – Main Wind Force Resisting System, shown in Figure 187. Based on maximum shear transferred to critical lateral resisting elements the earthquake load was determined to be the critical load case for this structure. Although Pennsylvania is not a particularly earthquake prone region, the large building weight and small overall height of the building both contribute to the earthquake load resulting in the controlling lateral load case. In addition to the lateral load calculations, a series of detailed shear capacity checks can also be found in Appendix A: .

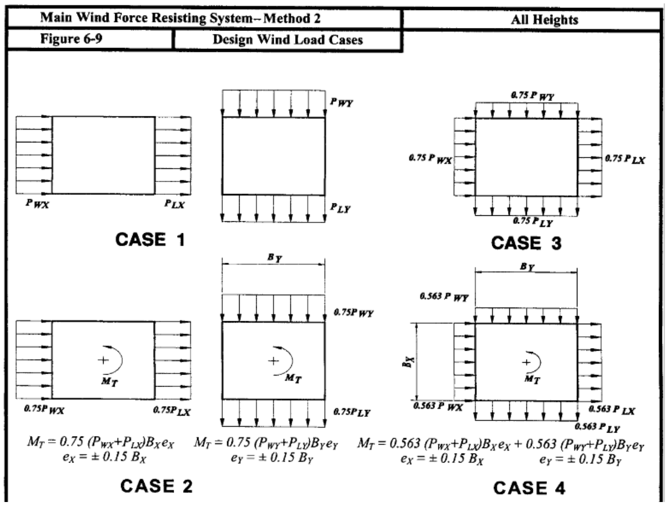



Figure 187: ASCE7-05 Figure 6-9 – MWFRS Wind Load Application.

## MAE Course Related Study

To fulfill the MAE requirements of BIM Thesis, material explored in both Computer Modeling of Building Structures and Building Enclosures was used to complete the structural analysis of the Millennium Science Complex. ETABS was used to model the lateral system of the building to perform a lateral system check for the existing structural system. The methods of placing rigid end offsets and modeling a membrane floor system for accurate in and out of plane lengthening in SAP 2000 was carried out for a thorough analysis of the cantilever. Also, methods learned in Building Enclosures were used to size the glazing and mullion system of the redesigned double skin façade.

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