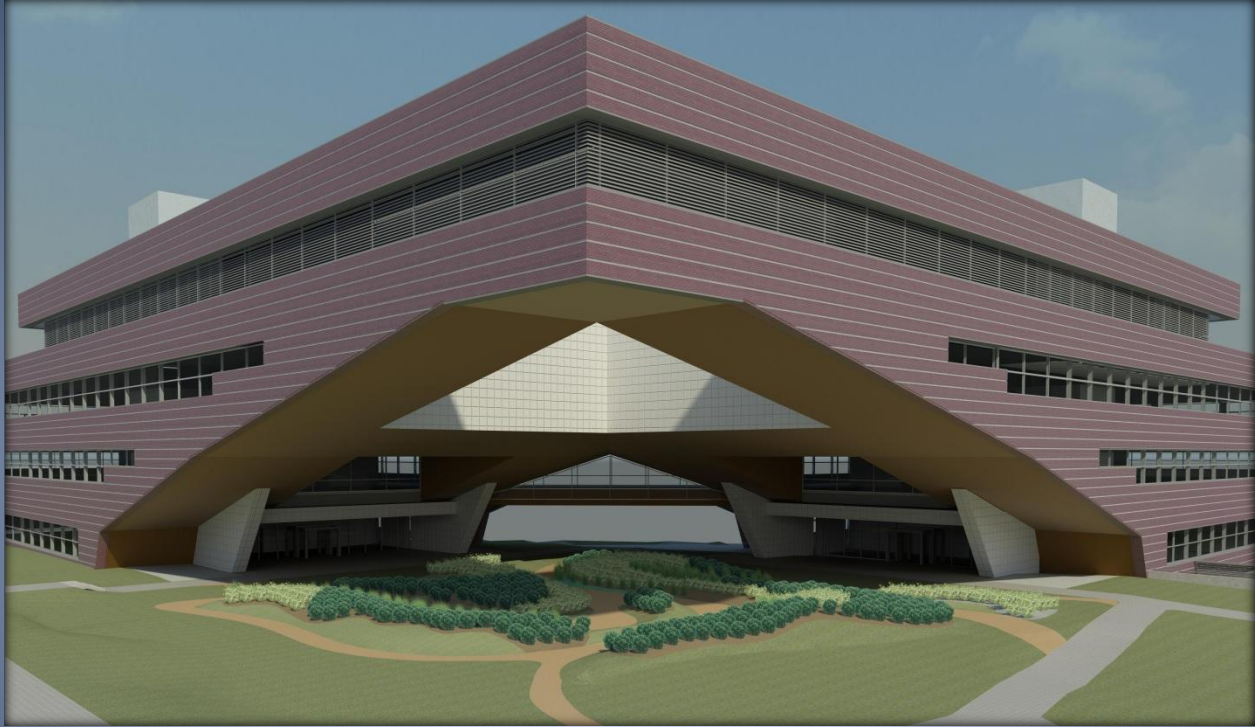




The Millennium Science Complex

The Pennsylvania State University



Stephen Pfund
Christopher Russell
Alexander Stough
Thomas Villacampa

IPD / BIM Thesis 2010-11

Final Report
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Advisors:

Prof. Robert Holland
Dr. Andres Lepage
Dr. Richard Mistrick
Prof. Kevin Parfitt
Dr. Jelena Srebric
Dr. John Messner
Prof. Ted Dannerth

Executive Summary

The following report provides an overview of the proposed redesigns and analyses that *BIMception*, composed of Stephen Pfund, Christopher Russell, Alexander Stough, and Thomas Villacampa, researched and produced in the spring of 2011 for the Millennium Science Complex. *BIMception* is dedicated to improving design through innovation and coordination. The purpose of this report is to generate redesigns for the existing building that are more energy-efficient, cost-effective, and of higher value to the building. An integrated approach was taken to determine designs that were executed for this project. Integrated Project Delivery conceives design as a team product, allowing each member to incorporate their expertise early in the design phase adding value to the building project. Building Information Modeling will become the tool that allows *BIMception* to quickly and effectively validate and communicate our design concepts.

Within this report, three main areas of focus have been evaluated. These interests were chosen as they provide opportunities for input from multiple disciplines, furthering the need for an integrated approach. These areas include the following:

1. Analysis of the building envelope with the intent to design a façade that is more efficient for the mechanical, lighting, and structural systems.
2. Investigation into the ceiling plenum space with the intent to examine the value of reducing structural depth through a redesign and reducing operational energy consumption
3. Redesign of the cantilever's structural framing and exterior plaza lighting system enhancing the architectural aesthetics with engineering solutions.

BIMception investigated the use of alternative system designs to modify the components of the Millennium Science Complex's building enclosure with the intent to engineer more efficient systems. Based on this, an analysis of the precast panel's composition, the window to wall ratio, and shading devices were conducted to improve optimal performance. While improving performance, the architectural aesthetics of the MSC remain unchanged, preserving Raphael Vinoly's vision. Each design alternative was selected based on criteria developed for energy performance, daylighting comfort, structural integrity, and life cycle cost.

The core investigation of the plenum space is a structural redesign entailing a change from the existing structural framing to a "three-building" design. This design is focused on redesigning the structural gravity system by maintaining the steel framing of the cantilever while using a concrete system for the wings. This design alternative investigated potential reductions of the structural depth within the plenum space. Based on the space gained through this redesign, the mechanical system investigated the opportunity to save fan energy by increasing duct size. The benefits of adjusting duct size are determined through energy consumption and life cycle cost. The coordination of the alternative structural and mechanical systems validates the opportunity to reduce system collisions and improve system integration. The concrete redesign of the wings also prompted a full redesign of the lateral resisting elements.

The cantilever of the Millennium Science Complex is the key architectural focal point of the building. An open-air plaza has been designed for below the cantilever, including an exterior lighting system. A redesign of the cantilever truss system produced a system that is efficient and reduces steel material costs. The structural truss modifications prompted an architectural change within the cantilever plaza. Subtle in nature, the new architecture of the plaza incorporates a progression of angles drawing the eye gradually from the ground to the tip of the cantilever revealing the massiveness and magnitude of this architectural statement. The redesigned cantilever plaza fully integrates structural efficiency, architectural masterpiece, and expressive lighting design.

Cost, schedule, and site logistic implications were assessed for all design decisions, adding additional measures to determine the benefits of alternative redesigns. Integration of all design decisions requires the input and selection criteria from each member of *BIMception*. The final products of each analysis represent the coordination of each system's design implications on each other, producing the most beneficial improvements for the entire building solution.

Table of Contents

<i>Executive Summary</i>	1
<i>Acknowledgments</i>	7
<i>Project Background</i>	8
ARCHITECTURE	8
BUILDING ENCLOSURE.....	9
CONSTRUCTION MANAGEMENT	9
EXISTING STRUCTURE	10
EXISTING MECHANICAL	12
EXISTING LIGHTING	13
EXISTING ELECTRICAL	13
ABSTRACT	14
<i>Project Construction Overview</i>	15
PROJECT SITE LOGISTICS.....	15
SCHEDULE NARRATIVE	17
PROJECT COST EVALUATION	18
PROJECT STAFFING	19
PROJECT DELIVERY METHOD.....	20
<i>Façade Redesign</i>	21
DESIGN APPROACH.....	21
WALL COMPOSITION ANALYSIS.....	22
<i>Design Approach</i>	22
<i>Thermal and Moisture Performance of Existing Façade</i>	23
<i>Structural Analysis of Existing Façade</i>	29
<i>Thermal and Moisture Performance of PCM Panel Alternate Façade</i>	31
<i>Structural Performance of PCM Panel Redesigned Façade</i>	35
<i>Glazing Property Comparison – Existing and Redesign</i>	37
<i>Energy Analysis of Design Options</i>	38
<i>Yearly Operating Costs of Design Options</i>	39
<i>Case Study Evaluation of Model Accuracy</i>	39
<i>Construction Cost of Façade Assemblies</i>	40
<i>Life Cycle Cost of Triple Pane Assembly</i>	41
<i>Final Selection of Wall Composition</i>	42

WINDOW TO WALL RATIO ANALYSIS	43
<i>Design Approach</i>	43
<i>Daylight Analysis</i>	44
<i>Energy Analysis Results</i>	46
<i>Schedule and Logistic Impacts of Final Selection</i>	47
<i>Criteria for Integrated Window to Wall Ratio Selection</i>	49
<i>Final Selection of Window to Wall Ratio</i>	56
SHADING ANALYSIS	58
<i>Design Approach</i>	58
<i>Interior Shelf Analysis</i>	59
<i>Project Vasari Analysis</i>	61
<i>Final Shade Selection</i>	64
LIGHTING REDESIGNS	65
<i>Design Approach</i>	65
<i>Student Areas</i>	65
<i>Private Offices</i>	73
<i>Cost Analysis of Lighting Redesigns</i>	79
<i>Daylight Integration Control Study</i>	80
<i>Energy Analysis of Lighting Redesigns</i>	83
<i>Schedule Implications of Lighting Redesigns</i>	84
<i>Lighting Redesign Conclusion</i>	85
FAÇADE CONCLUSION	86
Plenum Investigation	87
DESIGN APPROACH.....	87
STRUCTURAL FLOOR SYSTEM ALTERNATIVES	88
<i>Waffle Slab Design</i>	88
<i>Vibration Analysis/ SAP Modeling</i>	90
<i>One-Way Concrete Pan Joist/Girder Redesign</i>	97
<i>Impacts of Gravity System Redesign on Lateral Resisting System</i>	101
<i>Structural Cost Analysis</i>	105
MECHANICAL SYSTEM ANALYSIS.....	107
<i>Design Approach</i>	107
<i>Existing Mechanical System</i>	108

<i>Duct Sizing</i>	<i>109</i>
<i>Fan Selection.....</i>	<i>109</i>
<i>Hand Calculations – Static Pressure Loss.....</i>	<i>110</i>
<i>Existing – Static Pressure Loss</i>	<i>110</i>
<i>Duct Sizing Effects – Static Pressure Loss Alternatives</i>	<i>111</i>
<i>Energy Modeling – Static Pressure Loss Alternatives</i>	<i>112</i>
<i>Construction/Installation Costs of Alternate Duct Systems</i>	<i>113</i>
<i>Life Cycle Cost Analysis</i>	<i>114</i>
CONSTRUCTION SCHEDULE AND LOGISTIC IMPACTS OF FINAL SELECTION	115
<i>Site Logistics and Planning</i>	<i>115</i>
<i>Schedule Analysis.....</i>	<i>116</i>
<i>Concrete Pours.....</i>	<i>117</i>
<i>Crane Analysis.....</i>	<i>118</i>
<i>4D Modeling</i>	<i>118</i>
COORDINATION AND MODELING OF SYSTEMS.....	119
<i>Revit Modeling of Duct Systems</i>	<i>119</i>
<i>Building Information in Duct Systems.....</i>	<i>120</i>
<i>Revit Modeling of Structural Systems.....</i>	<i>122</i>
<i>Building Information in Structural Systems</i>	<i>123</i>
<i>Coordination of Mechanical Supply Duct and Structure 1</i>	<i>125</i>
<i>Coordination of Mechanical Supply Duct and Structure 2</i>	<i>127</i>
<i>Coordination of Mechanical Supply Duct and Structure 3.....</i>	<i>129</i>
<i>Coordination of Mechanical Drainage Pipe and Structure</i>	<i>132</i>
PLENUM CONCLUSION	135
<i>Cantilever Plaza Redesign.....</i>	<i>136</i>
DESIGN APPROACH.....	136
STRUCUTRAL TRUSS ALTERNATIVE	137
<i>Existing Truss Designs.....</i>	<i>137</i>
<i>Truss Alternatives</i>	<i>141</i>
<i>Cost Analysis.....</i>	<i>150</i>
<i>Schedule Analysis.....</i>	<i>150</i>
ARCHITECTURAL	151
LIGHTING REDESIGN	152

<i>Cost Analysis</i>	160
<i>Schedule Analysis</i>	160
CANTILEVER CONCLUSION	161
<i>Electrical Work</i>	162
LIGHTING CIRCUIT REDESIGN	162
<i>Affected Panelboards</i>	162
<i>Student Area</i>	162
<i>Private Office</i>	170
<i>Cantilever Plaza</i>	172
SHORT CIRCUIT CALCULATION	179
DEVICE COORDINATION STUDY	181
ELECTRICAL DEPTH TOPIC 1: SKM ANALYSIS	182
ELECTRICAL DEPTH TOPIC 2: UPS VS. POWER CONDITIONER	196
<i>IPD / BIM Lessons Learned</i>	199
INTEGRATED PROJECT DELIVERY EVALUATION	199
BIM EX PLAN	200
BUILDING INFORMATION MODELING EVALUATION	200
<i>Final THESIS Conclusion</i>	202
APPENDIX A: MAE/BAE Requirements	205
MECHANICAL MAE	205
STRUCTURAL MAE	205
APPENDIX B: List of Tables and Figures	206
APPENDIX C: Citations	212
APPENDIX D: Construction Management	214
<i>Project Staff</i>	214
<i>Project Delivery Method</i>	215
<i>Site Logistics</i>	216
<i>Project Schedule</i>	220
<i>Project Estimates</i>	233
APPENDIX E: Lighting/Electrical	264
<i>Window to Wall Ratio Results</i>	264
<i>Interior Shelf</i>	274
<i>Lighting Plans</i>	287
<i>Luminaires</i>	294

<i>Electrical</i>	332
<i>APPENDIX F: Mechanical</i>	364
<i>Thermal and Moisture Performance</i>	364
<i>Energy Analysis of Alternative Façade Compositions</i>	367
<i>Operating and Life Cycle Cost Analysis</i>	375
<i>Energy Analysis of Window to Wall Ratio Alternatives</i>	384
<i>Project Vasari Shading Analysis</i>	396
<i>Energy Analysis of Lighting Redesigns</i>	401
<i>Energy Analysis of Alternative Duct Systems</i>	402
<i>Modeling of Duct Systems</i>	410
<i>Complete Energy Analysis of All Design Alternatives</i>	411
<i>APPENDIX G: Structural</i>	413
<i>Façade Redesigns</i>	413
<i>Plenum Investigation</i>	417
<i>One Way Concrete Pan-Joist Designs</i>	425
<i>Pan-Joist Vibration Model</i>	449
<i>Lateral System Redesigns</i>	450
<i>Cantilever Redesigns</i>	465
<i>APPENDIX H: BIM Execution Planning</i>	469
<i>BIM Goals</i>	469
<i>BIM Software</i>	469
<i>BIM Uses</i>	470

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Project Background

The Millennium Science Complex is a 275,600 square foot, four-level research facility that will combine both the Huck Institute of Life Sciences and Material Sciences in one location. The project is owned by The Pennsylvania State University, located on the University Park campus at the intersection of Pollack and Bigler Roads, as seen in Figure 1. The building's signature feature is a 150-foot cantilever extending over an open air public plaza from the connection of the two wings at the main entrance. The project is targeted to achieve a LEED certification upon completion of construction. This project contains several unique features in addition to the cantilever. These include 20,000 square feet of vivarium space, 40,000 square feet of quiet laboratories, and 9,500 square feet of nano-clean rooms. Fully isolated labs are located below the exterior public plaza, and have extreme sensitivity and vibration adherence requirements.

There are four occupiable floors, including a basement and mechanical penthouse. The basement, accessed directly by the loading dock, contains three, fully isolated research labs. The first through third floors have a typical floor plan. Each wing has a central hallway surrounded by laboratories and student offices at the perimeter. Green roofs are located on the floors two, three, and four. The third floor of the Millennium Complex, roughly 45,000 SF, was selected as the focus of the building for this analysis and will be more strictly studied throughout the progression of our research. This floor provides a unique opportunity to study both life and material science laboratories, while incorporating common offices and conference rooms. The third floor is within the scope of a detailed analysis while providing complex interactions between all disciplines. While the whole building will be considered on a holistic level, actual calculations, coordination, and analyses in this report focus solely on the third floor.

ARCHITECTURE

The design intent of Rafael Viñoly Architects was to make an architectural statement. The building, which is an "L" shape, incorporates two separate wings combined at the intersection by a 150-foot cantilever protruding towards the Life Sciences Building. In addition to this cantilever, the building contains cantilevered portions at the end of each wing, and was designed to step down from the top mechanical level to the bottom level at the end of each wing. Combine this design with the prominent horizontal lines portrayed by the striations of glass and brick, the image of a building floating above the landscape is created. Incorporated into the steps of the roof of the building are five green roofs, which help push this project towards obtaining a LEED certification.



Figure 1: View of Millennium Science Complex from corner of Pollack and Bigler Roads courtesy of the Huck Institute at Penn State

BUILDING ENCLOSURE

A complex pre-cast panel system comprises the majority of the Complex's building enclosure. Figure 2 shows a mockup of this system. 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 3" of rigid insulation and a vapor barrier. Each 22' panel is supported against vertical loads by a bearing connection and lateral loads by a lateral connection. The bearing connection of each panel consists of a steel plate cast in the interior face of the precast panel resting on a steel gusset plate bolted to a steel column. The lateral connection consists of a threaded rod cast in the lower horizontal lip of each precast panel and then bolted to a steel member. 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 daylighting. A system of metal panels and storefront glazing encloses the building around the landscaped exterior atrium.



Figure 2: Mockup of building enclosure, including precast panels courtesy of Rvan Solnoskv

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 EPDM waterproofing membrane.

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

CONSTRUCTION MANAGEMENT

Preconstruction activities for the Millennium Science Complex began in March 2008, with construction beginning in June 2008. With an expected completion date of June 31, 2011, the project will have a construction duration of just less than three calendar years. The approximate total cost of the project has been reported as \$215 million, with construction costs totaling approximately \$140 million. The project is being produced with a Design-Bid-Build delivery system, but with the Construction Manager, The Whiting-Turner Company, acting as both a CM Agent and a CM-at-risk. This setup is due to the fact that The Pennsylvania State University is receiving Department of General Services (DGS) funding for a large percentage of the project. Due to this funding, the owner must hold contracts with all contractors under public funding, which Whiting-Turner then oversees and manages as a CM Agency. The remaining contracts are held by Whiting-Turner, which they oversee as a CM-at-risk.

The construction team has faced many challenges during the construction of the Millennium Science Complex. Due to the location of the project in the heart of The Pennsylvania State University main campus in University Park, PA, student safety and pedestrian traffic was an immediate concern. In addition, the constraints of the site posed concerns for the transportation of materials to the site, as well as storage of materials and placement of such equipment of cranes. The construction of the 150-foot cantilever also provided many challenges to the team, including the constructability magnitude, deflection concerns, and welding of connections during the winter months.

Further details on the construction management overview can be found in the Project Construction Overview section.

EXISTING STRUCTURE

The foundation of the Millennium Science Complex utilizes a system of pile caps, micropiles and grade beams. Each column ends at a pile cap on grid lines spaced twenty two feet apart in a square pattern. Groups of micropiles continue from the pile caps and make their descent through the soil allowing friction to carry the load of the building. Each of these pile caps are connected by grade beams helping to prevent differential settlement and to stiffen the foundation, a crucial design consideration for a laboratory building.

Forming the floor of the basement are four different slabs on grade in the occupiable area of the basement. The basement, extending 20 feet to the first floor of the building, covers only a portion of the entire footprint of the building. From approximately the halfway point of each wing (column lines R and 13) begins a compacted fill extending to the ends of each wing and to the first floor slab on grade. Columns and piers extend from the pile caps at the basement level up through the compacted fill, 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, 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 (column lines R and 13). Four isolation labs were placed at the basement level, designed to be completely disparate of the structural elements that make up the rest of the building. Slabs on grade, foundation walls, footings and piers use 4000 psi concrete; the pile caps are the only concrete items that use 6000 psi concrete. Reinforcement in the foundation and throughout the building is grade 60.

A one way composite steel beam system with typical 22 foot square bays forms the floor system for the Millennium Science Building, as shown in the simplified model of Figure 3. A typical floor layout for the wings contains a centralized corridor surrounded by rooms on either side. Those perimeter spaces are generally divided into either laboratories or offices. The floor loads are handled by three types of composite steel beams and metal decking used throughout the building, the most common of which is a 3 inch 18 gage deck with 3¼ inch light weight concrete topping. The concrete decking is supported by W21 beams and W24 girders which frame into W14 columns at the intersection of each grid line. 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



Figure 3: Model of typical steel framing layout

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. These hallways call for a slightly higher ceiling so W18 beams are used in the center bay of each frame.

Two moment frames, several bays of braced frames, and two shear walls located at the stairwells make up the dedicated 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 bays away. Figure 4 shows a layout of these frames and shear walls on the first floor. The objective of these staggered frames and walls is to distribute the lateral forces over the entire floor, preventing excessive localized stresses in the floor diaphragms. 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 dedicated lateral system more than suffices in resisting the maximum lateral loads State College demands.

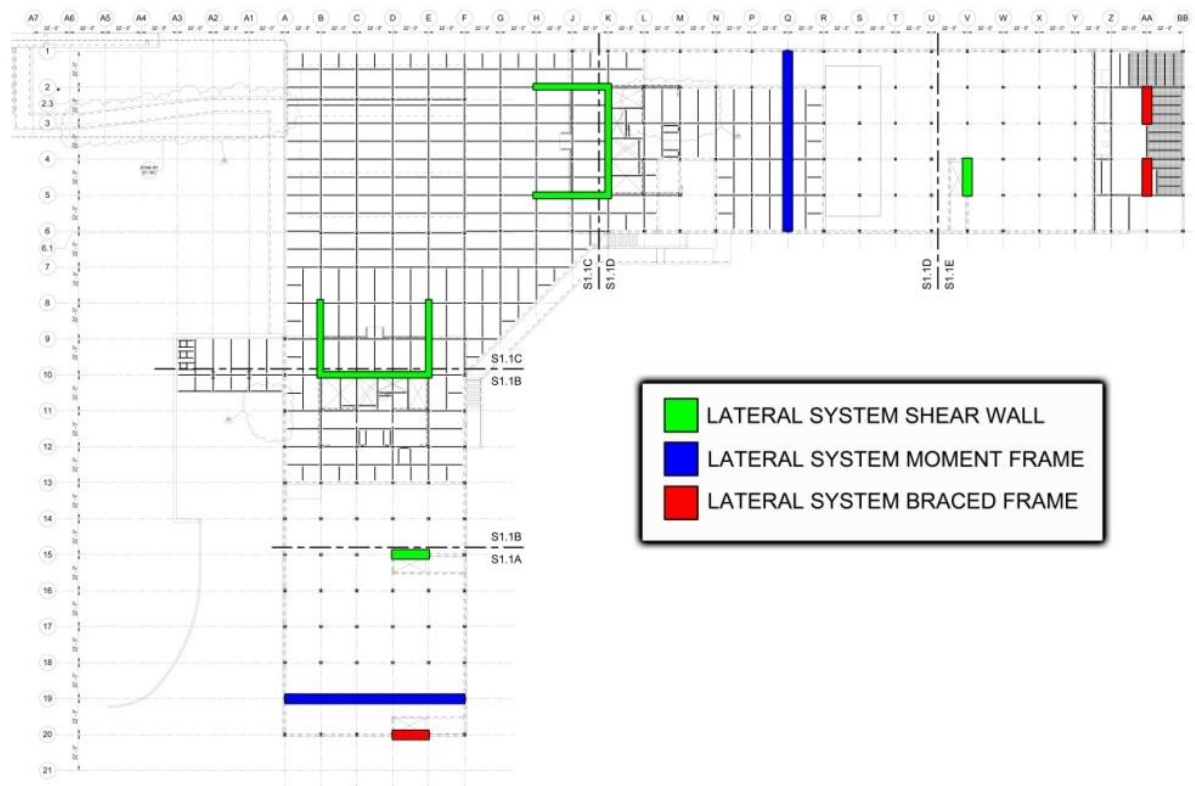


Figure 4: Layout of existing lateral system elements on first floor

To cope with the massive stresses induced by the 150 foot overhanging cantilever, a truss design was used to handle the gravity forces. Gravity loads start from the tip of the cantilever and are transferred into the diagonal compression members. Continuing on the load path, the truss feeds into a 30" shear wall integral with the truss frame. The loads from the diagonal compression members get carried into the shear wall and transfer into the foundation. The load is handled by 10 points in the foundation. These enlarged pile caps and grade beams act in compression and tension on the soil, using the micropiles as anchors. An image simulating the distribution of these forces is highlighted in Figure 5.

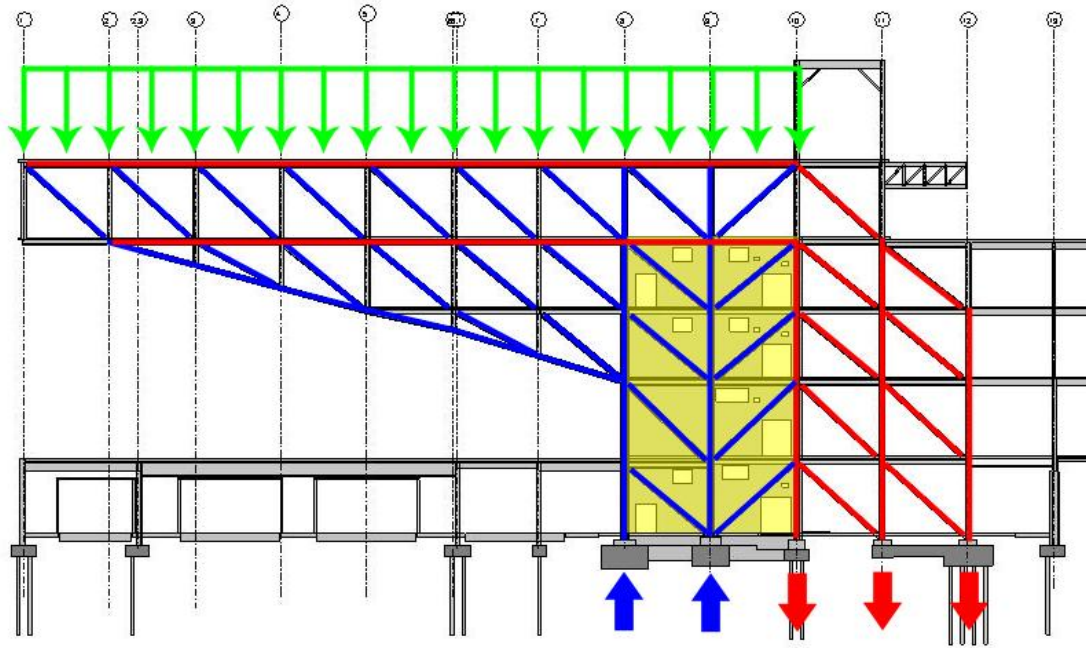


Figure 5: Gravity load simulation in cantilever truss along Frame B. Red and blue denote tension and compression respectively.

EXISTING MECHANICAL

The Millennium Science Complex connects into the existing campus steam and chilled water lines. Steam enters the building at high pressure, 140 psi, but requires two pressure reducing stations to reduce the 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 steam coils within the AHUs and in heat exchangers, producing hot water for reheat-coils at terminal devices.

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 serving the animal care facility and main laboratories are connected to standby power allowing for the cooling of these spaces during power loss.

The laboratory areas of the building are served by five (5) manifolded 50,000 CFM VAV AHUs. Each of these AHUs contains a supply fan, cooling coil, heating coil, humidification equipment, and MERV-14 filters. All laboratory AHUs deliver 100% outside air. In an effort to save operating energy and cost, the general laboratory exhaust air enters an enthalpy wheel exchanging energy 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. This ensures that the CO₂ concentrations in these areas are maintained at appropriate levels by supplying enough outdoor air.

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. Redundancy is needed to allow for continual service of the animal holding rooms and the rest of the animal facility should one unit fail. The clean room also has its own AHU 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.

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.

EXISTING 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 GRAFIK Eye system.

EXISTING ELECTRICAL

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, 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.

ABSTRACT



Millennium Science Complex

PENNSTATE


KGB-Maser	BIMception	Building Stimulus	Option
David Maser	Thomas Villacampa	Jonathan Brangan	Construction Management
Stephen Kijak	Stephen Pfund	Paul Kuehnell	Structural
Michael Gilroy	Alexander Stough	Sara Pace	Mechanical
Jason Brognano	Christopher Russell	Michael Lucas	Lighting/Electrical





The Pennsylvania State University
Life & Material Sciences Laboratory & Research Facility
275,600 SF
Whiting-Turner Contracting Company
Rafael Viñoly Architects
Thornton Tomasetti
Flack and Kurtz

With Support from:
Thornton Tomasetti Foundation
The Leonhard Center
Penn State

Construction Management

Project Delivery Method:

- Design-Bid-Build - CM Agency

Building Enclosure:

- Precast brick masonry panels with rows of glass curtain wall windows.
- The roof system is a built-up green roof system.

Sustainability Efforts:

- Over 90% of all construction waste has been diverted from landfills.
- Local materials used for a majority of the project.

Construction Logistics:

- Detailed phasing diagrams were put into effect to facilitate the ease of student travel around the construction of the tunnel from Life Sciences I to the Life Science wing of Millennium Science Complex.

Lighting/Electrical

Power Distribution:

- Campus 12.47kV through two pad-mounted service transformers to two 480V/277V switchgear in main-tie-main configuration.
- Emergency is fed through two additional switchgear from University backup power.
- Electrical distribution frames are clad with aluminum shielding to prevent electromagnetic frequency interference with sensitive equipment in adjacent spaces.

Lighting:

- All lighting is supplied at 277V.
- Occupancy and daylight sensors are present in perimeter spaces.

Telecommunications:

- Combination voice and data outlets integrated into furniture.
- Above-ceiling wireless access points.
- Basket-type cable tray for bulk routing.

Security System:

- Card reader access to lab zones.
- Cameras at main entrances, delivery and tunnel access, and some research areas.

Mechanical

HVAC:

- Nine 100% Outdoor Air Systems deliver air to the Vivarium, Clean Rooms, and Laboratories. Energy recovery wheels and run-around coils reduce energy usage.
- Three 33,000 CFM air handlers serve the office areas.
- Campus steam provides heating for process and building loads through perimeter heating and terminal reheat.
- Campus chilled water provides cooling from three variable speed split case pumps.
- Laboratories are supplied with process chilled water and lab gases. Quiet rooms are cooled with radiant panels.

Sustainability:

- Designed to be LEED Gold Certified.
- 60,050 SF of Green roof and 43,000 SF of black EPDM roofs help manage energy loads and storm water runoff. Storm water is collected in a large underground cistern for site landscaping.
- At least 20% reduction in water use from high efficiency and waterless fixtures.
- Exterior louvers and overhangs control solar gain.

Fire Protection:

- Automatic alarm and sprinkler system throughout the building including the first floor exterior atrium.

Structural

Sub Structure:

- Cast in place reinforced concrete foundation consisting of pile caps, at the base of the columns, placed on 7 in. diameter micro piles and connected by grade beams. Foundation walls line the footprint of the building.

Super Structure:

- Steel framing on 22 ft. square bays. Typical steel construction utilizes wide flange columns and beams. Floor systems are composite steel beams supporting concrete slab on metal deck.

Lateral Force Resisting System:

- The primary system consists of concentric braced frames. Moment frames and shear walls also exist on both wings. Two 30 in. concrete c-shaped shear walls poured integral with two bays of braced frames, extending from foundation to the fourth floor, also contributes.

Special Systems:

- Supports 155 ft. cantilever connecting the two wings on the North West Corner. Two truss frames extend from each wing transferring all loads down to the foundation through the c-shaped shear walls.

IPD/BIM Thesis 2010-2011

Integrated Project Delivery | Building Information Modeling



Project Construction Overview

PROJECT SITE LOGISTICS

The project site is located on The Pennsylvania State University campus at the corner of Bigler Road and Pollock Road, directly across from the Pollock Commons. Figure 6 shows the site for Millennium Science Complex and some of the surrounding buildings. To the North of the project site is the Eisenhower Parking Deck; to the East are the Nittany Apartments; to the South is the Pollock Commons; and to the West is the existing Life Sciences Building.

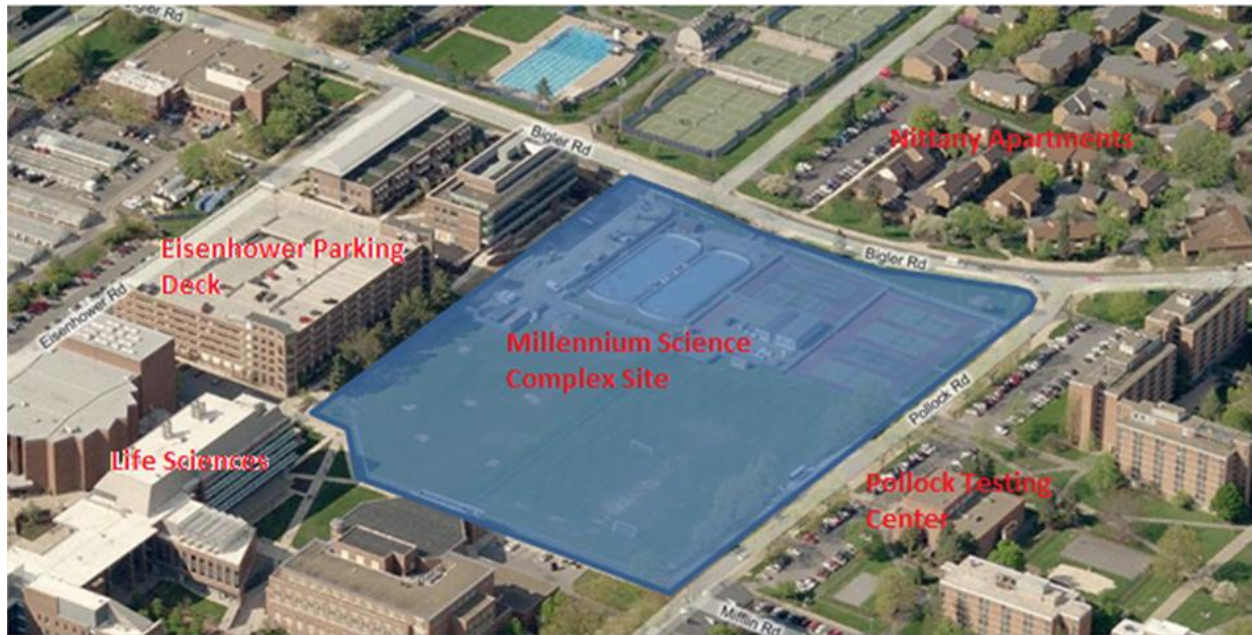


Figure 6: Bing Map of Millennium Science Complex Site

The site was originally occupied by two roller hockey rinks, tennis courts, and intramural sports fields. The site for Millennium Science Complex is also surrounded by a variety of different building types, and vast amounts of student and vehicular traffic. Coming from the east, students living in the Nittany Apartments must be able to easily travel through this location of campus for class and various activities. To the North of the site, along adjacent to the Eisenhower Parking Deck, is a main walking path of student travel. Safety is of the utmost concern in this location for students traveling to and from the northeast part of campus. On the South edge of the Life Sciences Wing, the building cantilevers over the pedestrian walkway. Once again, safety is a main concern. Temporary structures were erected to protect pedestrians walking through this area, and proper coordination needed to happen during the construction of this location of the building.

Another main concern during the construction of Millennium Science Complex is the amount of vehicle traffic that is on Bigler Road and Pollock Road. Catabus Community Service Lines use both Bigler Road and Pollock Road as part of their routes. The Blue Loop also travels on these roads as part of its campus loop. Both vehicle and pedestrian traffic play a role in another issue faced by the construction team, which was how to bring materials and equipment into the site. Because the site is located in the middle of the Penn State University campus, available space is at a premium. The site did not offer much space for material storage, so materials were typically scheduled to be brought in the day it was needed. It was required that trucks were not driven through campus, so it was planned that the trucks

would be brought in from University Avenue onto Hastings Road, which connects to Bigler Road and the construction site. This path can be seen in Figure 7 below. As can be seen, vehicle and pedestrian traffic were a main consideration in the site logistics planning for the Millennium Science Complex.

Aside from the complexities that Whiting-Turner had to deal with outside of the site, creating a site logistics plan for the building has also proved to be cumbersome. Whiting-Turner first began with a two phase site logistics plan. The first plan covers from site preparation through the foundation being complete. The second phase site logistics plan covers from steel erection to interior finishes. Whiting-Turner's site logistics plans can be found in Appendix D.

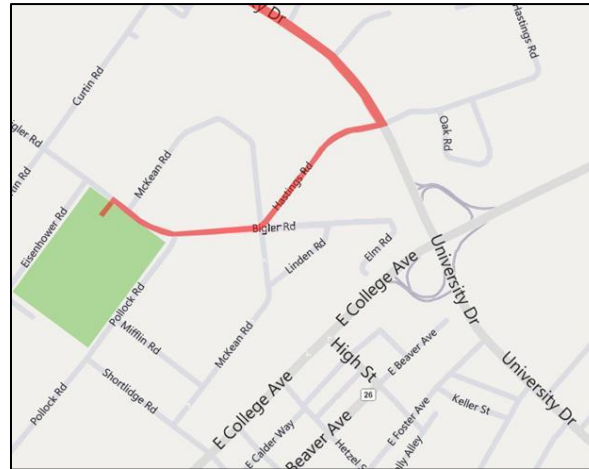


Figure 7: Map of Material Delivery Route

SCHEDULE NARRATIVE

The Millennium Science Complex project summary schedule encompasses a selection of key activities, starting with the design, bidding and awarding of the project through building turnover to The Pennsylvania State University. The full summary schedule can be found in Appendix D. In Table 1 is a short summary made of several key construction activities and their durations and dates.

Construction Phase	Duration (Days)	Start	Finish
Notice to Proceed	-	3-24-08	-
Foundation/Substructure	270	2-16-09	2-26-10
Superstructure	274	7-7-09	7-23-10
Enclosure	303	11-9-09	1-5-11
Building Systems/Finishes	345	12-14-09	4-8-11
Substantial Completion	-	5-12-11	-
Construction Duration	758	8-12-08	7-7-11

Table 1: *Schedule Summary of Key Tasks*

Preconstruction for this project began in March 2008 and included the design, bidding and awarding of the different project components and packages. Department of General Services (DGS) project packages were decided, which are the publicly funded portions of the project. These packages consisted of primarily upfront construction activities (information on this can be found later in the report.) In addition, the qualification and evaluation of designers and contractors for the clean rooms was also decided during this time.

Primary coordination meetings and reviews began in May 2009. Per the contract, all main building system trades, such as structural steel, mechanical, electrical and plumbing, were required to model their systems using programs compatible with a 3D DWG file format. Because of the complexity of this project, the use of building information modeling and the coordination that comes from this was of the utmost importance.

The structural steel erection began in July 2009, lasting just under seven months, and was done in gradual stages. Erection began at the ends of the Material and Life Sciences wings, and progressed towards the perpendicular interception of the two wings. All levels of the structural steel for each wing were complete before the erection of the cantilever began.

Commissioning will begin in November 2010, and lasts until building turnover to The Pennsylvania State University in July 2011. Initial inspections are done after all major systems are completed, and final inspections, completion of the punchlist and closeout are set to take place starting in January 2011.

PROJECT COST EVALUATION

Considering the sheer magnitude of this project, in combination with the complexities contained within the building systems and finishes, it was assumed early on that the cost of this project would ultimately be high. While the exact total cost of the project is not known, an approximate total cost of \$215 million has been obtained, and will be assumed as the total cost of the project. In addition, all construction and systems costs were obtained based on budgets provided by Whiting-Turner (dated July 3, 2008), and may not be up-to-date.

Total Cost	Total Cost Per Square Foot
\$215,000,000	\$788/SF

Table 2: Total Cost of Building

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

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

Table 3: Construction Cost of Building

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
Fire Protection	1.0%	\$1,362,000	\$4.99/SF
HVAC	18.1%	\$25,159,105	\$92.26/SF
Electrical	8.9%	\$12,313,658	\$45.15/SF

Table 4: Building System Costs

PROJECT STAFFING

Whiting-Turner is staffing the project based on the project size and complexity. A simplified staffing plan is shown below (Figure 8), and a full staffing plan is attached in Appendix D. This project has two Senior Project Managers, four Project Managers, a Senior Superintendent, two Superintendents, and five Project Engineers.

Dick Tennant, a Construction Manager owner's representative from the Office of Physical Plant, oversees the project. Both the project management and field supervision staff are placed on site in the trailer complex. Typically, the management staff holds weekly subcontractor coordination meetings.

The project management staff handles all project submittals, most of the RFI's, and reviews the payment requisitions from the subcontractors. Superintendents and their assistants handle all field installations using approved submittal and shop drawings. Superintendents also supervise the subcontractor's daily activities. Whiting-Turner's safety efforts are in the mind of everyone on the staff; however Cesar Sastoque, a Safety Specialist Superintendent, is responsible to help create a safe environment by preventing dangerous practices on site. He is accountable for being aware of proper procedures and safe construction methods during the hours of construction.

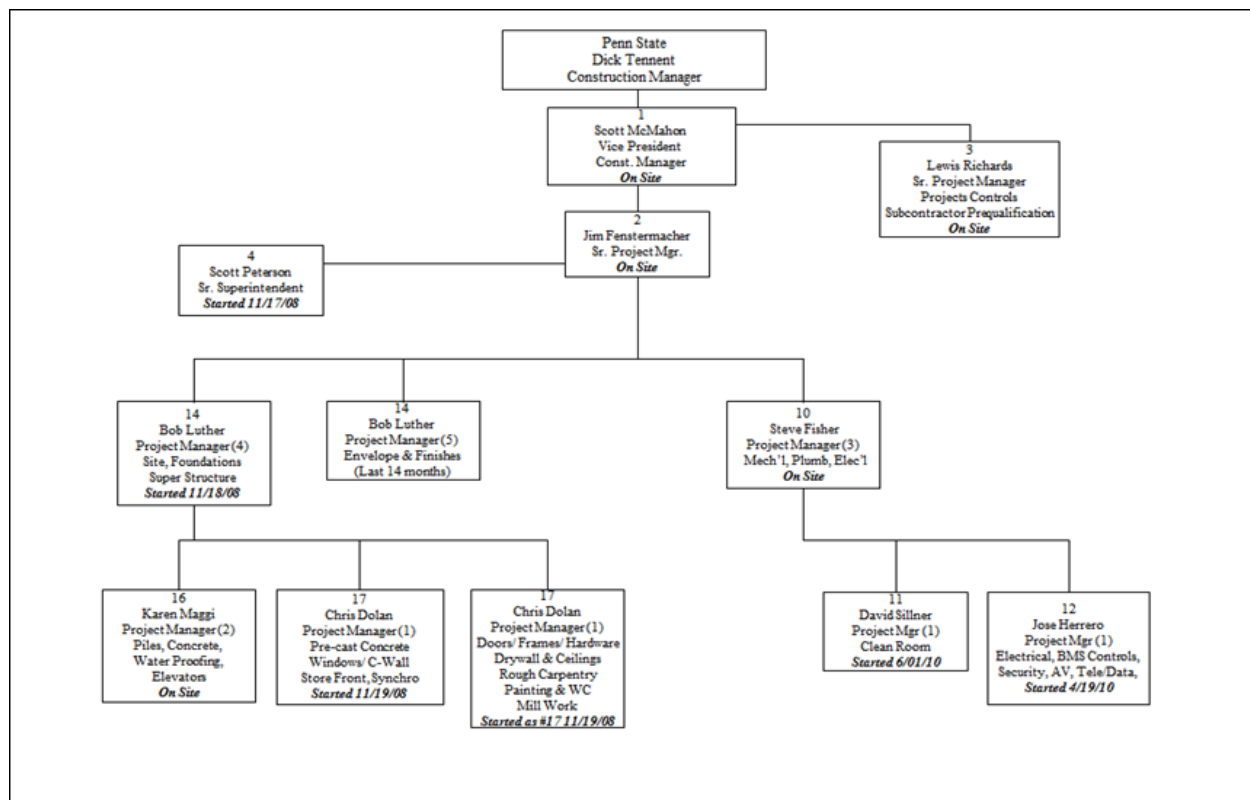


Figure 8: Whiting-Turner Staffing Plan

PROJECT DELIVERY METHOD

The Millennium Science Complex is primarily a Design-Bid-Build delivery system, with a form of Construction Management Agency and Fee in place with Whiting-Turner Contracting. Because this project does have Department General Services (DGS) funding, Penn State University is required to hold the contracts which are publicly funded directly. These contracts and packages, which primarily consist of activities which are upfront in the construction of the building, can be seen in Appendix D. This project encompasses an interesting set up in that the owner, Penn State University, holds contracts with both a construction manager, as well as subcontractors. Whiting-Turner, in effect, acts as a construction management agent to Penn State University, and is held responsible for overseeing, managing and coordinating the trades with which Penn State University holds contracts directly. At the same time, Whiting-Turner maintains contracts with all other subcontractors on site, and must maintain their responsibilities to manage their own subcontractors. Through their contract with Penn State University, Whiting-Turner performs their work for a fee, and because they are not self-performing any work, they are not at risk with Penn State University for the work performed by their subcontractors.

One unique aspect of this project was in the bid and award process used for the clean rooms within the basement of the building. Because of their complexity and importance to the facility, these were not bid out as the rest of the building was done. Instead, these rooms were done with a Design-Build method, selecting contractors and designers who would be given permission to submit proposals for the design and construction of these laboratories. This process was much more tedious than the selection of the remaining bids for the building in that each proposal was scored and ranked based on specific technical and design criteria before the cost of the proposal was made public and evaluated. For this evaluation process, the scientists who would be using these spaces were brought in to place opinions and input on the proposals based on their wants and needs, which would ultimately result in laboratory space customized to what was required by them. This ensured initial rankings based on quality rather than cost. However, it was not confirmed whether Penn State University ultimately chose the designer and contractor based on the input of the scientists or the lowest cost.

Façade Redesign

DESIGN APPROACH

BIMception's redesign of the Millennium Science Complex's façade will retain the integrity and symbology of the architect's, Raphael Viñoly's, vision. This vision is created by the horizontality of the façade's panel and strip window construction, creating the illusion of a building floating in the landscape. To do this, the façade is uniform and consistent in its expression and construction, disregarding solar orientation and building structure. It is BIMception's plan to respect the architect's vision by not altering the cohesiveness of the façade elements.

The redesign of the façade system will focus on deconstructing elements of the exterior wall and analyzing their performance in isolation. BIMception will investigate three specific focus areas that will be evaluated for improvement – Wall Composition Analysis, Window to Wall Ratio Analysis, and Shading Analysis.

The façade of the Millennium Science Complex is composed of approximately 25,000 pound prefabricated concrete panels used uniformly on all building surfaces. While a defining architectural feature, they can be improved to reduce all forms of building loading. By redesigning the panel's composition to reduce its self-weight exterior structural loads can be reduced. The use of phase change materials will be used to reduce the volume of concrete needed for thermal storage and performance. This savings in weight will decrease the deflections in the cantilever and decrease the bending stresses on exterior connections and columns. The façade will be visually unchanged, but the material and structure behind the veneer will be engineered to increase structural and mechanical performance.

Reevaluating the wall to glass ratio will select a façade that balances external thermal loads with improved daylighting opportunities and life cycle costs. The proper selection of glazing area will improve the value of the façade assembly. Selection criteria were developed by each member of BIMception and the selection of window to wall ratio is the optimum compromise of integrated design. The selection of the final wall to glass ratio will be an interdisciplinary effort synergizing the energy savings, daylighting improvement opportunities, and construction value.

The Millennium Science Complex's façade does not address the changes in solar orientation, as it retains its uniformity throughout all building faces. This creates unique problems for the selection of components designed to control daylighting and solar heat gain, as they are unable to react to differentiations in varying solar intensity around the building. In keeping with the architect's vision, this uniformity will not be altered, but elements will be redesigned to improve the façade's performance. Reevaluating the wall to glass ratio will allow BIMception to select a ratio that provides opportunities for more comfortable daylighting and for better control of thermal loads. These two opportunities can also be realized by reengineering the interior and exterior shading devices. By optimizing the current design, BIMception can respect the architectural features while providing improvements in the façade's performance.

WALL COMPOSITION ANALYSIS

Design Approach

The façade of the Millennium Science complex will be reevaluated to investigate the potential to better control exterior thermal loads. By retaining the exterior brick veneer, the architectural aesthetics of the building will be unchanged, while the internal components of the façade are allowed to evolve. The redesigned façade will appear identical to the existing, but incorporate new engineering solutions.

To improve thermal performance, the existing façade will be analyzed for its heat and moisture transfer properties. This will provide a basis of comparison for future redesigns. The inclusion of phase change materials in concrete has been selected to improve the wall's thermal capacitance and improve building loading. The existing mass wall has been decomposed into a cavity wall with a specified drainage plane to mitigate moisture condensation.

The pcm cavity wall redesign allows the mass of concrete to be split into two sections, an exterior layer to provide structure for the brick veneer, and an interior layer to improve thermal performance. The insulation and air gap between the two panels was engineered to ensure the pcm concrete panel remains in the pcm's operating range of 55-85 degrees.

Redesigning the composition of the façade panel required structural analysis to confirm the panel's integrity. Evaluation of existing in place loads, wind analysis, and gravity loads revealed potential to reduce concrete volume by removing the side returns. The reduction in panel thickness from the thermal redesign supports the effort to reduce each panel's self-weight.

In addition to the static in place loading conditions, constructability and serviceability analyses introduced new loading cases for consideration. The inclusion of transportation and installation requirements increased the panel's loads effectively increasing concrete volume and eliminating the pcm redesign.

The final redesign wall composition remains identical to the existing's, but alterations to the head, sill, and side returns are incorporated to reduce concrete volume. To support this effort, the panel depth has been reduced to 16" and thermal performance benefits are realized with the use of triple pane glazing.

Thermal and Moisture Performance of Existing Facade

Mechanical Design Criteria

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

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

Table 5: ASHRAE Weather Data for University Park, PA

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

Table 6: OPP Interior Design Conditions

R-Value H.A.M. Analysis of Existing Facade

The performance of the existing wall design was modeled in The Heat, Air, and Moisture (HAM) analysis software made by the Building Science Toolbox V.1B.

The existing façade panel consists of 2" face brick, 6" concrete, and 3" polyisocyanurate rigid insulation with an integral vapor barrier seen in Figure 9. A half wall composed of 2 5/8" gypsum boards and 3 1/2" batt insulation filled metal stud separates a large plenum space from the conditioned room.

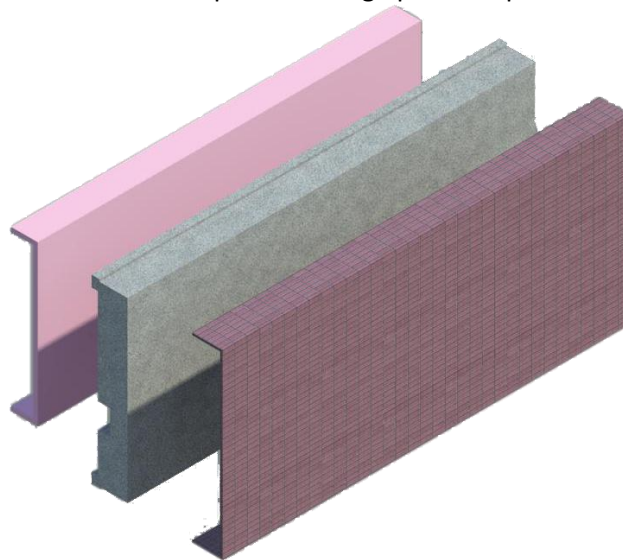


Figure 9: Exploded View of Existing Façade Panel Composition

Assumed that the large space between the exterior panel and interior wall was only 5 ½", because the added effects of extra air space are lost due to convection currents. Due to limitations in the HAM program, the brick thickness is modeled as 4 inches, rather than 2, while the concrete is modeled as 4 inches, rather than 6. This retains the combined total 8 inch thickness of the brick and concrete layers.

The analysis, found in Appendix F, reveals the total R value of the wall assembly, Figure 10, to be about 26.45, because of variances in thicknesses and properties another iteration of R-value analysis will be performed later to verify HAM's accuracy.

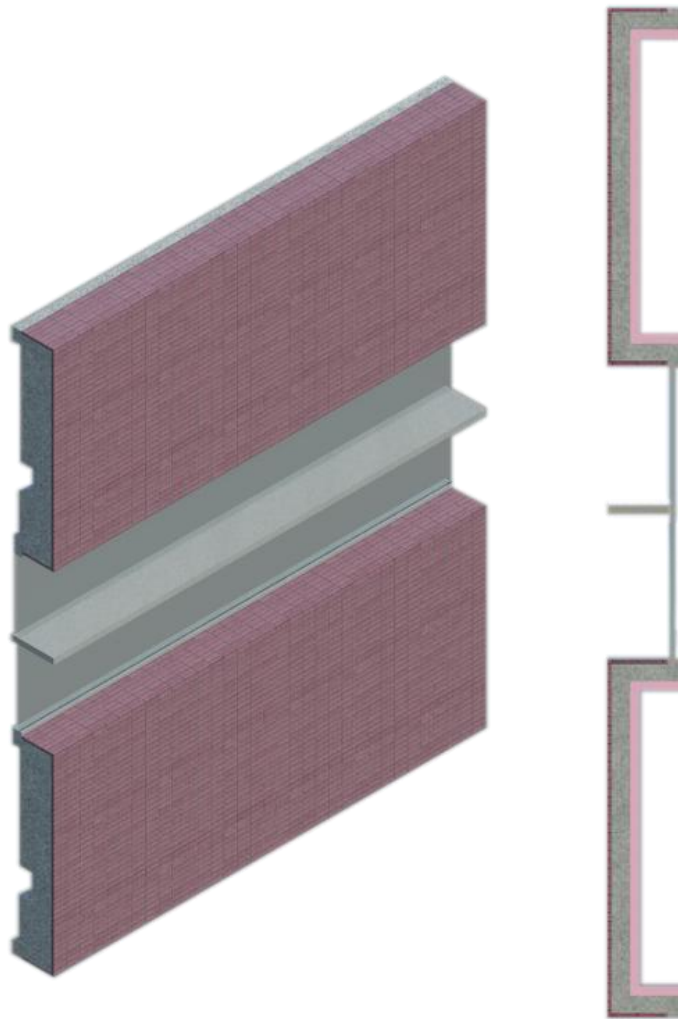


Figure 10: 3D Render and Section of Existing Façade Composition

Condensation H.A.M. Analysis of Existing Facade

A second analysis in HAM was performed to evaluate condensation potential. No condensation was found to occur in any of the summertime conditions Appendix F, but in winter design conditions, Figure 11, .08 fluid ounces per square foot per day was found to saturate the exterior portion of insulation, concrete and brick. This condition neglected to incorporate the integral vapor membrane of the insulation and a follow up analysis was done to prove the effectiveness and integrity of the assembly. As shown in Figure 12, if installed properly the vapor barrier effectively prevents vapor condensation in the wall assembly.

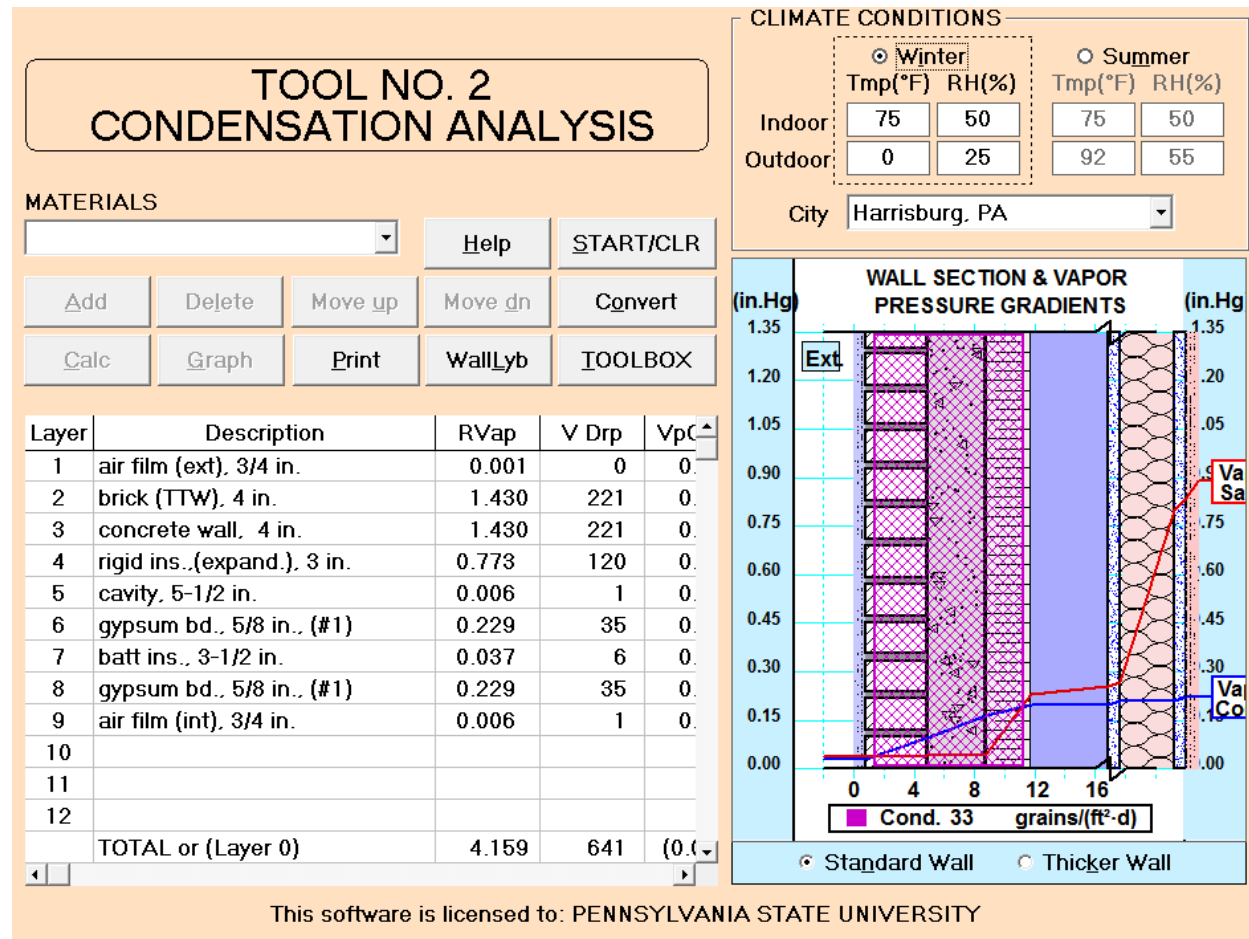


Figure 11: HAM Condensation Analysis of Existing Wall – Winter Condition – No Vapor Barrier

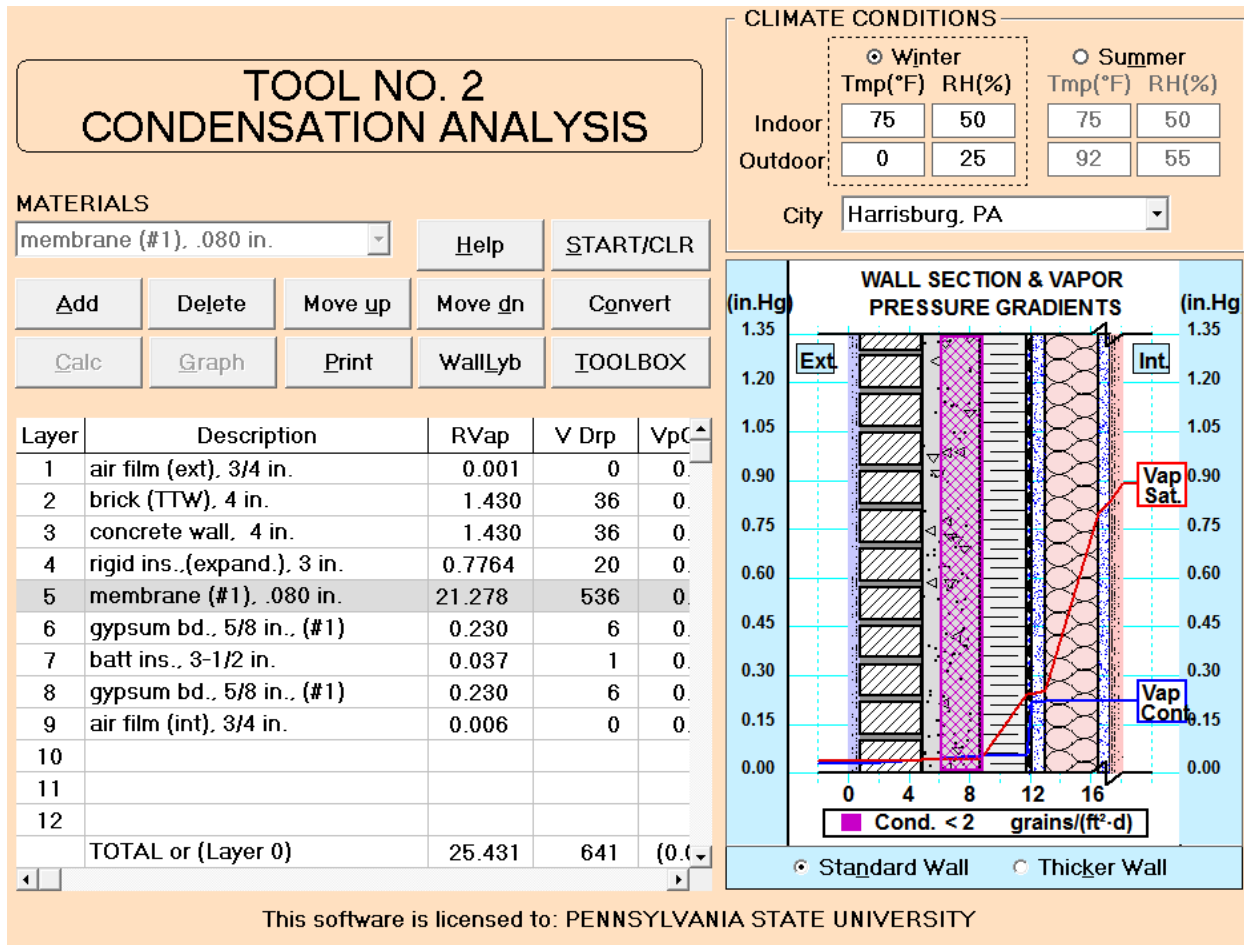


Figure 12: HAM Condensation Analysis of Existing Wall – Winter Condition – Vapor Barrier

Condensation Hand Calculations of Existing Facade

Hand calculations were done to ensure the validity of HAM's analysis (Table 7). The hand calculations confirm potential condensation problems if the wall were to be installed without the integral vapor barrier (Figure 13).

Values for R-values and Permeance were found according to ASHRAE 2009 Fundamentals Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values and Table 7 Typical Water Vapor Permeance and Permeability for Common Building Materials.

	Temperature	R-value	Saturated Humidity Ratio	Humidity Ratio	PERM
Outside Air – Brick Interface	4.7	0	0.004	0.002	0
Brick – Concrete Interface	5.8	0.33	0.004	0.006	1.5
Concrete – Polysisocyanurate Interface	8.2	0.4	0.004	0.008	0.15
Polyisocyanurate – Interior Air Interface	75	20	0.019	0.009	1.03
Interior Air	75	0	0.019	0.009	0

Table 7: Hand Calculation Condensation Analysis of Existing Wall – Winter Condition – No Vapor Barrier

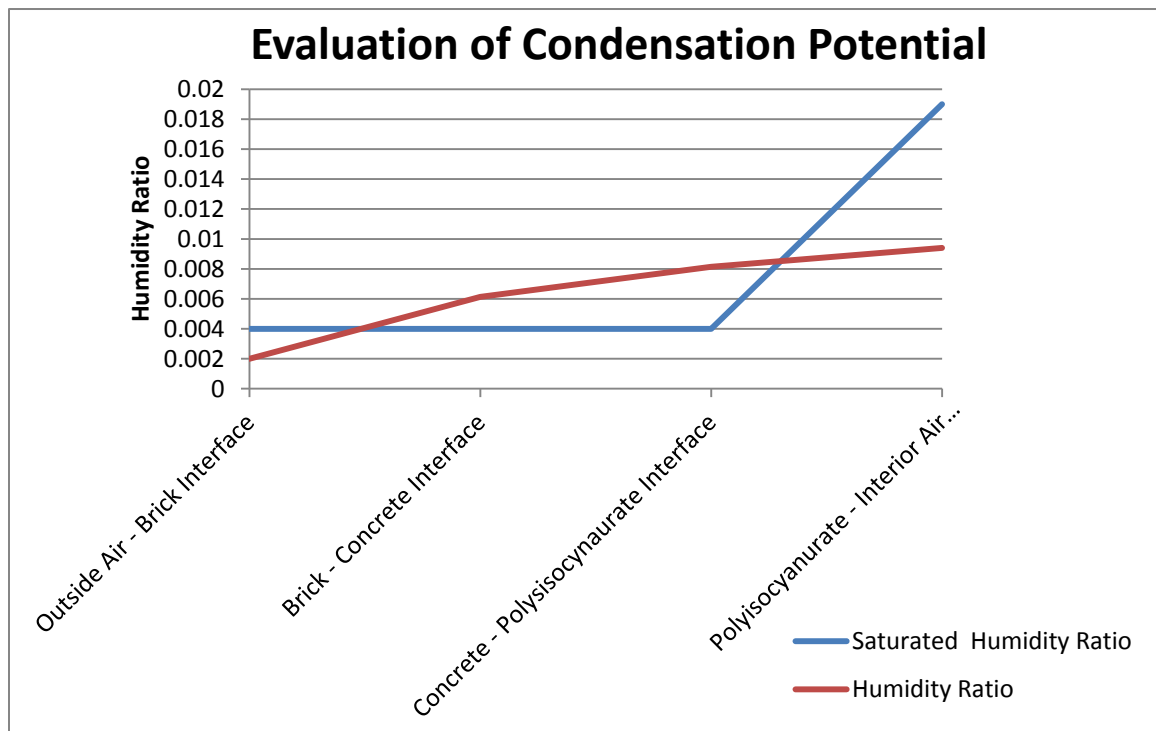


Figure 13: Evaluation of Condensation Potential of Existing Wall – Winter Condition – No Vapor Barrier

CTSF Analysis of Existing Facade

To more accurately analyze the performance of the existing assembly a Conduction Time Series Factor Analysis was performed through ASHRAE distributed Load Calculation Software. The assembly was recreated with the thermal properties of conductivity, density, specific heat, and resistance as given per ASHRAE Fundamentals. Accurate thicknesses were used, and the assembly received an R value of 29.7. In addition the wall produced a CTSF that represents a relatively flat loading profile, as seen by Figure 14.

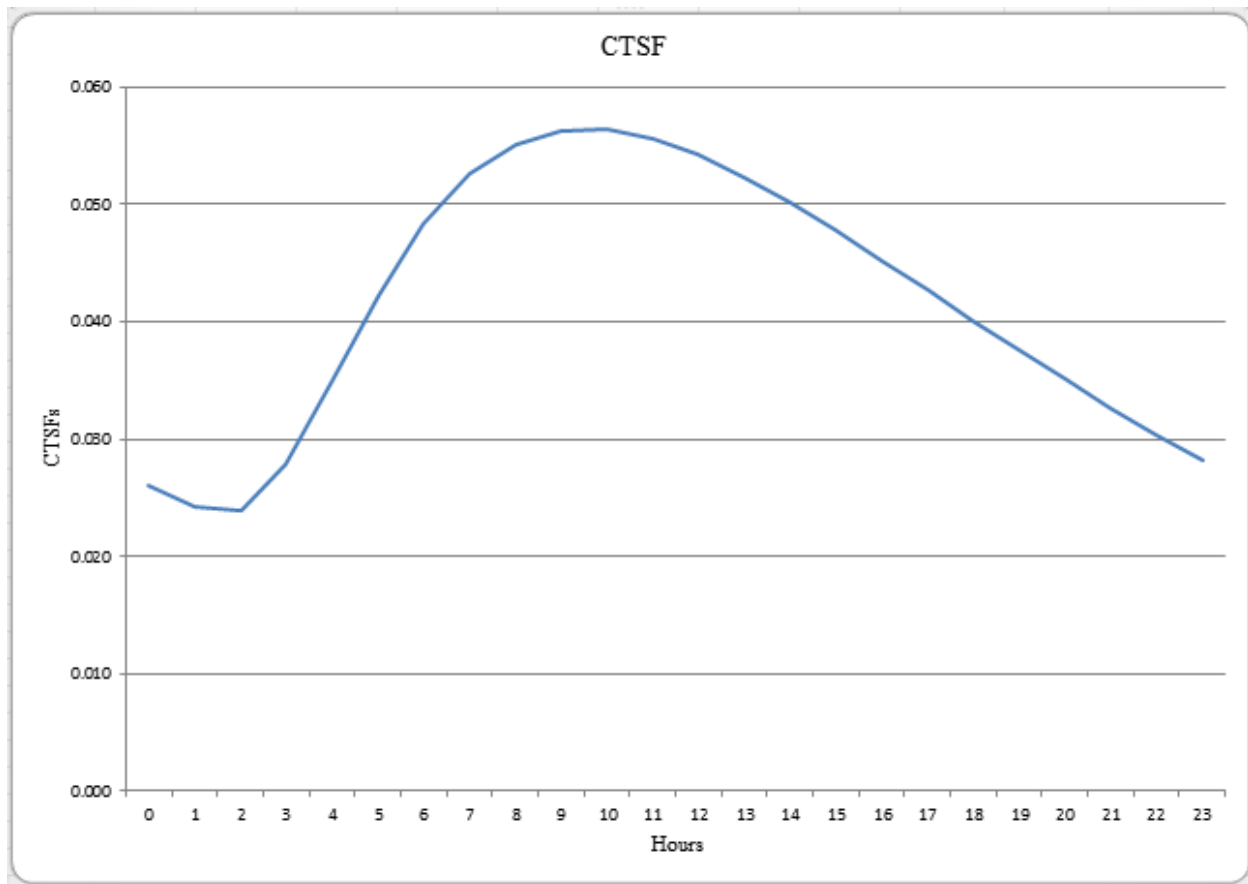


Figure 14: Conduction Time Series Factor of Existing Wall

Structural Analysis of Existing Façade

Structural composition of the existing panel consists of a 6in exterior panel with 5 ¾" top and bottom returns and 9in side returns. The largest typical panel spans an entire 22ft bay horizontally and 11'-9 ¾" span vertically. Due to the large ratio in length-to-width it can conservatively be assumed that the vertical section of the precast concrete panel spans vertically between the top and bottom return and the top and bottom return span between the two end returns.

In order to properly redesign the wall composition incorporating high performance elements including phase change materials and an air gap it benefits the design team to understand the structural implications of changing concrete thicknesses, adding concrete, and structural connections that hold the panel together and in place. To gain this knowledge base structural analysis of the existing panel including critical load cases and design loads need to be considered. Critical stresses must be calculated in the structural materials and monitored as changes are made to the façade panel composition.

Design Load Cases

The initial loads cases considered were obvious for an architectural façade panel supported on the exterior of a building structure. The two load cases considered were in place loads due to localized wind pressures and self-weight of the panel itself. Localized wind pressures were calculated per ASCE7-05 chapter 6. The most critical wind load was used to analyze the panel. Wind pressures on a building increase as we move upward across the building height. Therefore the maximum wind pressures occur at the maximum vertical height of the building. ASCE7-05 defines specific localized pressures for components and cladding specifically. Although the Main Wind-Force Resisting System wind loads had already been calculated and used in the lateral analysis of MSC additional calculations were necessary to calculate the critical localized pressure on the façade panels. These calculations are available in Appendix-G. The critical localized design pressure was calculated as 31.87psf.

This localized pressure was used to calculate the maximum stresses in the existing panel, with 6in of effective concrete, due to flexural tension. This was directly compared to alternative thicknesses for future use in designing alternative panel compositions. It was found from this analysis that the existing 6in of concrete was more than adequate to take the design loads due to wind. In fact for wind alone, even a thickness as small as 3in could be used safely, in ideal conditions, to adequately resist the design wind loads. This assumption was used initially in designing the PCM wall composition. Tables 8 and 9 summarize the results from this analysis.

The analysis for self-weight for in-place loads, by inspection, can be essentially disregarded as a critical load case. The effective depth for bending in flexure due to dead loads is the entire width of the panel, so the tensile stress in the concrete at the base of the panel is very low. In fact the panel only needs to be 2in to stay uncracked due to this load case alone. Figure 15 shows the design theory behind the two load cases considered for the existing panel analysis.

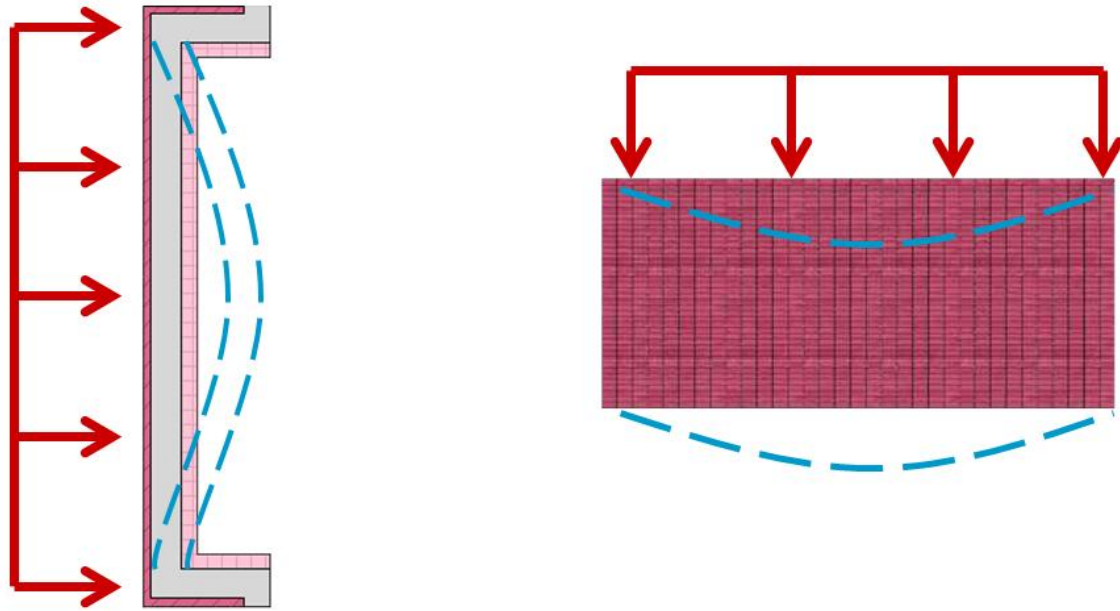


Figure 15: Structural Load Cases: Left- Flexure Due to Wind, Right- Flexure Due to Dead Loads

Thickness (in)	I (in4)	C (in)	Fr (psi)	ϕM_{cap} (lb-ft)	Mu(wind)
2	8	1	530	318	694
3	27	1.5	530	716	694
4	64	2	530	1273	694
5	125	2.5	530	1989	694
6	216	3	530	2864	694

Table 8: Thickness Analysis Due to In Place Wind Loads For Existing Façade Panel

Thickness (in)	I (in4)	C (in)	Fr (psi)	Mcap (k-ft)	Mu(sw)
2	341352	68.1	530	222	>128
3	502652	68.1	530	326	>128
4	663952	68.1	530	431	>128
5	825252	68.1	530	536	>128
6	986552	68.1	530	641	>128

Table 9: Thickness Analysis Due to In Place Dead Loads For Existing Façade Panel

Thermal and Moisture Performance of PCM Panel Alternate Facade

A proposed redesign of the façade panel aims to improve thermal performance while reducing panel weight.

The composition of the redesigned panel, Figure 16, will be 2" face brick, 3" concrete, 3" airspace, 3" polyisocyanurate rigid insulation, 3" PCM impregnated concrete, and 5/8" gypsum board. This composition will create a plane designed to wick and weep water to the exterior, preventing condensation problems. It will also reduce panel depth, effectively reducing concrete weight, while improving thermal performance.

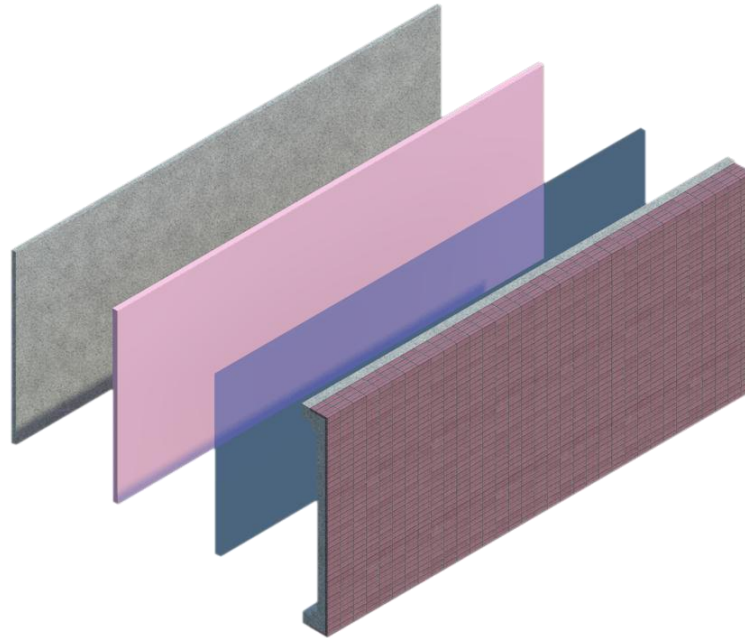


Figure 16: Exploded View of Alternate PCM Façade Panel Composition

A phase change material (PCM) will be impregnated into the concrete to enhance the CTSF of the wall. The specific material to be evaluated is BASF's Micronal PCM. This powder is able to be dispersed in cement mortar (concrete) easily incorporating it into the precast assembly. There are no associated workability or longevity issues with the Micronal product. The PCM material has a high overall storage capacity, 135 kJ/kg. The density of the material is about 900 kg/m³ with about 100 kJ/kg of latent storage.

To confirm the attributes of the Micronal product, research was done to compare its properties to other established materials. The Micronal product appears to be similar to Parafin Wax C18, given by the article "Review on Thermal Energy Storage with Phase Change: Materials, Heat Transfer Analysis and Application" by Zalba. Through the research in "Potential Applications of Phase Change Materials in Concrete Technology" by Bentz, a 15 percent by weight mixture could effectively use the PCM material to replace sand in the concrete mix. The combined properties of the PCM and PCM concrete can be compared in the Table 10 below.

	Conductivity (W/m ² K)	Density (kg/m ³)	Specific Heat (kJ/kg K)	Specific Heat (kJ/m ³ K)
Insulation	.03	42.4	1.214	51.5
Concrete	1.73	2200	0.841	1,850.2
Phase Change Material	.15	900	12.143	10,928.7
15% PCM Concrete	1.49	2005	2.536	5,084.7

Table 10: Comparison of Thermal Properties

R-Value H.A.M. Analysis of Redesigned Façade

To ensure the PCM material will operate to its maximum potential, the wall composition will be designed to retain the PCM concrete section within a 55-85 degree range. A HAM analysis, (Appendix F), was done to evaluate the required thickness of insulation to retain the PCM in its operative range. The 3" existing insulation thickness will be retained. The total thickness of the redesigned panel will be 16", seen in Figure 17.

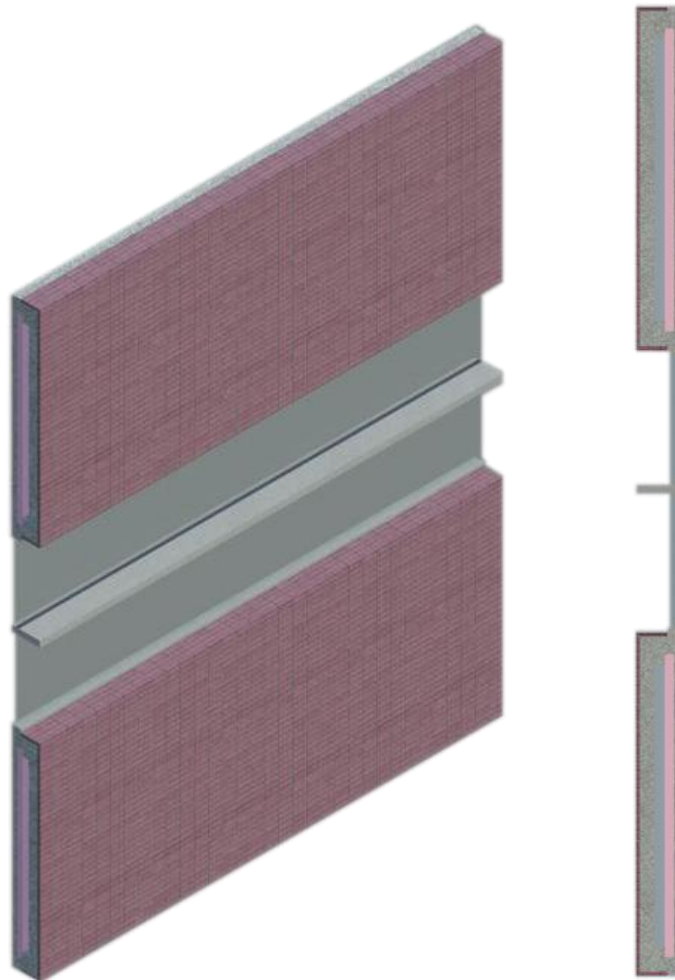


Figure 17: 3D Render and Section of Alternate PCM Façade Panel Design

Condensation H.A.M. Analysis of Alternate PCM Façade Design

To evaluate condensation potential, a HAM analysis was performed on the redesigned assembly. The summer conditions show no condensation (Appendix F), but the winter conditions show condensation within the air gap, Figure 18. The redesigned assembly is designed like a cavity wall. It will allow for condensation to form on the exterior side of the insulation where it will follow a drainage plane down the wall to be wicked and weeped out of the cavity, effectively negating any potential condensation issues. According to Lstiburek's article, "Confusion About Diffusion", moisture in an assembly will migrate and condense on the coldest surface, rather than within the insulation. To help prevent detrimental effects of moisture, the insulation board should be specified for exterior use and construction practices should ensure proper weeping out of the cavity.

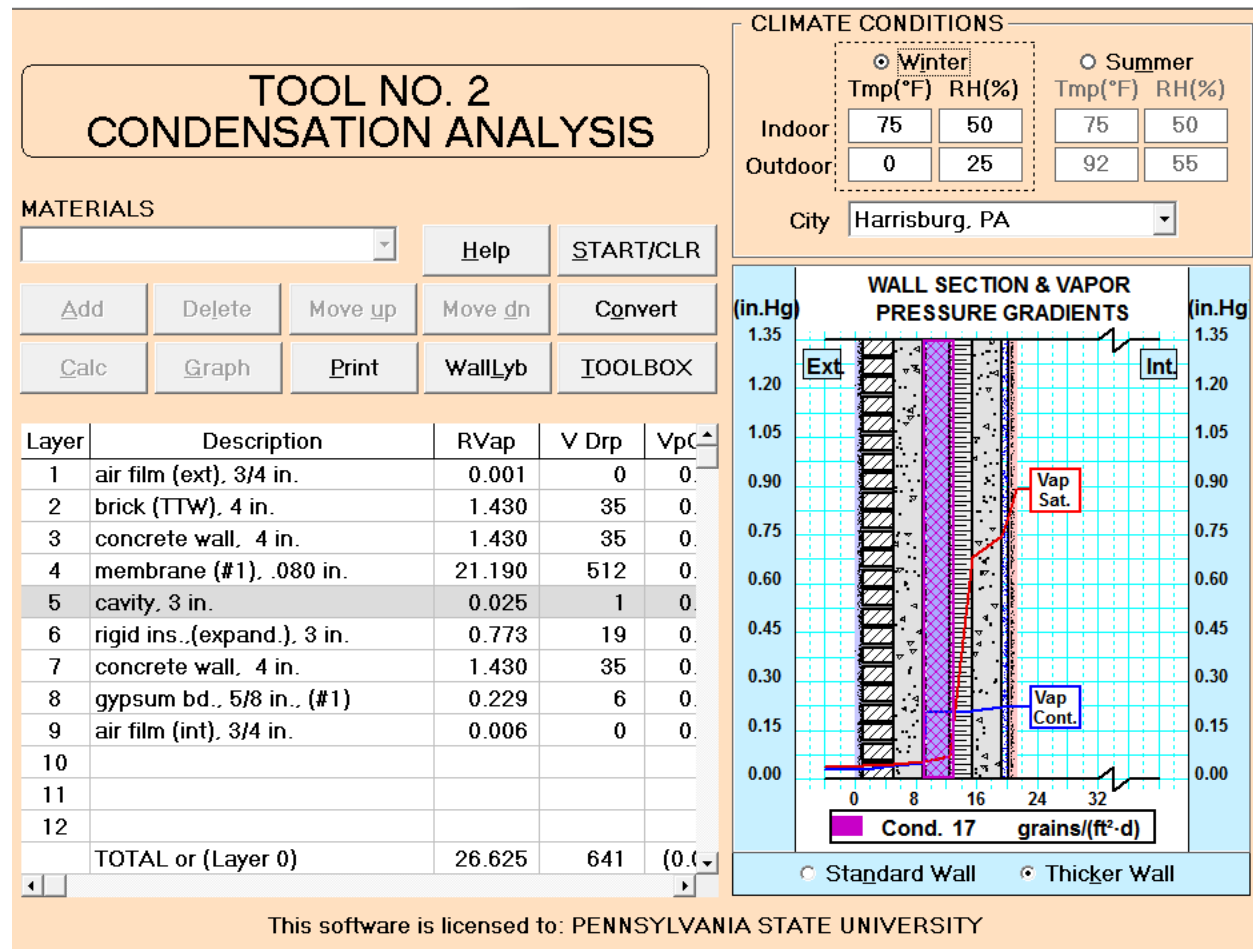


Figure 18: Condensation Analysis of Redesigned Wall – Winter Conditions

CTSF Analysis of Redesigned Façade

To evaluate the thermal performance of the redesigned assembly a Conduction Time Series Factor analysis was performed. The redesigned façade, incorporating the pcm concrete, has a lower R-value of 18.3, but it has a significantly flatter load profile Figure 19. This flattered load profile allows for the potential to reduce mechanical equipment size and off set peak loads. The lower R-value is mainly due to the removal of the existing half-wall separating the plenum and conditioned room. This removal has potential to increase floor area around the exterior perimeter of all spaces.

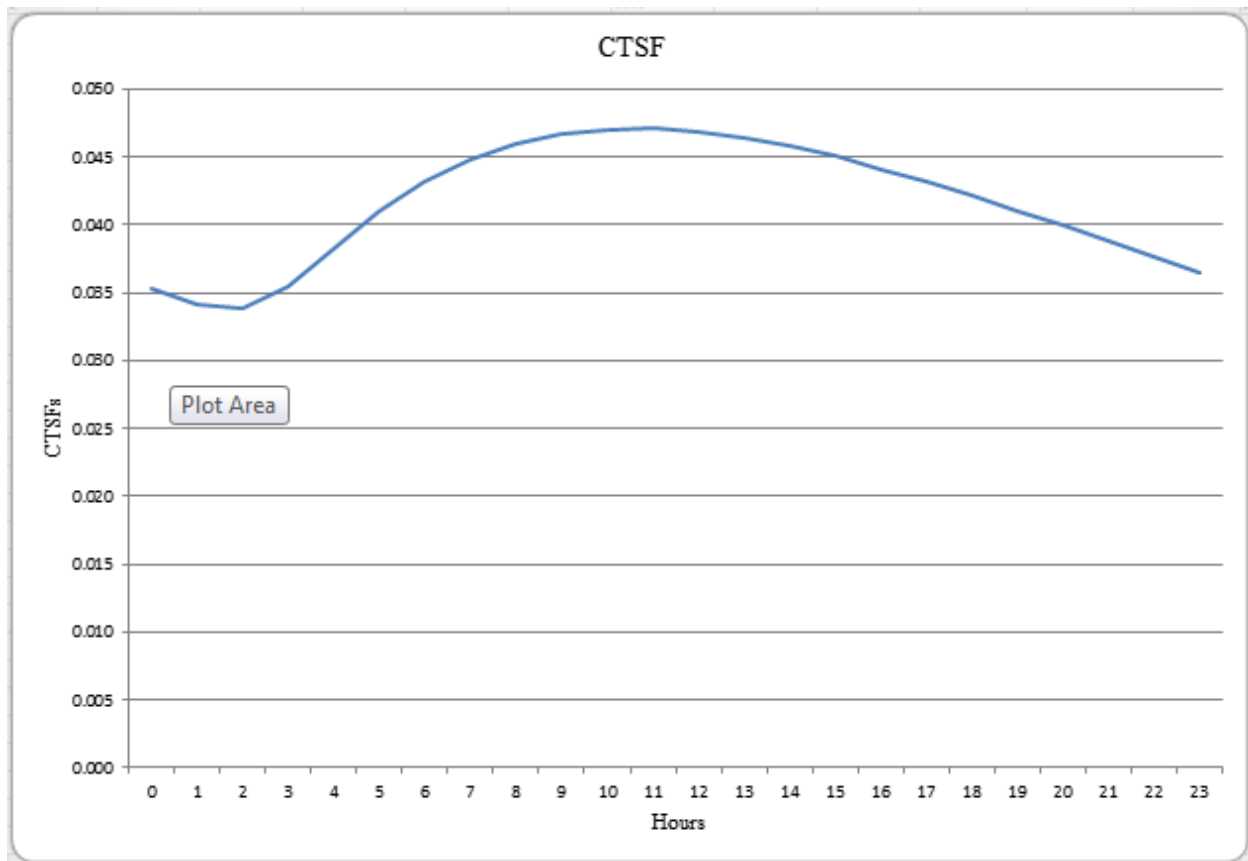


Figure 19: Conduction Time Series Factor – Redesigned Wall

Structural Performance of PCM Panel Redesigned Facade

Structural

During the conceptual and performance based design of the new PCM panel and wall composition analysis secondary considerations arose that affected the structural integrity of the proposed PCM façade panel composition. Issues were discovered during structural and construction management coordination discussions. In place wind and dead loads were adequate considerations for the analysis of the existing panels, however, other loads cases became more critical when considering the entire precast panel process from the precast plant and fabrication process, through the act of transportation, lifting on site, as well as the in place loads.

The most critical load case determined from a constructability analysis of the precast panel life cycle was realized when looking at images of the fabrication at the precast plant. The panels were cast with the front panel face down and all returns projecting upward. When the formwork was to be removed and the panel stood up it would have to be picked up from one side or the other to stand it up. During this process the panel is essentially bending out of plane, similar to the wind load case, under its own dead weight. When this load case was analyzed with respect to minimum permissible thickness of the front panel it was determined that the minimum thickness was 4.5in instead of the original minimum of 3in. Figure 20 shows the load theory behind this load case. Table 11 summarizes the results of this study.

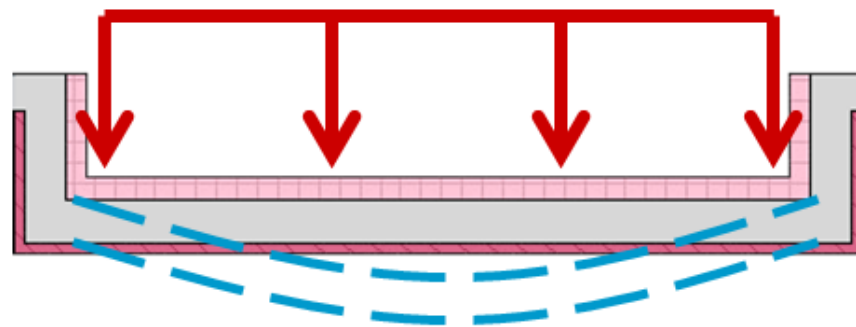


Figure 20: Structural Load Case: Bending Due to Self-Weight During Precast Fabrication.

Thickness (in)	I (in4)	C (in)	Fr (psi)	ϕM_{cap} (lb-ft)	Mu(SW)	Mu(wind)
2	8	1	530	318	858	694
3	27	1.5	530	716	1096	694
4	64	2	530	1273	1335	694
4.25	77	2.125	530	1437	1394	694
5	125	2.5	530	1989	1573	694
6	216	3	530	2864	1811	694

Table 11: Thickness Analysis Due to Self-Weight Flexure During Precast Fabrication

Constructability Design Review

The key concerns for the design of the precast panel were the ability to transport and erect it. A panel which was too thin would have a higher chance of cracking during transportation due to movement on the trucks. This would also hold true during the fabrication of the panel. In order to lift the panels with a crane during erection, hooks needed to be anchored into the panels. Without the proper thickness, the reinforcing required would not be able to be placed within the panel. This also holds true for the reinforcing required for the panel itself. The concrete sections needed to have enough concrete to cover the reinforcing required for the panel.

Glazing Property Comparison – Existing and Redesign

Analysis on the thermal performance of the glazing assembly will also be analyzed. The current assembly consists of Viracon's VE1-2M double pane low-e glazing assembly. A proposed redesign would utilize a similar glass, but in a three pane configuration with two low-e surface coatings on surfaces 2 and 4. The U values and SHGC factors of the glass are converted to overall values incorporating the framing assembly through ASHRAE 2009 Fundamentals Table 4 U-Factors for Various Fenestration Products in Btu/hft²F and Table 10 Visible Transmittance, Solar Heat Gain Coefficient, Solar Transmittance, Front Reflectance, Back Reflectance, and Layer Absorptances for Glazing and Window Systems. Using just the glass factors would generate inaccurate results, as they do not account for the highly conductive aluminum framing system. The framing system was selected to be a thermally broke aluminum frame. Table 12 shows the glazing properties and the adjusted glazing assembly properties.

	Low-e value	U-value	SHGC	Tv	Cost/SF
Double Pane Glazing	0.05	0.28	.38	0.72	\$13
Double Pane w/ Aluminum Frame	0.05	0.41	0.37	0.72	Installed \$55
Triple Pane Glazing	0.10	0.18	.27	0.55	\$21
Triple Pane w/ Aluminum Frame	0.10	0.27	0.26	0.55	Installed \$65

Table 12: Comparison of Thermal Properties

Energy Analysis of Design Options

To evaluate the inclusion of the façade redesigns, both the wall and glazing options, a Trane Trace model will perform an energy analysis comparing the performance of iterative design options. The base model from Technical Assignment 1 will be used. The most accurate façade thermal properties will be used as calculated in preceding sections. To best take advantage of the load flattening ability of PCM, Trace will use the RST cooling and CEC-DOE2 heating methods. These methods most accurately model the radiant time series factor and include thermal capacity calculations. Using a Trace model will enable the depiction of total energy savings throughout the year, incorporating the many interdependencies of systems that are often difficult to accurately track.

The complete Trace Outputs can be found in Appendix F.

Graphical break downs of this information can also be found in Appendix F.

Table 13 below reveals only modest savings of the PCM Panel design, and negligible decreases in peak loads. Due to this modest savings, the PCM Panel Redesign does not appear to be a feasible solution as the existing system currently performs well and will no longer be included in future design options. Table 13 below does, however, show promising opportunity in energy savings for the Triple Pane Glazing Assembly.

	Existing	PCM Panel Redesign	3 Pane Glazing Redesign	PCM and 3 Pane System
Building Energy Consumption (kbtu/ft2-yr)	154.1	150.9	141.0	138.8
Source Energy Consumption (kbtu/ft2-yr)	247.8	243.9	235.2	232.4
Electricity (kWh)	597,990	593,556	602,542	598,554
Purchased Steam (therms)	20,676	20,217	18,065	17,795
Purchased Chilled Water (therms)	27,109	26,295	23,753	23,177
Electricity On- Peak Consumption (kWh)	56,350	55,822	57,301	56,825
Purchased Steam On- Peak Consumption (therms)	3,000	2,999	2,688	2,698
Purchased Chilled Water On- Peak Consumption (therms)	5,888	5,801	5,351	5,297

Table 13: Total Energy Consumption of Design Options

Yearly Operating Costs of Design Options

Applying the total energy consumption to the Penn State Utility Fact Sheet, found in Appendix F, allows for calculation of yearly operating costs Table 14. It is assumed that all utilities will be purchased from Penn State at the given rates. No adjustments have been included for peak demand charges.

	Existing	PCM Panel Redesign	3 Pane Glazing Redesign	Redesigned Façade System
Electricity Costs	\$59,799.00	\$59,355.60	\$60,254.20	\$59,855.40
Purchased Steam Costs	\$44,763.54	\$43,769.81	\$39,110.73	\$38,526.18
Purchased Chilled Water Costs	\$49,699.83	\$48,207.50	\$43,547.17	\$42,491.17
Total Yearly Costs	\$154,262.37	\$151,332.91	\$142,912.09	\$140,872.74

Table 14: Yearly Operating Cost Breakdown

Case Study Evaluation of Model Accuracy

The estimated operating cost is about \$3.50 / SF. In order to put this value into perspective, the Millennium Science Complex was compared to a base case established by the Department of Energy's "Laboratories for the 21st Century - Energy Analysis". The study "analyzes the effects of energy efficiency measures in a simplified laboratory model". An example for the case study in Seattle can be found in Appendix F. The Seattle case incorporating an enthalpy wheel with a VAV system, similar to the MSC system, consumes the least amount of energy at \$4.70 / SF. Compared to the MSC design, the Seattle case consumes a significantly increased amount of energy. Despite the large difference, the MSC energy model appears to be accurate. The high performing façade, district utility costs, demand control ventilation, newer more efficient systems, and a high proportion of office to laboratory space could account for the energy savings in the MSC model compared to the DOE model. This comparison establishes credibility of the modeling accuracy of the MSC energy model.

Construction Cost of Façade Assemblies

In order to fully evaluate the benefits or disadvantages of changing the existing glass assembly from double pane glazing to triple pane glazing, a cost must be determined for each. As referenced in a previous section, costs were obtained from a Viracon representative for each of the two types of glazing. Based on cost estimates provided by Whiting-Turner in a 2008 bid estimate, a cost per façade section was determined. Each façade section consists of the following:

- Precast Panel (of specified size)
- Structural Steel Connections
- Light Shelf
- Insulation
- Window Assembly/Glazing

In order to provide an accurate comparison of the cost of the existing double pane glazing assembly to the same assembly with triple pane glazing, Whiting-Turner's estimates were adjusted to account for the change. Using the given cost of \$55/SF of window, the cost of the existing glazing was subtracted out, and the cost of the triple pane glazing was added in. This resulted in a gain of approximately \$10 in the material cost, which left a new overall cost at \$65/SF. Using this cost, in conjunction with the costs of the remaining components of each façade section, the cost per façade section could be determined. Keeping in mind that the focus of this analysis is on the third floor, the façade sections were broken into three differing units, based on the three precast panel lengths on the floor. These consisted of the typical 22-foot panel length, as well as a 14-foot and 31-foot panel length. The following table shows the total costs of the façade sections for the third floor using the existing panel, broken down by panel length and double/triple-pane glazing. As can be seen in the table below, the change to a 3-pane glazing assembly increased the cost of the façade enclosure on the third floor by \$98,720. In order to determine whether this increase in material cost is justified, it must be compared to the life cycle cost of the third floor with the new glazing system. For a more detailed breakdown of the costs in the table below, please see Appendix D.

Third Floor, Existing Panels		
Length of Panel	2-Pane Glass Assembly	3-Pane Glass Assembly
22ft	\$1,496,443	\$1,587,963
14ft	\$41,091	\$43,331
31ft	\$78,510	\$83,470
Total	\$1,616,044	\$1,714,764
Increased Cost of 3-Pane	\$98,720	

Table 15: Construction Costs of Existing Panels on Third Floor with 2 & 3-Pane Glass

Life Cycle Cost of Triple Pane Assembly

A life cycle cost analysis was performed to evaluate the energy savings potential of incorporating triple paned glass. A full break down of calculations can be found in Appendix F. The calculations for the existing design will be incorporated, but for future life cycle costs only the final values will be tabulated and included.

From the energy analysis, total values for electricity, steam, and chilled water were used to calculate a 30 year life cycle cost. From the construction manager, installed costs of each system were tabulated. Adjustment factors including discount rates with inflation were found from the Energy Price Indices and Discount Factors for Life Cycle Cost Analysis 2010, US Department of Commerce. A discount rate of 2.7% was found from Table A-1 for Office of Management and Budget 30 Year Discount Rate, found in Appendix F. The corresponding correction factor was applied to each year's energy cost. Table Ca-1 allows for the escalation in fuel prices, found in Appendix F. Given the current market conditions and the future of Pennsylvania's energy sources, natural gas is assumed to be the future producer of all electricity, steam, and chilled water. A 5% fluctuation in energy costs helps account for market volatility and encourages the investment in energy savings.

By summing the aggregate present values of the 30 year energy costs, energy can be compared to installed costs. In final comparison, the option with the lowest present value cost is the most economical design. Care must be taken in choosing an option with only marginal benefits, because of the inaccuracies in predicting energy costs.

By selecting the triple pane glazing assembly, there is potential to save \$11,350 a year on operating costs, creating a simple payback of about 9 years. Real payback will be slightly longer, but a total Life Cycle Cost savings potential of \$194,000 justifies the increase in initial investment shown in Table 16.

Life Cycle Cost Assessment 30 Year	Existing Design	3 Pane Glazing Redesign
Installation Cost	\$1,912,205	\$2,010,925
Electricity Cost	\$1,541,063.92	\$1,552,794.75
Chilled Water Cost	\$1,280,801.01	\$1,122,242.30
Steam Cost	\$1,153,589.13	\$1,007,911.96
Present Value Total Life Cycle Cost	\$5,887,659	\$5,693,874

Table 16: 30 Year Life Cycle Cost Assessment

Final Selection of Wall Composition

The redesigned alternative façade composition will retain the existing façade’s panel construction consisting of 2” face brick, 6” concrete, and 3” insulation. Evaluation of the PCM alternative will be dropped from further analyses as it failed to prove significant energy savings and reliable structural integrity. Inclusion of triple pane glazing will be integral to all future analyses as it produces a simple payback period of just less than nine years, with significant energy savings seen in Table 17.

	<i>Existing</i>	<i>Triple Pane Glazing</i>	<i>Savings</i>
<i>Total Yearly Operating Costs</i>	\$154,262	\$142,912	\$11,350
<i>Installation Costs</i>	\$1,616,044	\$1,714,764	\$-98,720
<i>30 yr Life Cycle Cost</i>	\$5,591,498	\$5,397,713	\$193,785

Table 17: Wall Composition Life Cycle Cost Analysis Summary

WINDOW TO WALL RATIO ANALYSIS

Design Approach

Reevaluating the wall to glass ratio will select a façade that reduces building energy with improved daylighting opportunities. The ratios of wall to glass will be determined within the room cavity, so that 50% glass will, in reality, refer to a whole building 30.6% glazing, as 90% glass will refer to a whole building 55% glazing. The total floor to floor height is 18' and the room cavity is 11'. The ratios evaluated were 50%, 60%, 70%, 80%, and 90% with base case is represented by the 70% glazing Existing Façade. All façade orientation naming (North, South, East, West) in this report refer to project North, South, East and West. The final reports reflect the analysis and inclusion of the improved triple pane glazing option. The proper selection of WWR will reduce the yearly building energy while improving daylighting performance.

Mechanical performance will be evaluated by a reduction in yearly energy consumption. Whole building energy consumption will be used to evaluate the benefits of changing wall to glass ratios. This whole building energy analysis, performed in Trane Trace, will account for both increases and decreases in heating and cooling loads as window to wall ratios change. Performance will be measured in total energy savings relative to the existing designs 70% WWR. The whole building approach will also account for varying performance throughout all orientations and seasons

In order to optimize the façade the lighting/electrical window to wall ratio analysis was conducted utilizing Daysim, and its ability to evaluate daylight performance metrics. The performance of the new WWR ratios was evaluated with respect to useful illuminance and daylight autonomy values, 100-3000 lux, and 322.8 lux respectively. The architecture of the Millennium Science Complex contains relatively shallow perimeter spaces, the majority being 15' deep. The study started by looking at the third floor as a whole. The analysis was used to show that daylight was a viable option for the perimeter spaces in the MSC. From there the perimeter Student Study Areas were evaluated using more detail in the model, including all mullions and higher simulation settings. The new window to wall ratios will then be compared with the existing façade.

The Window to Wall Ratio results were plotted and overlaid with the mechanical team member's results to select a final WWR. The selection of the final window to wall ratio will be done in coordination with the Mechanical team member. This report will create criteria in tandem with the L/E's daylighting report to help select an optimum glazing percentage.

Daylight Analysis

Daysim provides important information regarding the performance of a buildings daylight delivery system. Those metrics are daylight autonomy, continuous daylight autonomy, and useful illuminance. Daylight autonomy (DA) provides the percentage of the year when a specified illuminance level is reached through daylight during a given operating period. This metric is useful in analyzing a system where the electric lighting will be controlled using a switching system. Continuous daylight autonomy (DA_{con}) operates on the same principle as DA with an adjustment and partial percentage given to times when the illuminance level is partially met. This metric is useful in analyzing an electric lighting system integrated with daylight through a dimming system. Useful Illuminance is a daylight performance metric that determines the percentage when a point is within a specified illuminance range. This metric is helpful to determine times when excessive daylight is present. Decreasing these times helps reduce the cooling loads, and discomfort glare.

The daylight study of the third floor was the conducted to determine the feasibility of changing the Window to Wall Ratio for the Millennium Science Complex façade. The model excluded mullions, and the Daysim settings (see table 18) were run at lower settings do to the size of the model. The calculation grid was placed at a typical work plane height of 2'-6". The Daylight Autonomy calculations for the whole third floor can be found in Appendix E, while a sample DA calculation can be found in Figure 21. The outcome of this portion of the study was that the reduction of the WWR still provided useful daylight performance.

Daysim Input Settings	
Ambient Bounces	3
Ambient Divisions	300
Ambient Resolution	100

Table 18: *Third Floor Daysim Settings*



Figure 21: Millennium Science Complex Third Floor Daylight Autonomy 322.8 lux

After the feasibility study was conducted a more detailed analysis was conducted on the Millennium Science Complex Student Area. The study included the new dimensions from the Mechanical team member's wall composition analysis. The wall composition analysis resulted in a panel with a thickness of 16". The student area was evaluated with each of the four building façade orientations with mullions. This portion of the study also used increased Daysim settings (see Table 19). The initial study was conducted without an exterior shade. When evaluating the façade performance it was decided that the exterior shade needed to be included due to increased percentages with excessive daylight.

Daysim Input Settings	
Ambient Bounces	5
Ambient Divisions	1000
Ambient Resolution	300

Table 19: Student Area Daysim Settings

Energy Analysis Results

Evaluation of both the existing façade and 3 pane glazing façade design options were modeled in Trane Trace. This model is the same model used in previous analyses, ensuring the continuity of data. The only variables changed were the percentage of glass in rooms affected by such a design change. Table 20 below shows the comparative energy consumptions of switching to 3 Pane glazing and altering the percentage of glass. Complete detailed Trace results can be found in Appendix F.

	50% Glass	60% Glass	70% Glass	75% Glass	80% Glass	90% Glass
3 Pane Façade Energy Consumption (kbtu/ft2yr)	134.8	136.9	139.5	141.0	142.5	145.8
Existing Façade Energy Consumption (kbtu/ft2yr)	142.9	146.9	151.6	154.1	156.8	162.3

Table 20: Room Cavity Glass to Wall Ratio Energy Analysis

Schedule and Logistic Impacts of Final Selection

The erection of the precast panels of the façade required much coordination in order to maintain the schedule. Precast deliveries needed to be coordinated with the erection of the precast as to ensure that panels did not arrive early or late. In addition, the erection of the precast needed to be coordinated with the erection of the steel framing. The goal was to have the precast erection occurring as early as possible based on the steel erection in order to enclose the building as early as possible. Erection of the precast began on November 16, 2009 on the Material Science Wing, and was completed at the cantilever on May 19, 2010. The breakdown of the schedule dates for the precast can be seen in the table below. The precast panels were erected in a typical sequence, starting at the north side of the Material Science Wing, and circling the building until the cantilever. The precast panels at the cantilever were erected on both sides of the cantilever simultaneously. This was done to balance the weight on the cantilever, and to prevent uneven loading and deflection on the steel. A site plan with the erection sequence can be found in Appendix D. One of the challenges faced by Whiting-Turner during the erection of the steel and precast panels was weather. The majority of the erection occurred during the winter months, which turned out to be a harsher winter in terms of snow than most predicted. Even considering any potential setbacks that may have occurred due to weather, Whiting-Turner did a great job in maintaining the schedule.

Task	Start	Finish
MS North Elevation PC Panels	11/16/09	12/11/09
MS East Elevation PC Panels	11/23/09	11/27/09
MS South Elevation PC Panels	12/7/09	3/31/10
LS East Elevation PC Panels	3/24/10	3/30/10
LS South Elevation PC Panels	3/22/10	3/26/10
LS West Elevation PC Panels	3/15/10	5/7/10
Areaway (MS) North PC Panels	5/14/10	5/19/10
Areaway (LS) West PC Panels	5/10/10	5/17/10

Table 21: *Original Erection Dates for the Precast Panels.*

Even though the precast panels were redesigned with a slightly different composition, this should not affect the speed at which the precast panels can be erected. The increase in size of the panel adds weight, but the removal of the side returns, as well as the decrease in the size of the top and bottom return, helps to balance the increase. Because of this, the mobile cranes used will be able to handle the redesigned panel. One of the concerns with a panel of increased height is transportation. The transportation route must be taken into account, especially when the route brings the trucks under bridges or overpasses. The height of the panel on the flatbed truck must not exceed the maximum height to go under any overpasses or bridges. It is assumed that with the increase in height, the flatbeds used for delivery could be engineered to carry the redesigned panels in order to keep them to a height acceptable for the delivery route.

Although the expectation is that the redesigned panel will not have any significant effects on the erection of the precast panels, it must still be coordinated with the construction of the structure. As will be seen later in this report, the structure is changed to concrete, which changes when the precast panels can be erected onto the building. Below is a summary table of the new erection dates and durations. These durations are based on the expected durations provided in Whiting-Turner's schedule. It is important to keep in mind that these durations are based off the erection of the precast panels under an ideal situation, without interruptions due to weather. As can be seen, the new schedule for the precast, based around the redesigned structure (seen later in the Plenum Investigation section of the report), finishes approximately two months earlier than the original schedule. The erection sequence of the precast panels was not changed due to the expected efficiency of erection is already presented. A full schedule

Task Name	Duration	Start	Finish
MS North Elevation PC Panels	10 days	Mon 12/7/09	Fri 12/18/09
MS East Elevation PC Panels	5 days	Mon 12/21/09	Fri 12/25/09
MS South Elevation PC Panels	13 days	Mon 12/28/09	Wed 1/13/10
LS West Elevation PC Panels	7 days	Thu 1/14/10	Fri 1/22/10
LS South Elevation PC Panels	5 days	Mon 1/25/10	Fri 1/29/10
LS East Elevation PC Panels	11 days	Mon 2/1/10	Mon 2/15/10
Areaway LS West Elevation PC Panels	7 days	Tue 2/16/10	Wed 2/24/10
Areaway MS North Elevation PC Panels	9 days	Mon 2/22/10	Thu 3/4/10

Table 22: *New Erection Dates for the Precast Panels.*

Criteria for Integrated Window to Wall Ratio Selection

After a group discussion it was decided that the WWR should not be above 70% because it would increase building loads, and not aid in the daylight delivery since the glazing would be below the work plane. The new ratios for consideration were 50%, 60%, and 70%

Lighting Electrical Criteria

For the daylight analysis the new ratios were analyzed with the exterior shade using Daysim and evaluated with respect to the existing façade, 70% WWR, performance (see Appendix E), using the Useful Illuminance metric. These values for the existing façade can be seen in Table 23, and the new ratios in Table 24. A sample comparison can be seen in (Figures 22-23). The remaining useful illuminance analysis can be found in Appendix E. Figure 24 shows the Lighting/Electrical graph that will be utilized to determine the final window to wall ratio against the other team member's graphs.

Existing Façade					
WWR	North	South	East	West	Average
Existing	0.78	0.69	0.82	0.67	74%

Table 23: Existing Façade Useful Illuminance Values by Orientation

Façade Orientation with Shelf					
WWR	North	South	East	West	Average
50	0.73	0.61	0.74	0.66	69%
60	0.76	0.68	0.78	0.67	72%
70	0.77	0.70	0.79	0.68	74%

Table 24: Useful Illuminance for tested Window to Wall Ratios

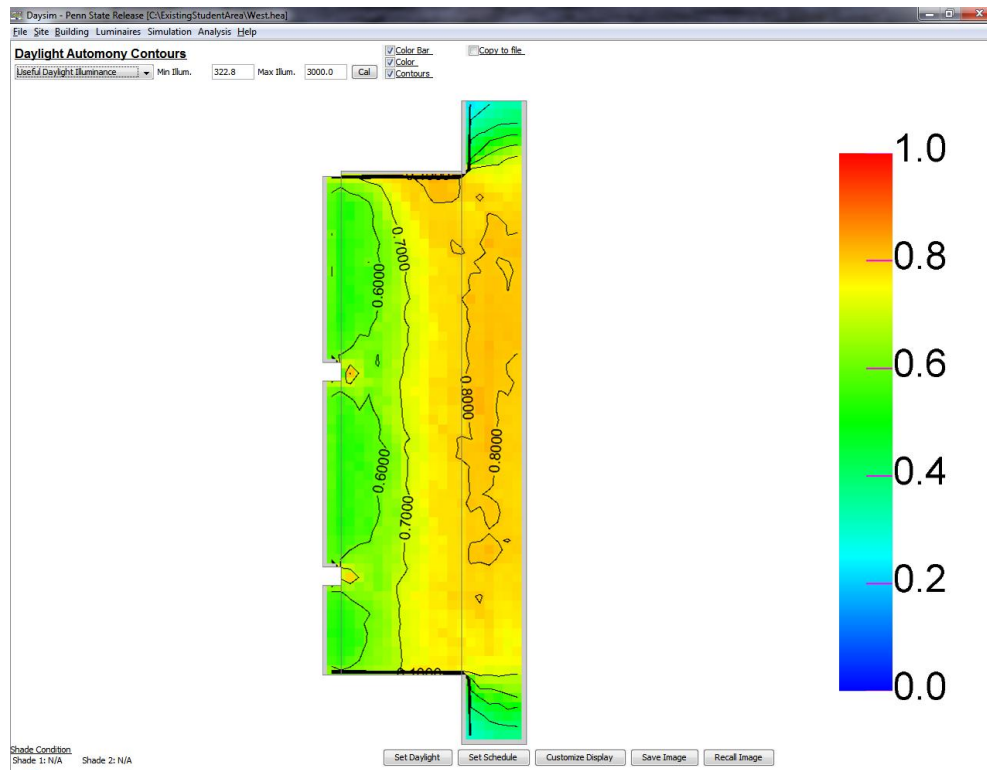


Figure 22: West Façade Existing Useful Illuminance

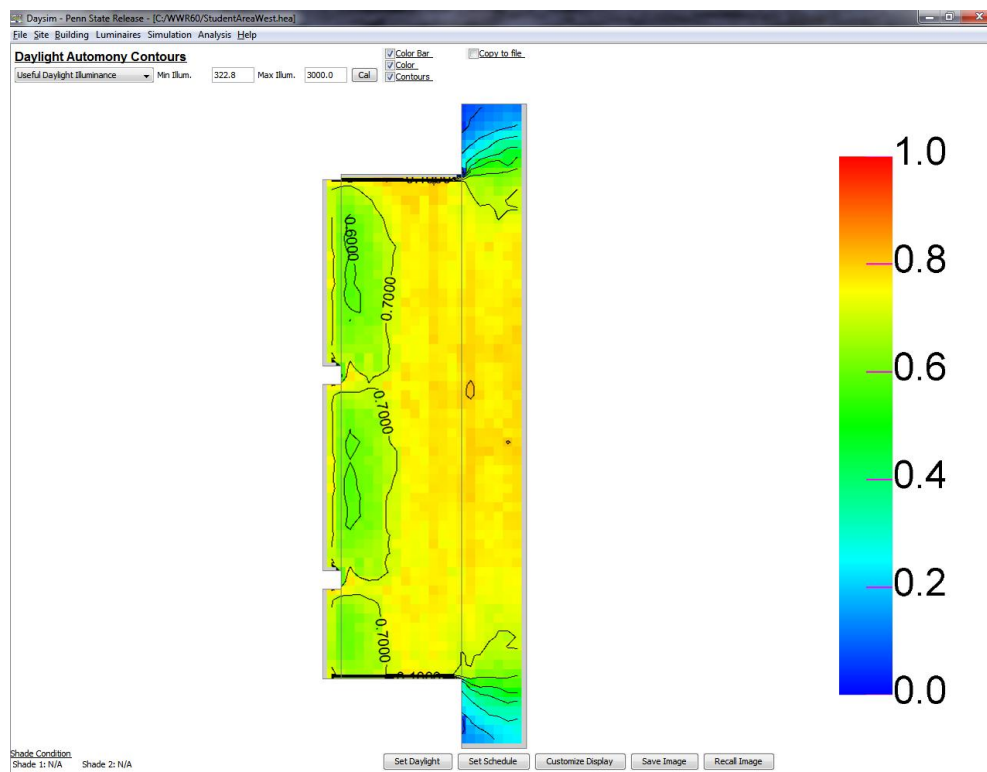


Figure 23: West Façade 60% WWR Useful Illuminance

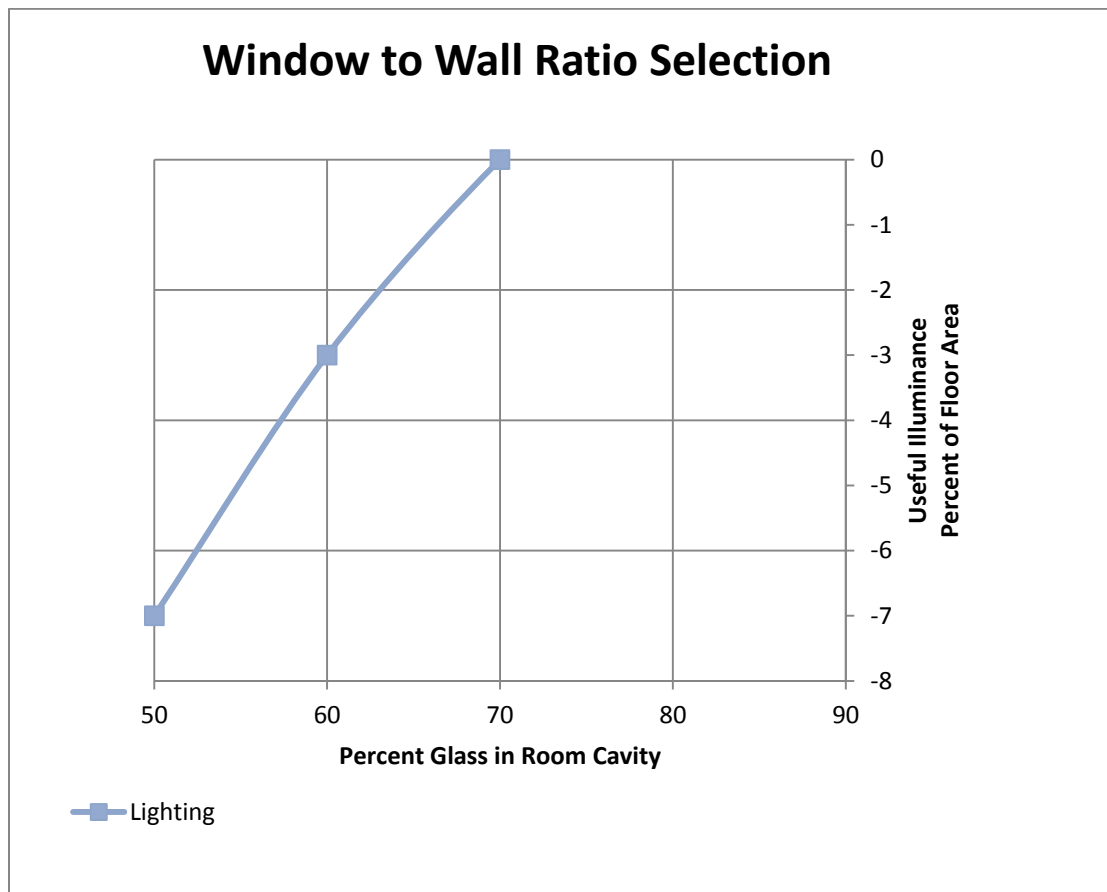


Figure 24: *Lighting/Electrical Window to Wall Ratio Analysis Graph.*

Mechanical Criteria

In order to select an optimum glazing ratio, mechanical energy results must be easily and coherently communicated to other team members. As it has already been determined economically feasible to use the redesigned 3 Pane Façade Assembly, mechanical input will refer the new design options back to the existing design. Below Table 25 represents the percent energy savings that each iteration will achieve compared to the base case, Existing Façade 70% Glass. This data was then plotted in Figure 25. The same chart will incorporate data from each other discipline selecting the final glazing percentage.

	50% Glass	60% Glass	70% Glass	75% Glass	80% Glass	90% Glass
Percent Savings Compared to Existing Design	11%	10%	8%	7%	6%	4%

Table 25: Mechanical Window to Wall Ratio Analysis

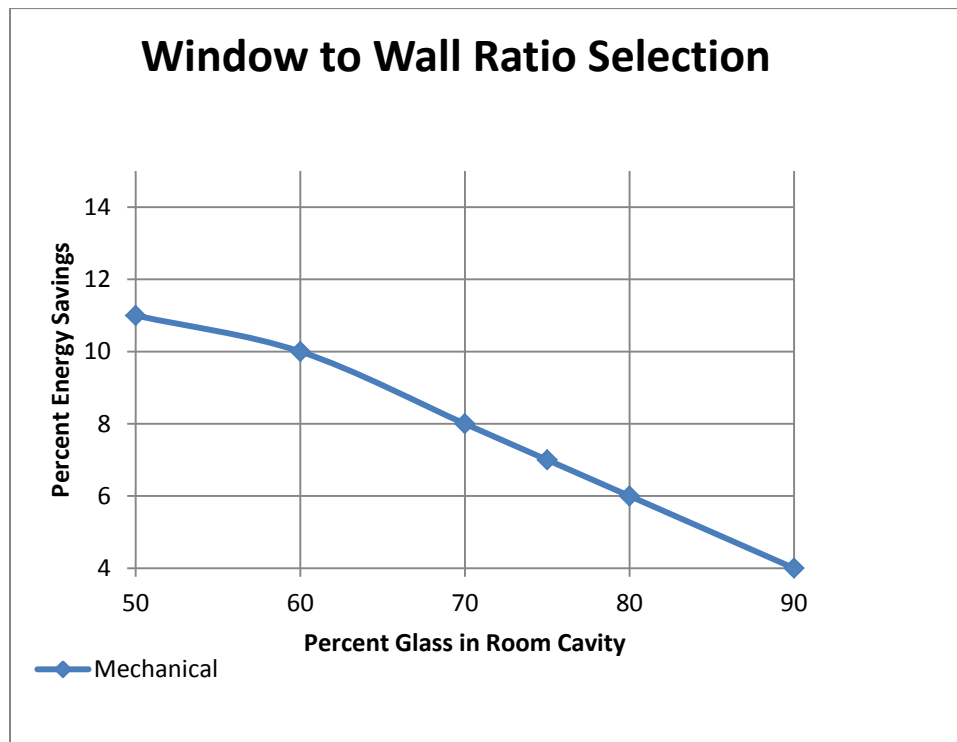


Figure 25: Mechanical Window to Wall Ratio Analysis Graph

Structural Criteria

A window to wall ratio was created considering the minimum thickness of the front panel of the façade. As the ratio decreases, the panel width increases which cause the dead load to increase and the span of the front panel to increase due to the top and bottom returns moving apart. As noted in Table 26 the largest minimum thickness requirement was due to the 50% window to wall ratio, which happens to be 6in. Structural and construction management collaboration hinted at reasons for the use of the existing 6in of concrete when observing details of reinforcement required for the front panel, top and bottom returns, and for the corbel style bearing connections. It turned out that the existing 6in of panel thickness was necessary simply to practically fit the required layers of reinforcement. Minimum reinforcing requirements and reinforcing required for shear and the corbel design are reported in Appendix-G.

Ratio (%)	Minimum Thickness (in)	M _{cap} (lb-ft)	M _{sw} (lb-ft)	M _{wind} (lb-ft)
50	6	2864	2819	1081
60	5.5	2406	2152	883
70	4.5	1611	1477	706
80	4	1273	1058	550

Table 26: Window to Wall Ratio Based on Minimum Thicknesses of Façade Panel

Construction Cost Criteria

Similar to the glazing analysis, a cost must be determined for the full redesigned panel and façade section to compare back to the existing façade. Through previous analysis, it was determined that the two most optimal window-to-wall ratios are the existing, 70%, and 60%. Based on cost estimates provided by Whiting-Turner in a 2008 bid estimate, as well as the costs for glazing provided in a previous section, a cost per façade section was determined for the existing and redesigned façade. As a reference, each façade section consists of the following:

- Precast Panel (of specified size)
- Structural Steel Connections
- Light Shelf
- Insulation
- Window Assembly/Glazing

With the existing dimensions for a ratio of 70% already determined, the cost of the redesigned features of the façade was created. Square foot numbers were determined for the precast panel and insulation, as well as the glass assemblies, based on their respective dimensions in the existing façade. The calculation of the light shelf was produced through several assumptions. By reducing the panel depth, and corresponding overhang, from 24" to 16", this forces the exterior light shelf to match the new depth. The original cost of this light shelf was provided as a cost per linear foot, which assumed a 24" light shelf depth. With the new depth of the light shelf changing to 16", which is two-thirds of the original, an assumption was made that the cost would be proportional to the depth. As such, two-thirds of the original cost per linear foot was used as the cost of the redesigned light shelf.

Using the same numbers provided by Whiting-Turner, a cost for the redesigned panel and glass was extrapolated for the façade at a ratio of 60%. On the third floor, the height of the precast panels were a typical height of 9'- 9 ¾". Using a window-to-wall ratio of 60% of the room cavity, it was determined that the precast panel would need to increase in height by 1'-1 1/5". With the precast panels being made of several courses of brick separated by a single course of blackened brick, it works out that if one course of brick is added per section, the panel would extend to the approximate height required by the 60% window-to-wall ratio. The ultimate height of this panel would be approximately 10'-11". Using this new height in combination with the panel lengths, new square foot numbers were produced for the precast panels. This change in size also affects the square footage of the insulation in the panels, which was adjusted based on the new height. In addition to the panel changing size, the glazing also changes in height. Using the ratio of 60%, the new height of the window assembly was determined, and a square foot number was produced for the redesign. The final change to the façade unit comes from the adjustment of the light shelf. As referenced above, the light shelf cost was determined to be two-thirds of the existing cost provided by Whiting-Turner.

With all these changes in mind, total costs for the third floor were produced for the redesigned façade components, based on the ratios of 70% and 60%. These numbers can be seen in the table below. The difference between the costs of these two different designs resulted in the 60% design costing \$9222 more than the design at a ratio of 70%. A more detailed breakdown of these costs can be found in Appendix D.

Third Floor, Redesigned Panel		
Length of Panel	70%	60%
22ft	\$1,530,763	\$1,539,322
14ft	\$41,131	\$41,331
31ft	\$81,270	\$81,733
Total	\$1,653,164	\$1,662,387
Increased Cost of 60%	\$9,222.715	

Table 27: Construction Costs of Redesigned Panel on Third Floor at 70% and 60% ratio.

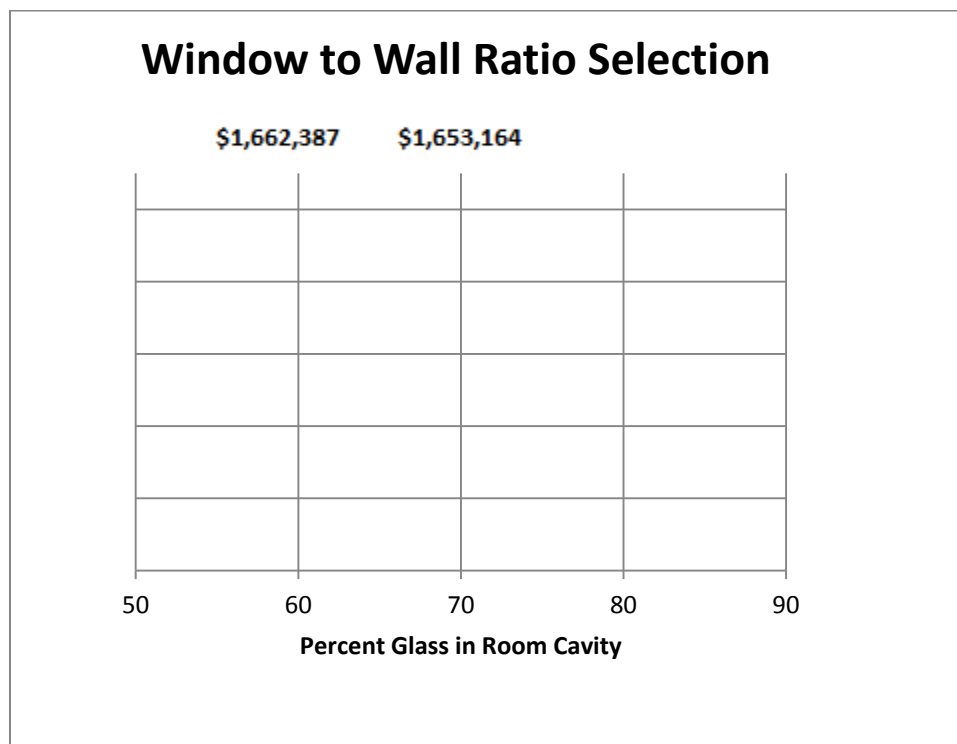


Figure 26: Construction Management Window to Wall Analysis

Final Selection of Window to Wall Ratio

The integrated selection of window to wall ratio, seen in Figure 27, decreases the percent glazing of the existing design from 70 to 60 percent. Sixty percent glazing reduces energy costs, decreases construction costs, and minimally affects useful illuminance. The change to 60% glazing produces a simple payback of 2.6 years, validating its life cycle cost in Table 28. To ensure this change does not adversely affect the architectural aesthetics, a new building rendering is compared to an existing render in Figures 28-29.

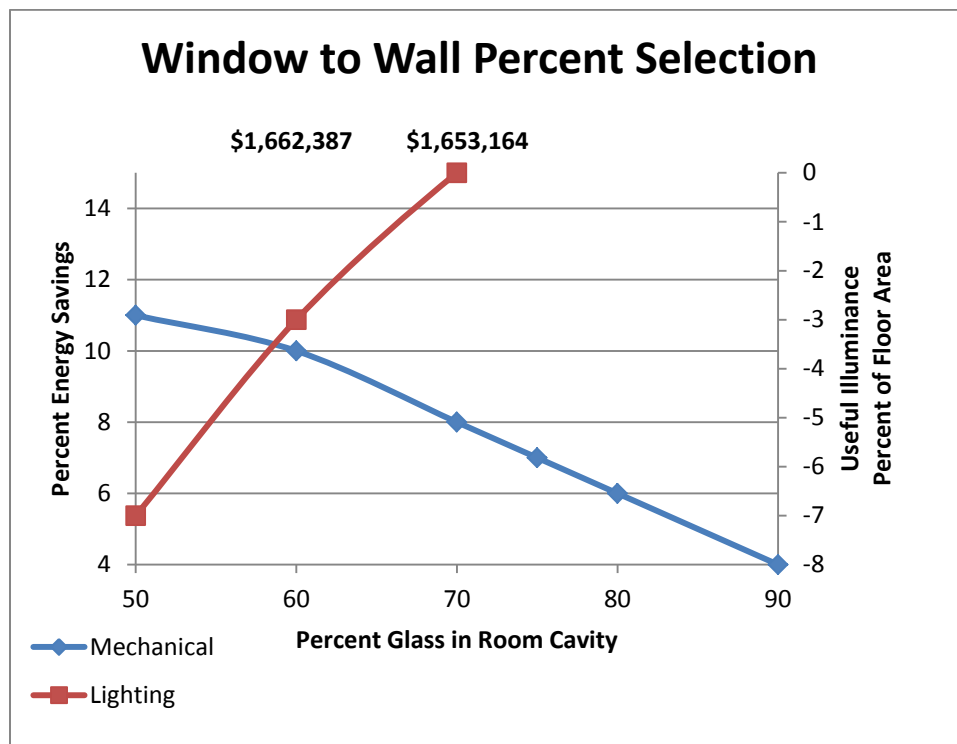


Figure 27: Integrated Window to Wall Analysis Graph

	70 % Glass	60 % Glass	Savings
Total Yearly Operating Costs	\$142,912	\$139,338	\$3,574
Installation Costs	\$1,653,164	\$1,662,387	\$-9,223
30 yr Life Cycle Cost	\$5,336,113	\$5,253,245	\$82,868

Table 28: Window to Wall Ratio Life Cycle Cost Analysis Summary



Figure 28: *Existing Building Rendering*



Figure 29: *Building Rendering With 60% Final Selection WWR*

SHADING ANALYSIS

Design Approach

Evaluating the performance of the Millennium Science Complex's shading devices will enhance daylighting while controlling excessive solar heat gain. Effective exterior and interior shading alternatives will reduce energy consumption and improve occupant comfort.

AGI32 daylight studies will analyze problematic hours where daylighting produces uncomfortable occupant conditions. Tables will be created targeting these problematic and interior shading options will be evaluated to control them. Project Vasari will analyze the effects of varying the length and mounting height of exterior shading devices. This will produce energy data that will help to schematically justify the inclusion and benefits of such design decisions.

The final selections for interior and exterior shading devices will be modeled and compared to the existing conditions performance. Inclusion of interior shading devices, depth of exterior shading devices, and mounting height of exterior shading devices will be selected after comparison to the existing façade's performance.

Interior Shelf Analysis

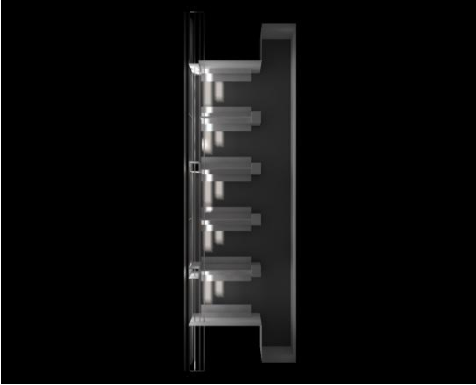
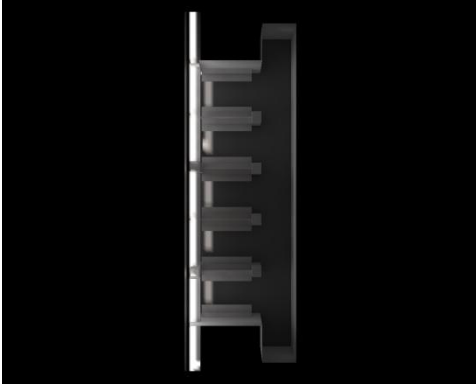
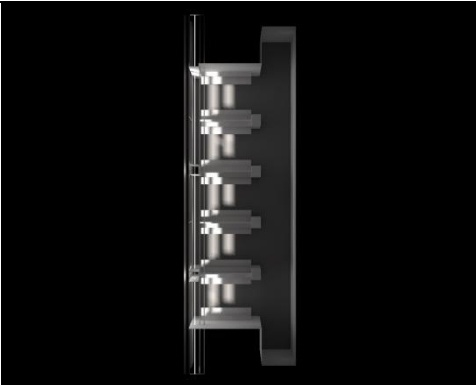
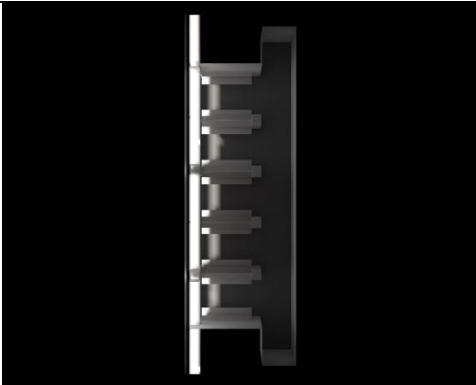
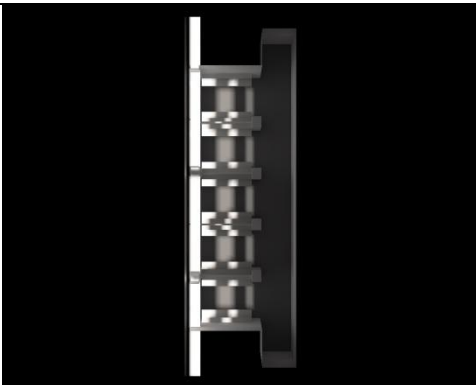
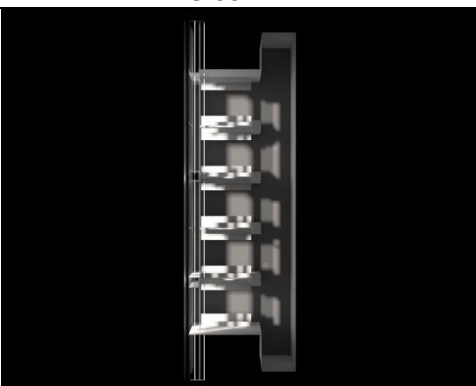
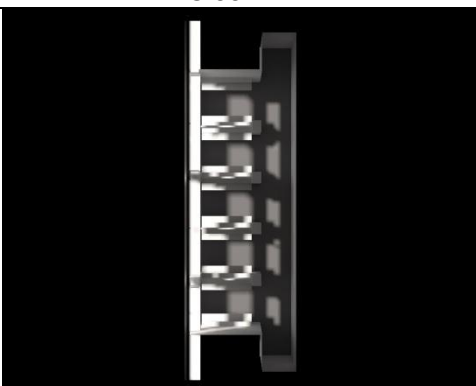
The interior shelf analysis daylight penetration study for the Millennium Science Complex was conducted utilizing AGI32 daylight studies. The study was performed from sunrise to sunset on the equinox and summer and winter solstices see table 29 for study times, and evaluated for the student study areas located on the building perimeter. The study started with a baseline using a trellis interior shelf with one foot increments into the space. The problematic times (see table 30) were then studied, and due to architectural constraints a two foot interior shelf was implemented for testing. The AGI32 daylight studies were then conducted with the two foot interior shelf and compared side by side with the baseline case (see figure 30 for example, and Appendix E for other daylight study results). The addition of the shelf resulted in the reduction of problematic times as seen in table 31.

Study Times		
Equinox	Summer	Winter
7:00:00 AM	6:00:00 AM	8:00:00 AM
8:00:00 AM	7:00:00 AM	9:00:00 AM
9:00:00 AM	8:00:00 AM	10:00:00 AM
10:00:00 AM	9:00:00 AM	11:00:00 AM
11:00:00 AM	10:00:00 AM	12:00:00 PM
12:00:00 PM	11:00:00 AM	1:00:00 PM
1:00:00 PM	12:00:00 PM	2:00:00 PM
2:00:00 PM	1:00:00 PM	3:00:00 PM
3:00:00 PM	2:00:00 PM	4:00:00 PM
4:00:00 PM	3:00:00 PM	
5:00:00 PM	4:00:00 PM	
6:00:00 PM	5:00:00 PM	
	6:00:00 PM	
	7:00:00 PM	
	8:00:00 PM	

Table 29: Interior Shelf Analysis Study Times

Problematic Times No Shelf											
East Equinox	North Equinox	South Equinox	West Equinox	East Summer	North Summer	South Summer	West Summer	East Winter	North Winter	South Winter	West Winter
7:00:00 AM	5:00:00 PM	7:00:00 AM	1:00:00 PM	7:00:00 AM	6:00:00 PM	7:00:00 AM	4:00:00 PM	8:00:00 AM	8:00:00 AM	8:00:00 AM	11:00:00 AM
8:00:00 AM	6:00:00 PM	8:00:00 AM	2:00:00 PM	8:00:00 AM	7:00:00 PM	8:00:00 AM	5:00:00 PM			9:00:00 AM	12:00:00 PM
		9:00:00 AM	3:00:00 PM	9:00:00 AM	8:00:00 PM	9:00:00 AM	6:00:00 PM			10:00:00 AM	1:00:00 PM
		10:00:00 AM	4:00:00 PM	10:00:00 AM		10:00:00 AM	7:00:00 PM			11:00:00 AM	2:00:00 PM
		11:00:00 AM	5:00:00 PM				8:00:00 PM			12:00:00 PM	3:00:00 PM
		12:00:00 PM								1:00:00 PM	4:00:00 PM
										2:00:00 PM	
										3:00:00 PM	

Table 30: No Shelf Problematic Times

West Façade Equinox No Shelf	West Façade Equinox 2' Interior Shelf
 1:00 PM	 1:00 PM
 2:00 PM	 2:00 PM
 3:00 PM	 3:00 PM
	

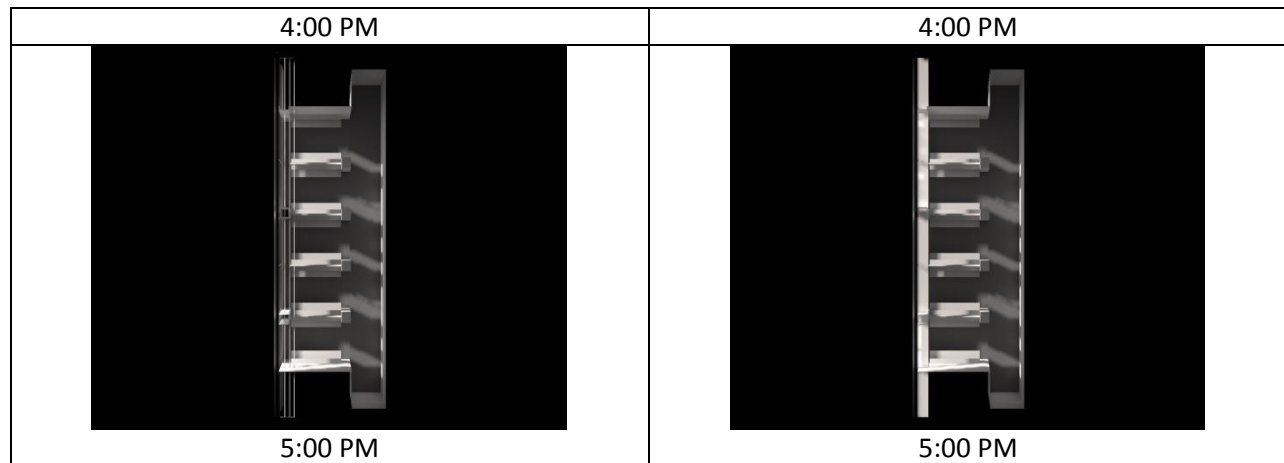


Figure 30: Equinox Direct Sunlight Penetration Comparison for West Façade

Problematic Times With Shelf											
East Equinox	North Equinox	South Equinox	West Equinox	East Summer	North Summer	South Summer	West Summer	East Winter	North Winter	South Winter	West Winter
7:00:00 AM	5:00:00 PM	7:00:00 AM	3:00:00 PM	7:00:00 AM	6:00:00 PM	7:00:00 AM	6:00:00 PM			9:00:00 AM	12:00:00 PM
8:00:00 AM		8:00:00 AM	4:00:00 PM	8:00:00 AM	7:00:00 PM	8:00:00 AM	7:00:00 PM			10:00:00 AM	1:00:00 PM
		9:00:00 AM	5:00:00 PM	9:00:00 AM	8:00:00 PM		8:00:00 PM			11:00:00 AM	2:00:00 PM
		10:00:00 AM								12:00:00 PM	3:00:00 PM
		11:00:00 AM								1:00:00 PM	
										2:00:00 PM	

Table 31: Interior Shelf Problematic Times

The interior shelf daylight penetration study showed that the addition of an interior shelf would be beneficial to the daylight delivery system of the Millennium Science Complex. Consultation with the construction management team member presented obstacles in constructability of the interior shelf. A main issue was the location of the perimeter structural columns. The interior shelf would need to be pieced together on each side of the column, or framed around adding difficulty in the construction. In addition the interior shelf would present additional cost at approximately \$150/lf. This cost increase and constructability challenges outweigh the benefit of the interior shelf. Further investigation revealed the majority of the problematic times the sun penetration came when the solar angle was below the shelf. This resulted in the decision to use bottom up shades that would allow daylight to enter the space, while still blocking the majority of the problematic times.

Project Vasari Analysis

Project Vasari is a new program introduced by Autodesk with a similar modeling interface as Revit. It has inherent schematic energy modeling capabilities that will be tested in this section of design. A quick reliable ability to evaluate solar loading conditions on multiple facades will enable designers with data to assist them in making schematic design decisions.

Vasari will be used to look at schematic level additions of shading devices and their effect on building loads. The heights and lengths of the shades will be manipulated to create a better understanding of how solar radiation affects building loads. This important schematic data can then be given to the lighting engineer to provide integrated data for solar shade selection.

Limitations

Due to its simplicity, Vasari will be unable to accurately model building energy use. A Trane Trace model has been created to provide accurate detailed data about building energy performance. Vasari will however be a valuable tool in evaluating schematic changes and their effects. Iterations of conceptual and schematic design options can quickly be analyzed to compare savings. These savings may not represent precise numbers, but their implications on scale and potential percent savings may be valuable.

Existing Conditions

The Millennium Science Complex's existing design includes a shade mounted at the midpoint of glazing at approximately 7' from floor. The façade panel effectively acts like an overhang as it protrudes 2' away from the glass at the 11' ceiling. For consideration in Project Vasari, both these elements will be modeled as 2' shades to analyze their effectiveness in controlling solar radiation.

Project Vasari Outputs

Project Vasari is capable of calculating energy reports, but as described above they are too unreliable to be effectively used for this study. The calculations will provide metrics of comparison between design options. Most importantly Vasari provides visual data for solar loading conditions that can be effectively understood and communicated through the team. Figure 31 shows a typical schematic level solar radiation analysis. It depicts yearly cumulative incident energy in btu/ft^2 on the 3rd floor façade and the effects of modeled shades.

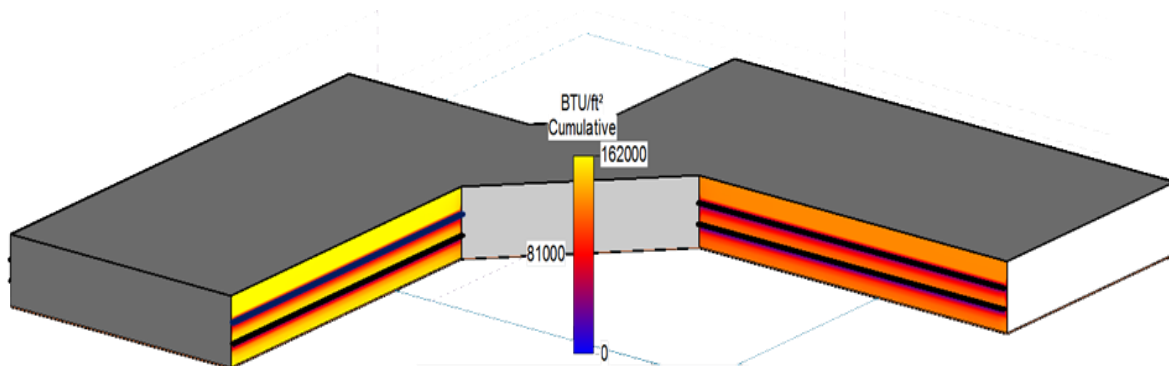


Figure 31: *Typical Vasari Visualization of Solar Loading with Shades Included*

Shade Height Analysis

Using the existing design, the shade located at the midpoint of the glass was evaluated at varying mounting heights. The purpose of this analysis was to see if mounting height has any effect on the solar control performance of the shade.

Adjusting the mounting height has negligible effects on the annual energy costs of the modeled 3rd floor as seen in Table 32. It seems that due to the shade's short length the total shaded area of the window remains unaffected. In proceeding forward, mechanical analysis will remain unaffected by a change in shade height. Additional graph can be found in Appendix F.

	5'6" Height	6'0" Height	6'6" Height	7'0" Height (Existing)	7'6" Height	8'0" Height
Percent Energy Consumption	99.99%	99.98%	99.99%	100.00%	100.02%	100.03%

Table 32: Analysis of Shade Mounting Height

Shade Length Analysis

Using the existing design, varying the lengths of the shade and overhang were analyzed. The purpose of this analysis was to understand the effects shade length have on thermal loading.

Adjusting the lengths of both sunshades proves to have potential in reducing building energy loading as seen in Table 33. Assuming a base condition with no sunshade, potential energy savings over a no shade condition can be easily understood. For each additional foot of shading device, there is an opportunity to reduce building loads by 1%. While the annual energy cost data is not accurate, this percent savings could be used to establish a cost savings scale for the design options. Additional graph can be found in Appendix F.

	0" Length	12" Length	18" Length	24" Length	36" Length
Potential % Savings	-	1.5%	2%	2.5%	3.5%

Table 33: Analysis of Shade Mounting Height

Visualizations

The complete set of Vasari visualizations can be found in Appendix F. There are examples of the whole building effects, and details of each façade orientation.

Final Shade Selection

Due to limited improvements from alternatives, the existing shading system will be kept with minor changes. The interior shade selected was a motorized, bottom-up, grey, MechoShade open vertical weave series 1810 (Figure 32). The bottom up configuration was selected from the daylight penetration study, which showed the majority of the problematic daylight entered below the exterior shade. The bottom-up configuration provides the ability to block the problematic times, and still provide additional diffuse ambient light to enter above the exterior shade. As the total structural panel depth was reduced to 16" through the Wall Composition Analysis, the overhang and exterior shade will mimic this depth.

ThermoVeil™		TOTAL SOLAR / VISIBLE					
SHADECLOTH							
■ Open Vertical Weave		T _S	R _S	A _S	T _V	T _{UV}	O _F
1801	White	0.22	0.63	0.15	0.18	0.13	0.11
1802	Beige	0.14	0.44	0.42	0.12	0.10	0.09
1803	Grey	0.13	0.26	0.61	0.15	0.13	0.12
1804	Blk/Brown	0.15	0.04	0.81	0.17	0.15	0.14
1810	Grey	0.10	0.36	0.54	0.11	0.09	0.09

Figure 32: MechoShade Material Properties

LIGHTING REDESIGNS

Design Approach

The lighting design approach for the Millennium Science Complex is intended to reinforce the overall architectural theme of a floating horizontal building. The MSC is a LEED building so it's important to utilize energy efficient fixtures while still creating a comfortable environment for occupants. The interior space redesigns are located on the perimeter of the building so it's essential to integrate the lighting design with *Bimception's* daylight delivery system redesign. Energy and life cycle cost analyses will provide additional feedback.

Student Areas

Space Description

The student areas are located on the perimeter of the Millennium Science Complex. These spaces interact with an adjacent corridor. The close proximity of the two spaces presents a situation where spill light from each area contributes to the illuminance of one another. For this reason they two areas were grouped together for the redesign. These areas also contain partitioned workstations that use computer screens. The perimeter location for the student area allows for integration with the Millennium Science daylight delivery system.

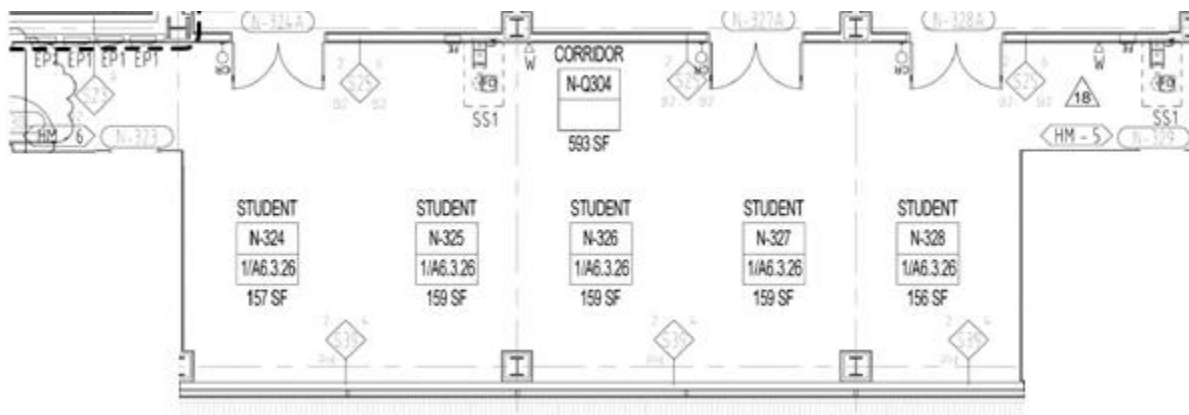


Figure 33: *Student Area/Corridor Floor Plan*

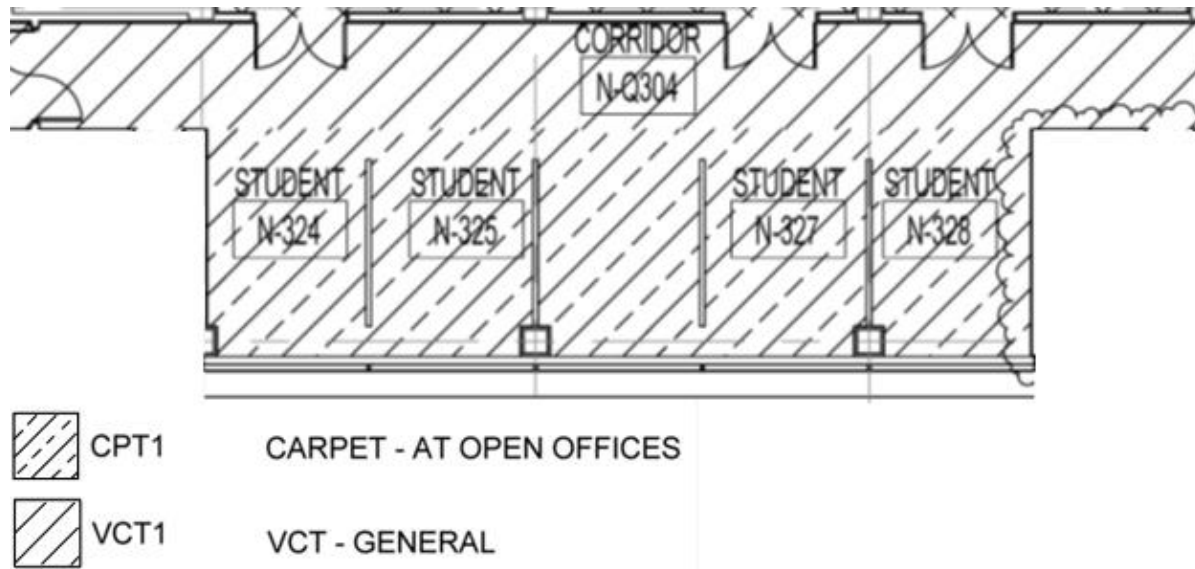


Figure 34: Student Area/Corridor Materials

Materials – Student Area/Corridor		
Surface	Reflectance Value	Transmittance Value
ACT Ceiling	0.76	
Carpet	0.13	
Cubicles**	0.22	
Door**	0.5	
Exterior Glazing		0.59
Shade		0.07
VCT Floor**	0.88	
Walls	0.76	
**Values from AGi32 swatches for similar materials		

Table 34: Student Area/Corridor Material Properties

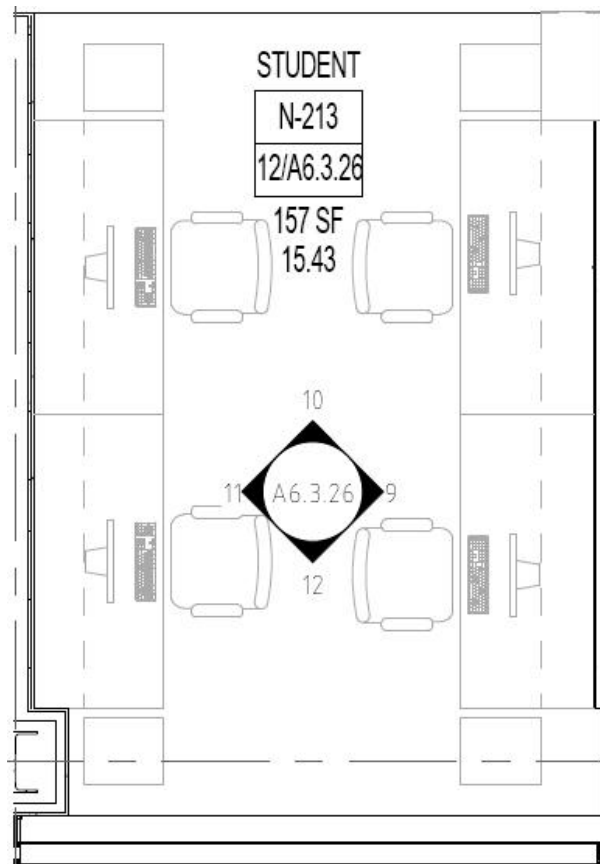


Figure 35: Student Area Furniture Plan

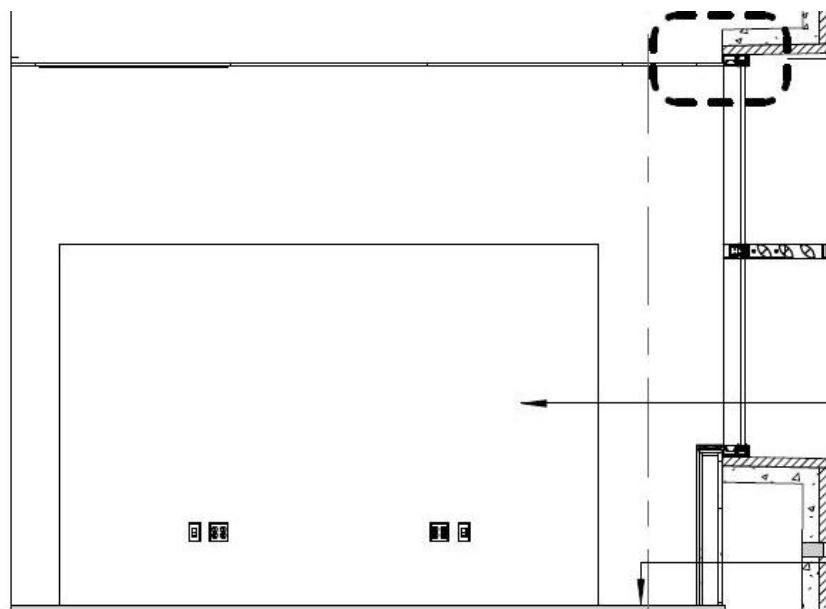


Figure 36: Partition elevation

Design Criteria

IESNA Illuminance Recommendations

	Illuminance
Corridors	5 fc Horizontal
	Illuminance
Study Areas (Reading Tasks)	30 fc Horizontal
	Illuminance
VDT Screens	3 fc Horizontal
	3 fc Vertical

ASHRAE 90.1 Lighting Power Density

Corridors	0.5 W/ft ²
Study Areas	1.2 W/ft ²

Design Considerations

Very Important

Avoid Direct Glare (*IESNA*)

In order for students to efficiently utilize this space it's important to avoid direct glare conditions. Direct glare can cause discomfort for the occupants of a space. This can be addressed in fixture selection.

Avoid Reflected Glare (*IESNA*)

The student area contains computer screens so it's important to minimize reflected glare. This can be achieved with proper location of fixtures, and by orienting the screens perpendicular to exterior windows.

Luminance of Room Surfaces (*IESNA*)

Luminance of Room Surfaces is important can be addressed by utilizing appropriate contrast ratios. Creating uniformly illuminated surfaces with a 10:1 luminance ratio between surrounding surfaces can help prevent occupant discomfort.

Source/Task/Eye Geometry (*IESNA*)

In order for students to efficiently use this space it's important to implement the above considerations regarding glare and luminance ratios. This will allow for occupants to easily transition between the computer screen and work surface.

Daylight Integration and control (*IESNA*)

The student study areas are located on the perimeter of the Millennium Science Complex so it's important to consider the interaction between the space and windows. It's important to implement the proper use of shading devices and luminaire control.

Luminaires

Luminaire Schedule								
Fixture Type	Image	Description	Mounting	Lamp	Voltage	Ballast	Wattage	Notes
A3		Linear Lighting Ellipse 27. 1'x4' Indirect/Direct Pendant Fixture, Extruded Aluminum Housing, Baked White finish. Concave louver blades with clear convex insert Catalog #: EL27-B-1-ET5-277-PV1-IC-LS	Pendant 9'-0" A.F.F.	(1) 28W T5 CCT 4100K CRI 85	277V	Electronic Dimming Advanced Transformer	32W	
B		Ledalite Voice. Recessed 1'x4' Fixture, Die-Formed Cold Rolled Steel Housing, Flat Acrylic Panels Connected to Prismatic Acrylic Diffuser Catalog #: 9814D1-ST-F128-S-1-2-E	Recessed	(1) 28W T5 4100K CRI 85	277V	Electronic Advanced Transformer	31W	
C1		Philips Alko Aris Series. 11" Low Profile LED Fixture, Extruded Aluminum Housing, Pearl Finish, Extruded Clear Polycarbonate Lens. Integrated On/Off Switch Catalog # ARIS-11-40-120-PRL-DWC	Surface	(5) 1W LEDs CCT 4000K CRI 71-73	120V	Integrated Driver	5W	Surface mounted to bottom of shelf at 4'-3" A.F.F.
C2		Philips Alko Aris Series. 21" Low Profile LED Fixture, Extruded Aluminum Housing, Pearl Finish, Extruded Clear Polycarbonate Lens, Integrated On/Off Switch Catalog # ARIS-21-40-120-PRL-DWC	Surface	(10) 1W LEDs CCT 4000K CRI 71-73	120V	Integrated Driver	10W	Surface mounted to bottom of shelf at 4'-3" A.F.F.

Table 35: Student Area Luminaire Schedule

Light Loss Factors

Light Loss Factors – Student Area/Corridor				
Fixture Type	LDD	LLD	BF	Total LLF
A3	0.93	0.92	1.00	0.85
B	0.93	0.92	1.05	0.90
C1	0.75	0.92	1.00	0.69
C2	0.75	0.92	1.00	0.69
*Using new IESNA guidelines for Clean Environment based on 12 month cleaning interval				

Table 36: Student Area/Corridor Light Loss Factors

Control Scheme

The dimmable pendant fixtures will be controlled by ceiling mounted occupancy and photosensors. The task lights are plug loads with individual integrated on/off switches. A Daysim control study of the pendant fixtures was conducted for the student area for each of the four façade orientations (found in Daylight Integration Control Study section) to evaluate the energy savings for this control scheme. Wiring diagram for the control scheme can be found in the Electrical Work Section.

Lighting Plan

Lighting plans found in Appendix E.

Renderings



Figure 37: *Student Area Perspective Rendering*



Figure 38: *Student Area Perspective Rendering*

Design Performance

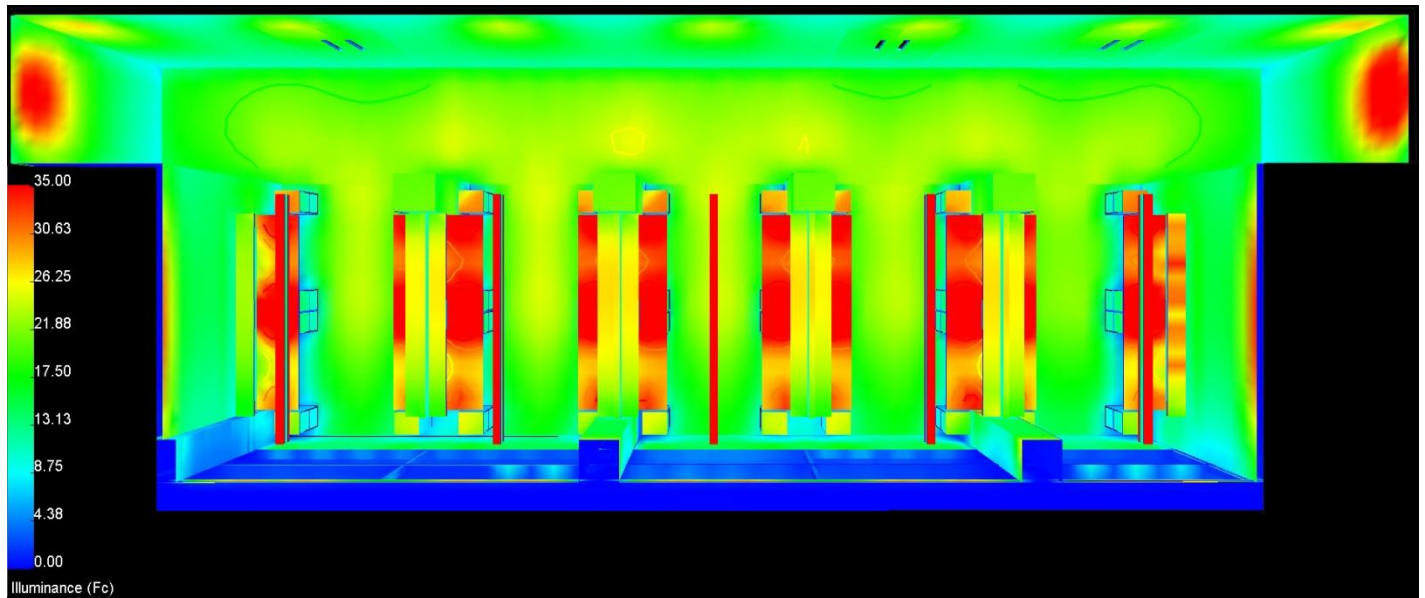


Figure 39: Student Area Pseudo Color

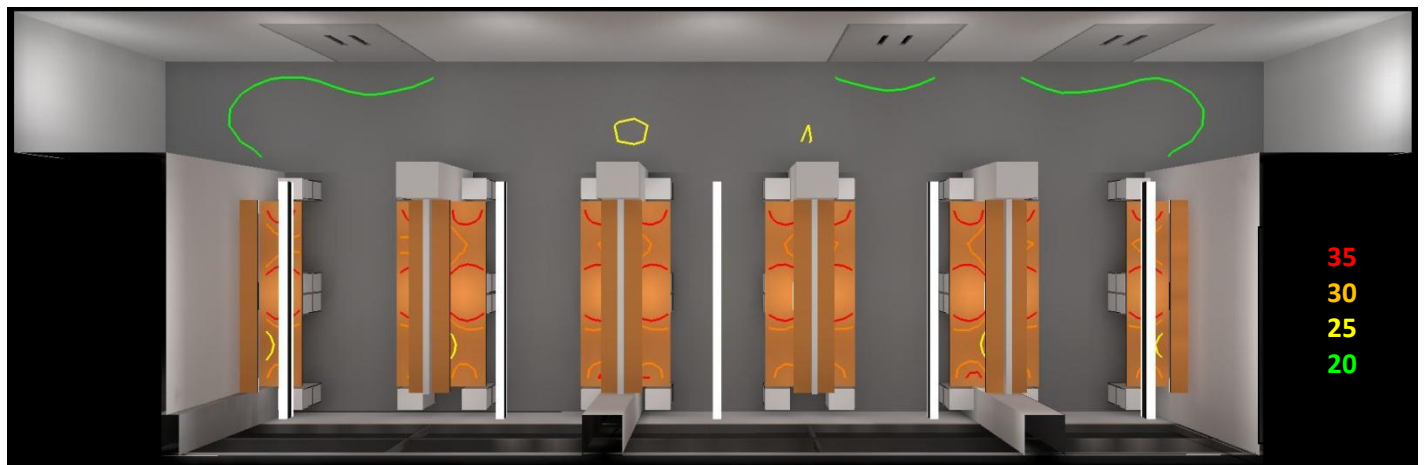


Figure 40: Student Area Contour Lines

Student Area Illuminance (FC)	
E _{average}	34.01
E _{Maximum}	60.3
E _{Minimum}	21.7

Table 37: Student Area Illuminance Values

Corridor Illuminance (FC)	
E _{average}	21.7
E _{Maximum}	25.6
E _{Minimum}	15.5

Table 38: Corridor Illuminance Values

Lighting Power Density

Student Area

32W * 15 Fixtures = 480 W

5W * 20 Fixture = 100 W

10W * 10 Fixtures = 100 W

680W/866SF = 0.78 W/SF

Corridor

31W*7 Fixtures = 217 W

217W/537SF = 0.40 W/SF

Performance Summary

The student study areas of the Millennium Science Complex lighting design uses indirect/direct pendants to provide the ambient light. Task lighting provides flexibility for individual students to increase the illuminance levels in their work area. The task lights are located on the sides of the computer screens to avoid uncomfortable luminance ratios between the screen and the background partition. The lighting design adequately meets illuminance and energy criteria while reinforcing the architectural floating theme. The space successfully integrates with the daylight delivery system and a different control study (see Daylight Integration Control Study section) for each façade provided accurate energy savings for Bimception's mechanical team member's energy model.

Private Offices

Space Description

The faculty offices are located on the perimeter of the Millennium Science Complex. The faculty offices contain a computer and an L shaped workstation for the faculty member. The perimeter location for the student area allows for integration with the Millennium Science daylight delivery system.

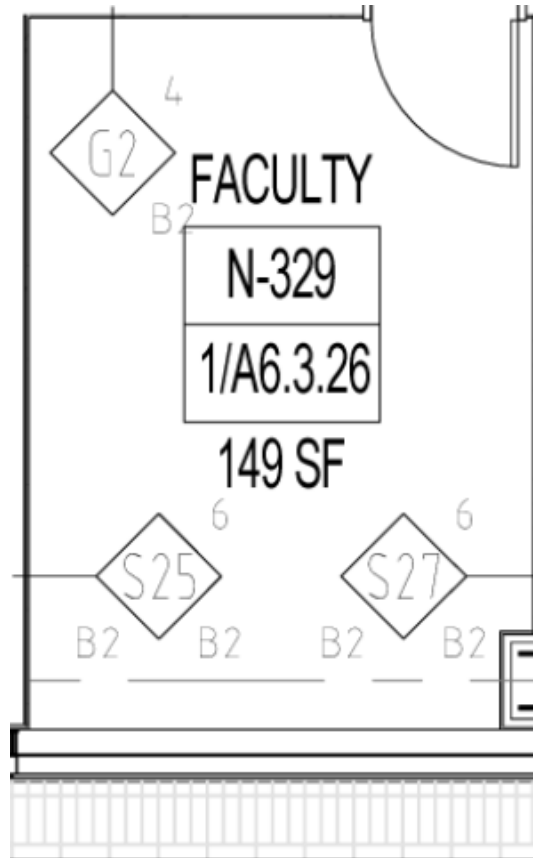


Figure 41: *Private Office Floor Plan*

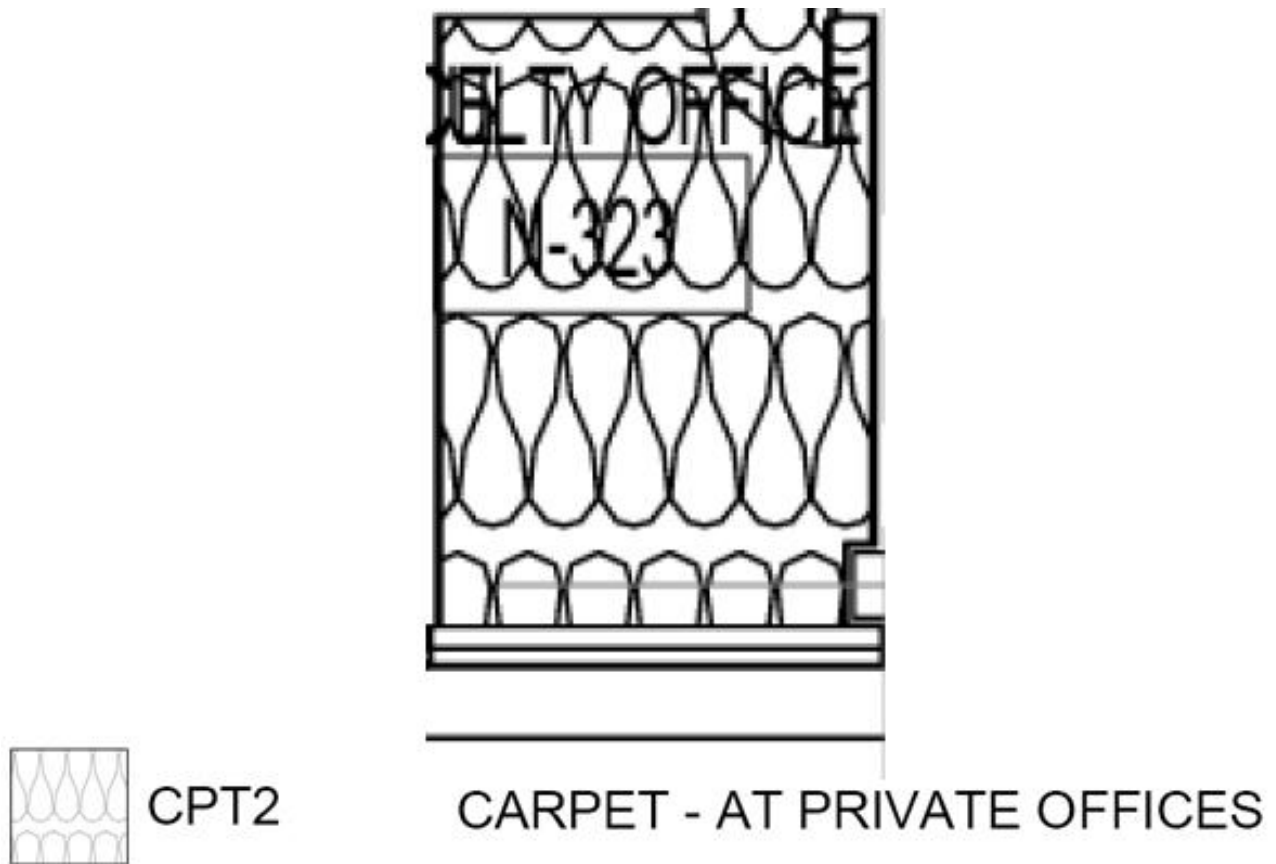


Figure 42: *Private Office Material Plan*

Materials – Office		
Surface	Reflectance Value	Transmittance Value
ACT Ceiling	0.76	
Door	0.5	
Door Trim	0.5	
Exterior Glazing		0.59
Floor	0.13	
Mullions	0.55	
Shade		0.07
Walls	0.76	
**Values from AGi32 swatches for similar materials		

Table 39: *Private Office Material Properties*

Design Criteria

IESNA Illuminance Recommendations

Offices	Illuminance
	30 fc Horizontal
VDT Screens	Illuminance
	3 fc Vertical 3 fc Horizontal

ASHRAE 90.1 Lighting Power Density Corridors

0.5 W/ft²

Design Considerations

Very Important

Avoid Direct Glare (*IESNA*)

In order for faculty members to efficiently utilize this space it's important to avoid direct glare conditions. Direct glare can cause discomfort for the occupants of a space. This can be addressed in fixture selection.

Avoid Reflected Glare (*IESNA*)

The private offices contain computer screens so it's important to minimize reflected glare. This can be achieved with proper location of fixtures, and by orienting the screens perpendicular to exterior windows.

Luminance of Room Surfaces (*IESNA*)

Luminance of Room Surfaces is important can be addressed by utilizing appropriate contrast ratios. Creating uniformly illuminated surfaces with a 10:1 luminance ratio between surrounding surfaces can help prevent occupant discomfort.

Source/Task/Eye Geometry (*IESNA*)

In order for faculty members to efficiently use this space it's important to implement the above considerations regarding glare and luminance ratios. This will allow for occupants to easily transition between the computer screen and work surface.

Daylight Integration and control (*IESNA*)

The private offices are located on the perimeter of the Millennium Science Complex so it's important to consider the interaction between the space and windows. It's important to implement the proper use of shading devices and luminaire control.

Luminaires

Luminaire Schedule								
Fixture Type	Image	Description	Mounting	Lamp	Voltage	Ballast	Wattage	Notes
A2		Linear Lighting Ellipse 27. 1'x4' Indirect/Direct Pendant Fixture, Extruded Aluminum Housing, Baked White finish. Concave louver blades with clear convex insert Catalog #: EL27-B-1-ET5-277-PVI_IC	Pendant 9'-0" A.F.F.	(1) 54W T5 CCT 4100K CRI 85	277V	Electronic Advanced Transformer	63W	

Table 40: *Private Office Luminaire Schedule*

Light Loss Factors

Light Loss Factors – Private Office				
Fixture Type	LDD	LLD	BF	Total LLF
A2	0.93	0.95	1.02	0.90
*Using new IESNA guidelines for Clean Environment based on 12 month cleaning interval				

Table 41: *Private Office Light Loss Factors*

Control Scheme

The switching pendant fixtures in the private office will be controlled by a wall mounted occupancy and ceiling mounted photosensor. The switching control scheme was selected based on the Daysim control study done in the student areas. The study Daylight Autonomy values proved a switching system would provide energy savings in this space. Wiring diagram for the control scheme can be found in Electrical Work Section.

Lighting Plan

Lighting plans found in Appendix E.

Renderings



Figure 43: *Private Office Perspective Rendering*



Figure 44: *Private Office Perspective Rendering*

Design Performance

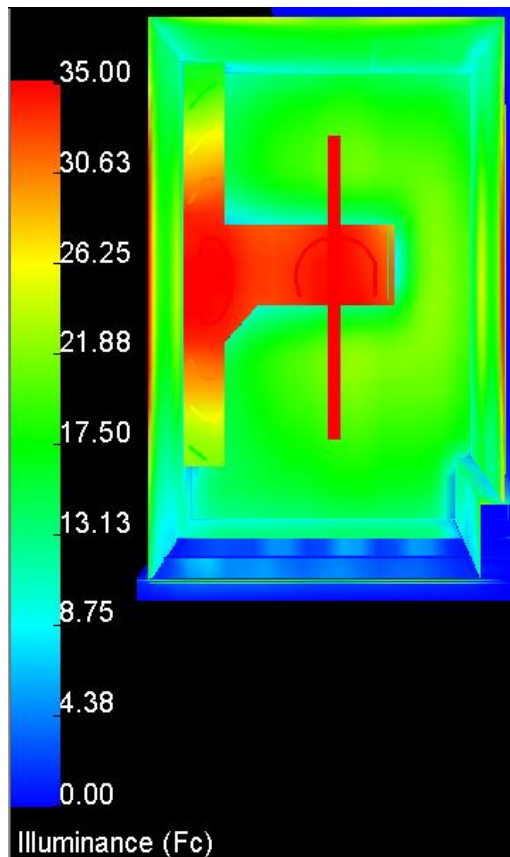


Figure 46: *Private Office Perspective Rendering*

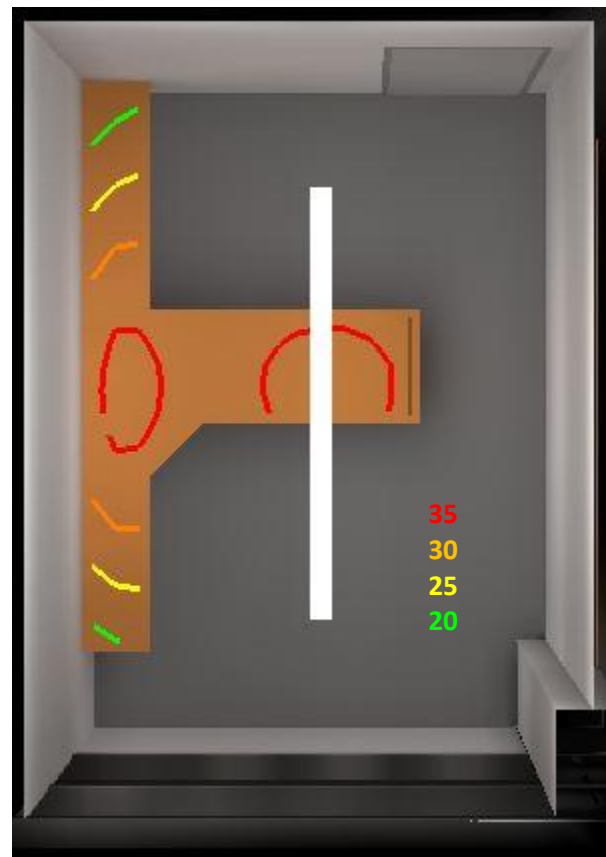


Figure 45: *Private Office Perspective*

Private Office Illuminance (FC)	
E _{average}	31
E _{Maximum}	36.4
E _{Minimum}	15.7

Table 42: *Private Office Illuminance Values*

Lighting Power Density

$$63\text{W} \times 2\text{Fixtures} = 126\text{W}$$

$$126\text{W} / 150\text{SF} = 0.84 \text{ W/SF}$$

Performance Summary

The private offices of the Millennium Science Complex lighting design use indirect/direct pendants to provide the ambient light. The lighting design adequately meets illuminance and energy criteria while reinforcing the architectural floating theme. While a comprehensive daylight integration study was not conducted. The control study (see Daylight Integration Control Study section) shows there is potential for energy savings with a switching system, thus allowing the private offices to successfully integrate with the Millennium Science Complex daylight delivery system.

Cost Analysis of Lighting Redesigns

In order to properly justify the redesign of the lighting system in the student area, offices and main corridors on the third floor, a cost must be determined for the change. The existing lighting in these areas used a typical recessed 1x4 fixture. The offices and corridors used non-dimming ballasts, whereas the student area used an intricate system for controls, the Lutron EcoSystem with a Grafik Eye. Based on take-offs of the third floor for these areas in combination with supplier data, the costs in the following table were determined.

Fixtures	Number of Fixtures	Notes	Cost per Unit	Total # of Units	Total Cost
Student Area Fixtures, Redesign					
EL27-B-1-ET5-277-PVI_IC-ED-12	15	Linear Lighting Ellipse EL27 *28WT5* 4100K	\$92	30	\$2,760
ARIS-11-40-120-PRL-DWC	20	Phillips ALKCO ARIS 11"	\$114	40	\$4,570
ARIS-21-40-120-PRL-DWC	10	Phillips ALKCO ARIS 21"	\$174	20	\$3,485
Office Fixtures, Redesign					
EL27-B-1-ET5-277-PVI_IC-ED-8'	2	Linear Lighting Ellipse EL27 *54W T5* 4100K	\$92	72	\$6,624
Corridor Fixtures, Redesign					
9814-D1-ST-F128-S-1-2-E	-	Changing out (2) 32WT8 to (1) 28WT5 1x4	\$246	70	\$17,220
				Total	\$34,659

Table 43: Cost of Existing Lighting, Third Floor

The lighting redesign of these locations entailed the replacement of all existing fixtures. Based on take-offs in combination with supplier data, the costs in the following table were determined for the redesigned lighting systems. Due to the similar ballast choices for the offices and corridors when compared to the existing, the cost difference was not investigated. However, the existing controls in the student area were a Lutron EcoSystem, which is a considerable cost in comparison to alternatives. A cost was not obtained for this system, but it is assumed that there would be a savings when changing from this system to a more typical dimming ballast arrangement.

Fixtures	Number of Fixtures	Notes	Cost per Unit	Total # of Units	Total Cost
Student Area Fixtures, Existing					
9814-D1-ST-T232-S-1-2-E	15	-	\$202	30	\$6,060
Office Fixtures, Existing					
9814-D1-ST-T232-S-1-2-E	3	-	\$202	108	\$21,816
Corridor Fixtures, Existing					
9814-D1-ST-T232-S-1-2-E	-	(2) 32W T8	\$202	70	\$14,140
				Total	\$42,016

Difference	\$7,357
-------------------	----------------

Table 44: Cost of Redesigned Lighting, Third Floor

As can be seen in the two tables above, the redesigned lighting presented a savings of \$7,357 when compared to the existing lighting. Labor was not investigated in this analysis. Based on inspection of the existing systems and their replacements, it was determined that the labor difference in changing lighting fixtures would not provide a significant change.

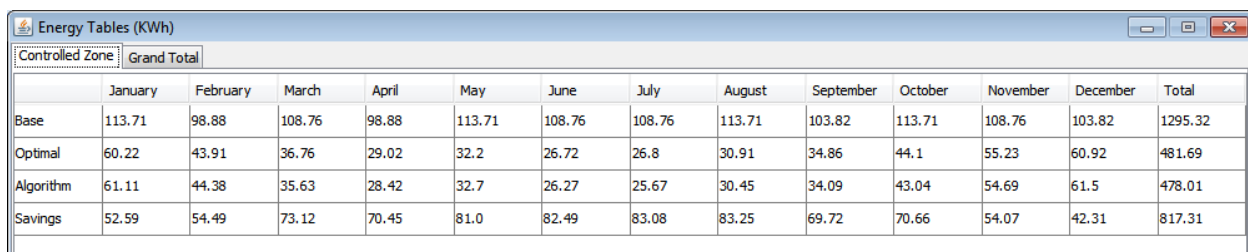
Daylight Integration Control Study

In order to integrate the perimeter lighting designs with the BIMception's Millennium Science Complex façade redesign a Daysim control study was conducted. The study assessed the feasibility and energy savings associated with an automated dimming system. The area studied was the student areas since the MSC contains a student area on each of the four dominant building facades. The analyzed lighting design only included the pendant fixtures due to occupant control over the individual task lights. The results from this study mainly the daylight autonomy values were used in determining the feasibility of the switching system in the private offices. The energy savings results were then coordinated with the mechanical engineer for incorporation into an energy model.

The lighting design above and selected shading devices were used to evaluate the overall perimeter lighting design's ability to integrate with the Millennium Science Complex daylight delivery system. The system was analyzed using Daysim based on an hourly annual simulation with hours of operation being 8:00AM to 6:00PM. Four separate models were built containing the entire shell of the building and surrounding buildings (see Appendix E). All of the pendant fixtures were controlled in the same zone due to the perpendicular orientation to the windows. The simulation was run with a work plane height of 2'-6" with one foot grid spacing. The shades for this simulation were the lower portion of the bottom up shades. This was selected based on the interior shelf analysis above. The shade system is a manually operated motorized shade system that depends on user preferences. This was simulated using a signal value of 6000 lux to represent when the occupant would close the shade due to direct sunlight penetration on the work surface. The sensor was located in the central aisle way at the work plane. The following is the system results for the south façade orientation the other orientation results are located in Appendix E.

Once the shades were implemented and working properly daylight autonomy and continuous daylight autonomy (Figures 47-48) were studied to determine if the lighting system should be controlled by dimming or switching. These figures show that both systems would be effective, but a dimming system would provide additional energy savings. For this reason a dimming system was chosen.

After the control scheme was selected illuminance contours were evaluated to find the critical point, location where the highest amount of light is needed to reach the target illuminance value, in this study 322.8 lux (see Figure 49). Once the Critical point was selected the photosensor control algorithms were processed using a closed loop sliding set point. A plot of the critical point signal vs. the system dimming level can be seen in Figure 50. This plot is used to determine if the dimming system is working effectively. The plot of the south façade has a strong distinction to the left of the graph, but as the signal increases there are some problems with the system. The higher signal at times doesn't result in the optimal dimming level. The system appears to be under dimming which reduces the potential energy savings. The energy savings for the south façade system can be seen in table 45.



	January	February	March	April	May	June	July	August	September	October	November	December	Total
Base	113.71	98.88	108.76	98.88	113.71	108.76	108.76	113.71	103.82	113.71	108.76	103.82	1295.32
Optimal	60.22	43.91	36.76	29.02	32.2	26.72	26.8	30.91	34.86	44.1	55.23	60.92	481.69
Algorithm	61.11	44.38	35.63	28.42	32.7	26.27	25.67	30.45	34.09	43.04	54.69	61.5	478.01
Savings	52.59	54.49	73.12	70.45	81.0	82.49	83.08	83.25	69.72	70.66	54.07	42.31	817.31

Table 45: South Façade Dimmed Zone Energy Savings

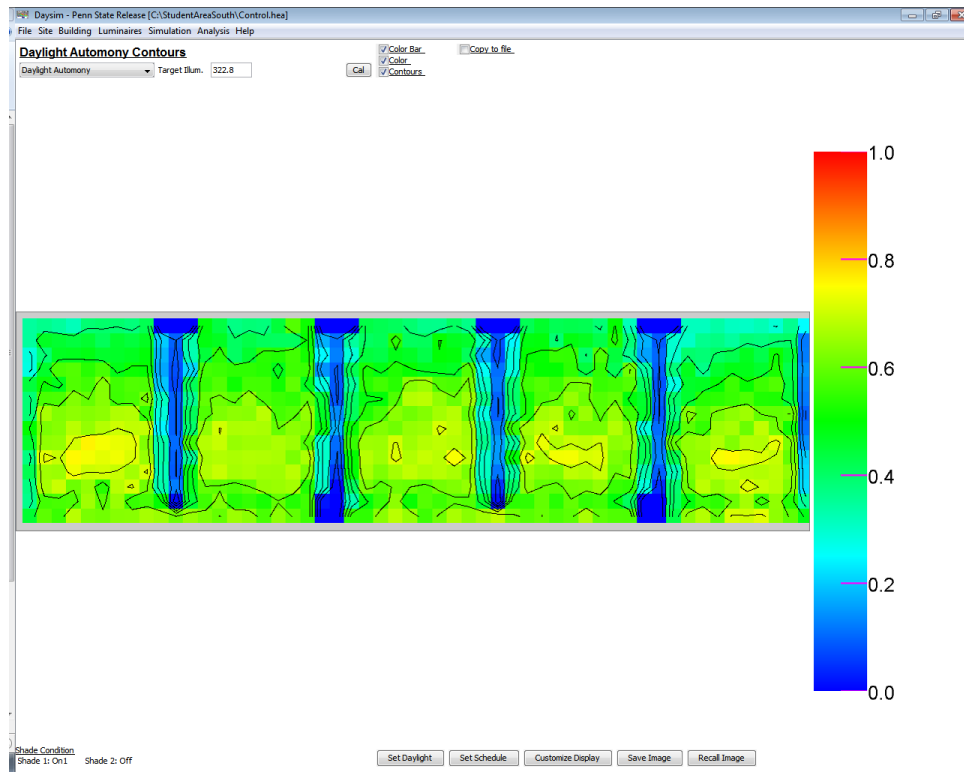


Figure 47: South Façade Daylight Autonomy

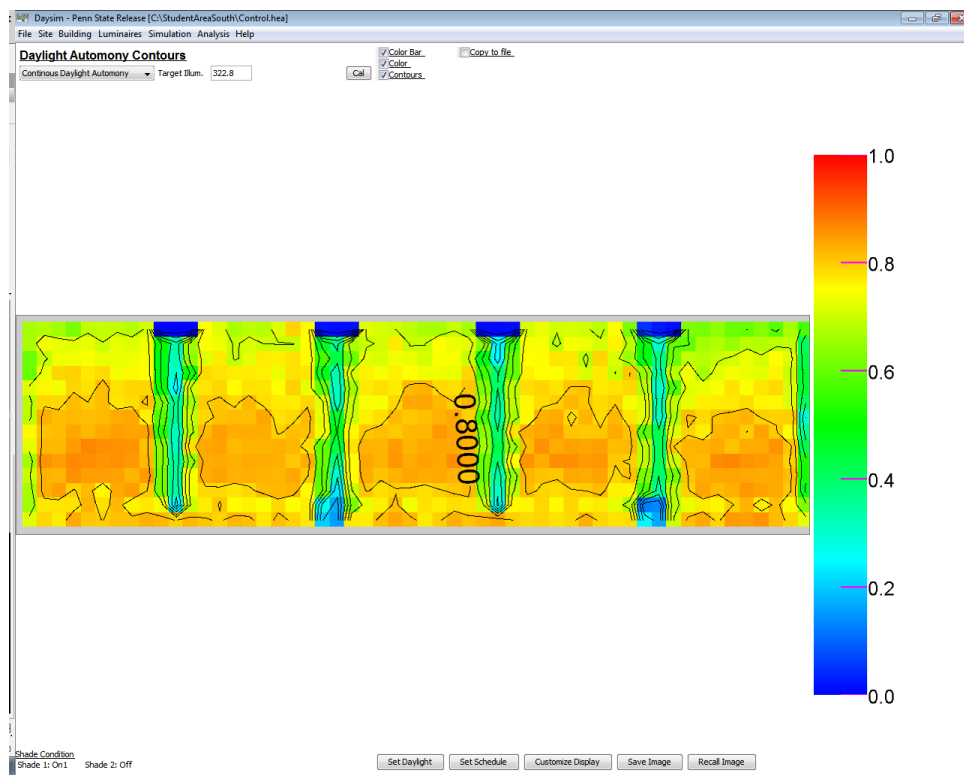


Figure 48: South Façade Continuous Daylight Autonomy

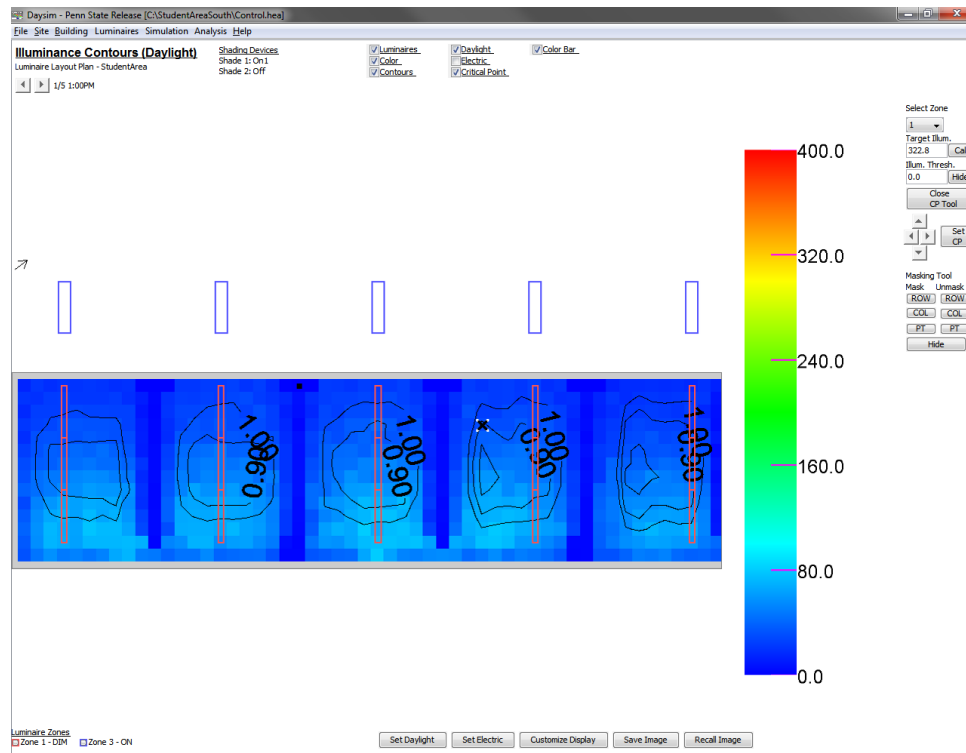


Figure 49: South Façade Critical Point Selection

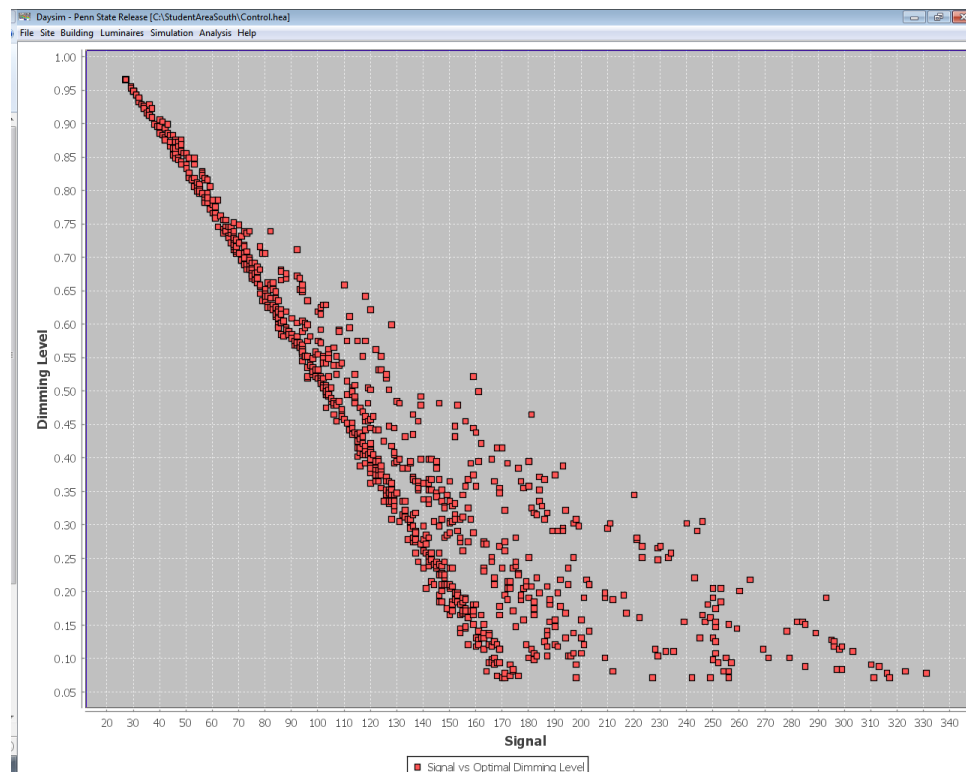


Figure 50: South Façade Signal vs. Dimming Plot

Energy Analysis of Lighting Redesigns

The redesign of lighting systems by the electrical engineer allowed for a more accurate update of lighting power density and lighting energy schedule. The current energy model uses ASHRAE Standard lighting power densities per given space.

The redesigned student area spaces were reduced from a maximum of 1.1 W/SF to 0.78 W/SF on the north side and 0.78 W/SF on the south side. In addition a more accurate schedule was created to take advantage of dimming opportunities per month. The lighting engineer provided his dimming schedule taking advantage of natural daylight. The dimming setbacks can be seen in Figure 51 for the North and Student Areas. The graphs show the percentage of peak yearly lighting load experienced each month. The month of January requires the most lighting energy with each corresponding month only using a fraction of this peak.

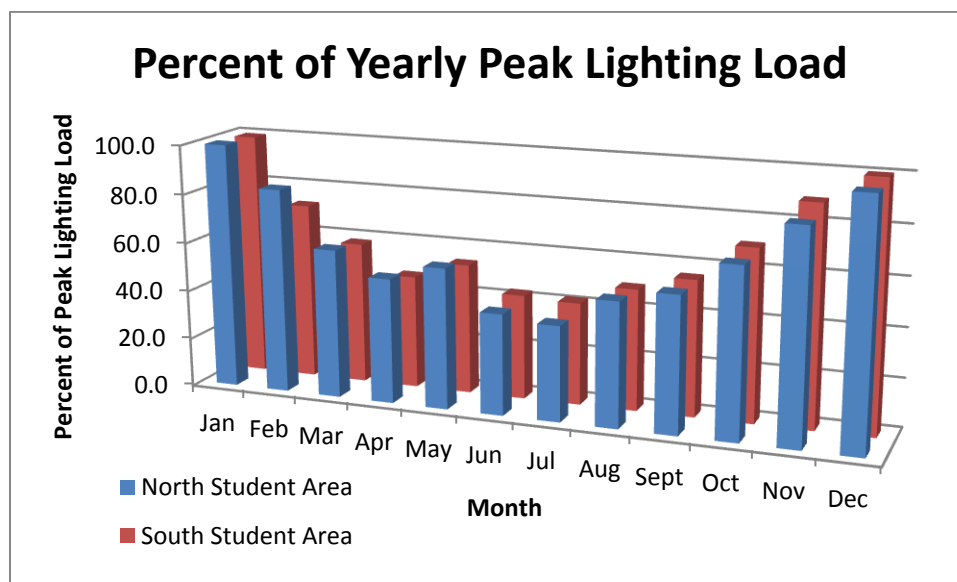


Figure 51: *Schedule of Lighting Power Density Monthly Setbacks –Student Areas*

The redesign of the corridors and offices allowed for a reduction from ASHRAE standard lighting power densities. Corridors will consume 0.4 W/SF, down from 0.5 W/SF, while the offices will consume 0.84 W/SF compared to 1.1 W/SF. These spaces were not studied for dimming, so they will have no advantage of incorporating a more accurate schedule. All laboratory spaces went unchanged.

An updated Trane Trace energy model reflecting the lighting redesign can be found in Appendix F. Electrical loads dropped significantly, while heating and cooling loads saw small changes. Due to lost space heat gain from the lighting fixtures, heating loads increased while cooling loads decreased.

An updated economic analysis, Figure 40, realizes \$2,520 in total yearly building energy savings from ASHRAE standard values to the new lighting redesign.

	<i>Existing Design</i>	<i>Lighting Redesign</i>	<i>Savings</i>
<i>Total Yearly Operating Costs</i>	<i>\$140,379.51</i>	<i>\$137,859.20</i>	<i>\$2,520.31</i>
<i>Installation Costs</i>	<i>\$42,016</i>	<i>\$34,695</i>	<i>\$7,321</i>
<i>30 yr Life Cycle Cost</i>	<i>\$3,659,698</i>	<i>\$3,587,427</i>	<i>\$72,271</i>

Table 46: Yearly Operating Costs – Lighting Redesign

Schedule Implications of Lighting Redesigns

The schedule implications of redesigning the lighting system were part of the original analysis. This included a look into the change in lead times in comparison to the existing lighting systems. Based on the redesigned lighting fixtures used, it was determined that the impact of the new lighting system would be minimal, and therefore, it was worth producing a full analysis for the lighting system. The primary differences between the existing lighting and the redesigned lighting include the following:

- Changing T8's to T5's
- Replacing recessed fixtures with pendent fixtures
- Adding task lighting to the casework in the student area

Lighting Redesign Conclusion

The Millennium Science Complex perimeter space lighting redesign incorporates energy efficient fixtures. The designs were integrated with the MSC daylight delivery system to maximize energy savings. Linear pendant fixtures were selected to enforce the architectural themes of floating horizontality. The same pendants were used in both the student area and private offices to maintain uniformity from the exterior. The fixtures selected lead to a \$7,357 savings in upfront cost, with a yearly energy savings of \$2,520. The lighting redesign of the Millennium Science Complex perimeter spaces creates a pleasant work environment, while maintaining BIMception's hierarchy to maintain the overall architecture.

Energy analysis of the lighting alternative redesign realizes instant yearly operating cost savings, as well as a reduction in construction cost, seen in Table 47.

	<i>Existing Design</i>	<i>Lighting Redesign</i>	<i>Savings</i>
<i>Total Yearly Operating Costs</i>	\$140,379	\$137,859	\$2,520
<i>Installation Costs</i>	\$42,016	\$34,695	\$7,357
<i>30 yr Life Cycle Cost</i>	\$3,659,698	\$3,587,427	\$72,271

Table 47: *Lighting Redesign Life Cycle Cost Analysis*

FAÇADE CONCLUSION

The final redesigned façade panel retains the existing layer composition of 2 " face brick, 6" concrete, and 3" polyisocyanurate rigid insulation wrapped in a vapor barrier. The reduction in panel depth to 16" and the redesigned head, sill, and side returns creates the opportunity to decrease the panel's concrete volume. High performing triple pane glazing will replace the existing double pane assembly. A reduction of window area to 60% glazing will also help to reduce yearly energy costs. The depth of exterior shading devices will be reduced to the redesigned panel depth of 16" to mimic the current architectural aesthetics. Interior shades will be switched to bottom-up automatic shades to improve occupant comfort, while dimming and switching lighting controls help reduce energy consumption. The summary energy analysis, incorporating all the alternative design options above, produces a yearly operating savings of \$16,403 and a simple payback of about 2.4 years, Table 48 .

	<i>Existing Design</i>	<i>Alternative Façade Designs</i>	<i>Savings</i>
<i>Total Yearly Operating Costs</i>	\$154,262	\$137,859	\$16,403
<i>Installation Costs</i>	\$1,658,060	\$1,697,082	\$-39,022
<i>30 yr Life Cycle Cost</i>	\$5,633,514	\$5,249,814	\$383,700

Table 48: Facade Redesign Life Cycle Cost Analysis

Plenum Investigation

DESIGN APPROACH

Reevaluating the structural design of the Millennium Science Complex allows for the integration and coordination of structural and mechanical systems. A full redesign of the structural system is proposed as a three building mixed system solution. This design consists of typical concrete floor system and frame within the North and West wings connected by a steel framed section forming the corner of the L-shape. The steel section includes the cantilever truss system, connecting the corner between the two wings. The three building sections will be connected with a seamless yet abrupt transition from concrete to steel framing, thus no expansion joints will be designed. A reduced structural depth could increase the usable space for long duct runs, which are governed by the lowest structural plane, allowing supply ducts to be increased in size, decreasing static pressure losses and potentially leading to energy savings.

Based on previous strength designs performed with multiple concrete systems, specifically a flat plate, flat slab, and one-way joist system, it was determined that concrete in general offers a much smaller vertical dimension of structure within the ceiling plenum, as compared to a steel structure. An alternative structure comprised of a one way pan joist concrete system is incorporated in all wings and floors. The central cantilever system will remain steel, while the wings become concrete. The concrete one way pan system will be controlled by the vibrational criteria for the laboratories, exceeding general strength requirements. The columns and lateral systems have been redesigned as they adjust to the redesigned concrete system.

A smaller structural profile creates the opportunity for an increased volume of useful space in the plenum. Existing collisions have been highlighted as issues that could have been addressed differently given a concrete design. An alternative mechanical duct system reacts to the redesigned concrete structure. The increased available plenum depth eliminates drainage pipe collisions, creates alternative duct routing solutions, and increases duct height. These reactions use modeling to propose integrated solutions to reduce field conflicts and improve energy use.

STRUCTURAL FLOOR SYSTEM ALTERNATIVES

Waffle Slab Design

As proposed a waffle slab was designed with the intention of redesigning the existing steel composite beam system with an efficient concrete system that would offer added stiffness yet reduced weight due to the dome pan formwork. The process included a design based on strength with a vibrational analysis following to determine the adequacy of the floor system within the lab areas with respect to the maximum velocity design criteria as noted before.

Waffle slab construction is a two-way concrete system consisting of a joist system run in two orthogonal directions creating multiple intersections of ribs within each bay, essentially mimicking a waffle shape. The spacing between the domes defines the rib width. The reinforcement is located within the rib space and suspended at the proper depths

ACI 318-08 was consulted for design procedures. It was determined that the floor system layout meets all requirements for Direct Design Method for designing two-way concrete slabs, therefore this method was used to design a waffle slab. Table 9.5c was consulted for minimum thicknesses based on span length. Minimum thickness of slab for the 22ft bays with 18in square columns and no edge beams is 6.83in. Researching typical dome pan sizes showed no pan sizes smaller than 8in. Therefore calculations were done with a minimum rib depth of 8in. and minimum pan size of 30in. 4000psi concrete will be used with a 4.5in slab topping to achieve the mandatory two hour fire rating between floors. Design loads were obtained from the structural drawings and confirmed by ASCE7-05 minimum design loads. The waffle slab was designed for the worst case scenario gravity loads as summarized in Table 49 below. All Calculations are reported in Appendix-G.

Floor Loading		
SW (PSF)	SDL (PSF)	LL (PSF)
118.8	30	150

Table 49: Worst Case Floor Loading

Column and middle strip moments were calculated as per Direct Design Method for a flat slab design. These calculations were based off a flat slab design because due to the 3ft module being used, 30in pans with 6in ribs, the ribs do not line up with the column lines. Therefore interior beams on the column lines were needed to account for extra dimension differentials between bays and the four pans surrounding the columns would need to be cast to the full depth creating drop panels as they are more than one sixth the span length in both directions. Figure 52 below shows a typical bay layout of the 3ft module. A 3D view of a typical interior bay is shown in Figure 53.

Reinforcement was design based on column and middle strip moments. Minimum required steel area was distributed as one bar per rib for those ribs who lie either within either column or middle strip. The 18in wide beams on the column grid lines assumes the rest of the column strip reinforcing that does not fit in the ribs. Typical reinforcement is summarized in Table 50 below.

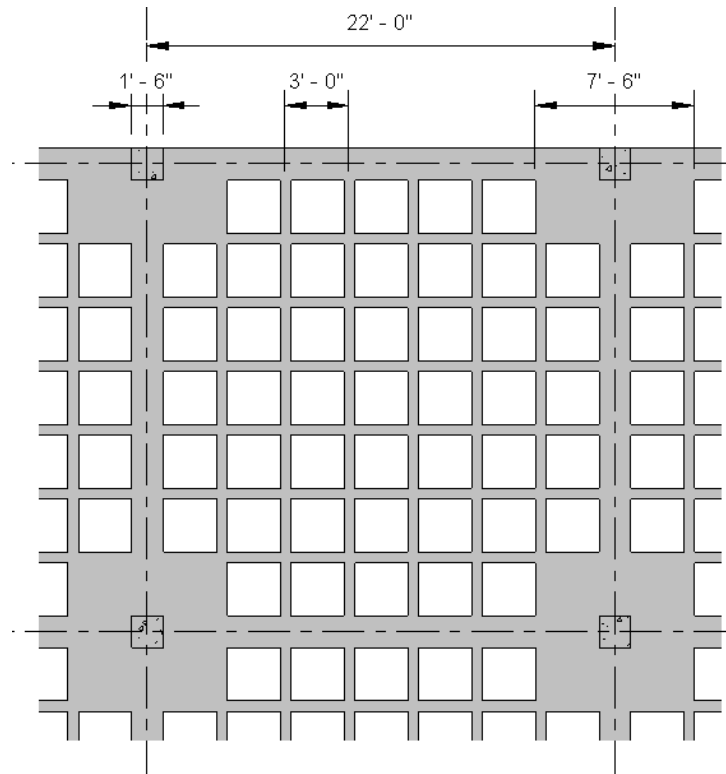


Figure 52: Plan View: *Typical Exterior Bay Layout of Waffle Slab With 3ft Module*



Figure 53: 3D View: *Typical Interior Bay Waffle Slab Construction*

Span	Column Strip			Middle Strip	
	Ext. Supp.	Positive	Int. Supp.	Positive	Int. Supp.
Exterior	(4) #8	(5) #8	(8) #8	(4) #7	(4) #7
Interior		(3) #8	(8) #8	(4) #7	(4) #7

Table 50: *Typical Reinforcement for Waffle Slab Design*

Vibration Analysis/ SAP Modeling

Although the waffle slab design, as summarized above, proves efficient and low profile based on strength design it must be analyzed for vibrations and compared to the existing to prove adequate for use as a floor system within the lab areas. Floor vibrations within a laboratory building are an issue for sensitive equipment and microscope that are required to be accurate with high sensitivities. MSC was reported to be rated for 4000ui/s, 2000ui/s, and 130ui/s in the LS wing, MS wing, and basement isolations labs respectively.

AISC Design Guide 11- Floor Vibration Due to Human Activity defines the process of analyzing a floor system and calculating maximum floor velocities. Equations and Methods were referenced from Chapter 6- Design for sensitive equipment. Figure 54 states the basic equation for calculating maximum floor velocity in micro-inches per second (ui/s).

$$V = \frac{Uv \cdot \Delta p}{fn} = Uv \cdot \Delta p \cdot T$$

Figure 54: *Reference Velocity Equation from AISC Design Guide 11*

Uv is a constant based on a typical person walking at a defined rate of walking. For MSC a value of 5500(lb-HZ²) was used for Uv , based on a 185lb person walking at a moderate pace of 75 steps per minute. Δp is the flexibility constant defined in units of in/Kip. This value is determined either by hand or computer analysis. The designer must calculate the maximum deflection within the bay of interest based on the application of one kip of load, thus mimicking an impulse foot load from someone walking. fn is the natural frequency of the bay of interest. This can either be determined by various hand methods or by computer analysis.

Knowledge obtained from AE 597A, advanced computer modeling for structures, incorporating the above method and equations from AISC Design Guide 11 was used to confirm the existing maximum velocity of the LS wing of MSC. A modeling process was developed to accomplish this task and then repeated with the newly designed waffle slab floor system. A computer model was created for each of these systems using SAP2000. The calculation and modeling process is explained herein.

SAP Modeling of Existing Composite Beams

SAP2000 was used in this vibration study to automate the point-load-deflection calculation of Δp using linear static analysis options. A modal analysis was also used to automate the calculation of, T , the period of vibration, for typical bays. These values of T were then compared to the results of a hand method, called Rayleigh method, used to calculate average period of vibration for a typical bay. The Rayleigh method of calculating floor vibrations is a well-known method comparing potential and kinetic energy. This check gives extra validation to the SAP model accuracy. The application of the Rayleigh method is explained below with a discussion of the results from the entire vibration analysis

Before an actual model of the existing composite beam system was created, it was worthwhile to confirm that the computer model would accurately model the composite action between the steel wide flange sections and the concrete slab. A few modeling processes for modeling this behavior were attempted. Modeling methods considered included a combination and meshing and dividing of area elements, frame meshing, and the incorporation of rigid link frame elements between the frame and area elements to mimic shear stud elements. Due to complication of modeling and inaccurate output the rigid link method was abandoned. The simplest scheme for modeling a composite beam system was one grid level for all floor elements, frames and areas, with proper insertion offsets to achieve proper stiffnesses, and proper area divides and frame meshes to achieve the composite action between the concrete slab and wide flange members. Figure 55 below shows an example of an initial model of a simply supported beam used to test this method. The figure clearly shows the beam and slab deflecting together as one composite section.

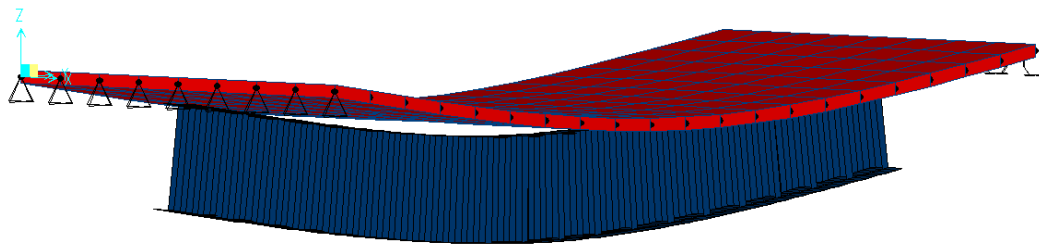


Figure 55: SAP 3D View: Composite Beam and Slab Modeled in SAP2000

Theoretical vs. Model Deflections

Visually the deflected shape above shows the composite action between the frame and area elements. This method was further approved by comparing maximum deflection values at the middle of the span with theoretical hand calculations. Considering linear elastic deflection output from SAP2000 and no cracked section modifiers modeled, referenced equations were used from AISC Steel Construction Manual 2005. Figure 56 lists the equation for this assumed deflection. Multiple beam sections, typical to the MSC LS wing, were modeled using this method to check for precision. All output values from SAP2000 were within 10 percent of the theoretical values calculated by hand, which exhibits adequate accurateness for moving ahead with the existing floor system model. Table 51 summarizes the results for this deflection check.

$$\Delta_{\max} = \frac{5wl^4}{384EI}$$

Figure 56: SAP 3D View: Composite Beam and Slab Modeled in SAP2000

	W18x40	W18x76	W21x44	W21x68	W24x84
Theoretical Deflection(in)	0.4425	0.2547	0.3340	0.2250	0.1552
SAP2000 Deflection (in)	0.4023	0.2756	0.3563	0.2426	0.1679
% Difference	9.08	8.19	6.67	7.81	8.21

Table 51: Summary of Theoretical vs. SAP2000 Deflections

Existing Conditions Vibration Modeling in SAP2000

Having confirmed the accuracy of the modeling scheme proposed above, a model was created to simulate the vibration criteria of the existing composite steel beam and slab system. A five bay by 3 bay model was created to simulate the LS wing of MSC, which is five bays wide and continuous in the other direction. Three bays were modeling in the length of the wing with the intention of viewing deflection and period of vibration output for the middle bays. Extra bays of length would increase accuracy, but three bays are a good approximation and ultimately a conservative approach. Figure 57 shows a floor plan of the typical bays modeled from the existing structure. Vertical grid lines are modeled along the column lines and half way in between, in both directions to cover the locations of the beams.

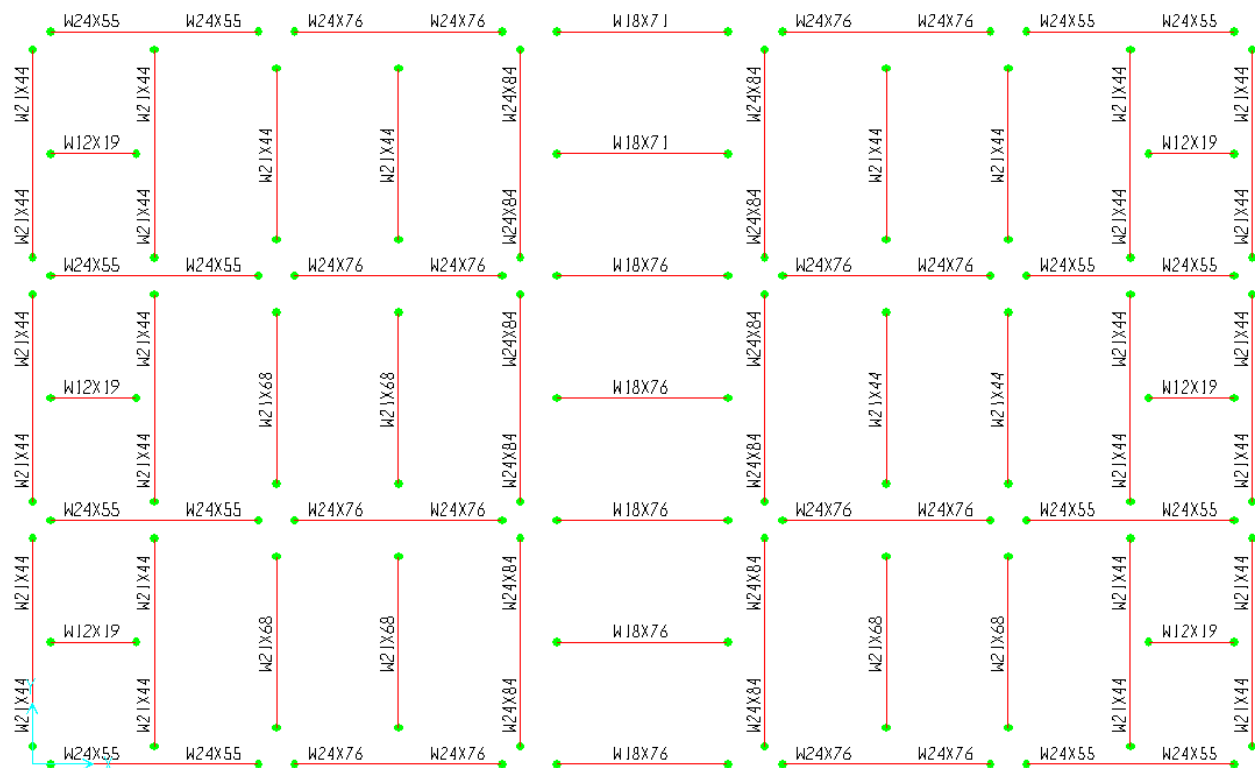


Figure 57: Plan View: SAP2000 Existing Structure Vibration Model

Three horizontal grid levels were defined 10ft apart. The lowest defined the center of the columns below the floor, the middle defined the floor level, and the highest defined the center of the columns above the floor. The columns were only modeled half way to the adjacent floors to simulate a hinge at the center of the columns where the column moments would switch sign from positive to negative. Conservatively it is a location where the column moments can be approximated as zero, and helps to simplify the model. The concrete floor slab was modeled as a shell element with a thickness assignment equal to the thickness of the existing topping concrete above the metal decking, 3.25in. The centroid of the slab will then be at the grid level. The wide flange elements are modeled on the same horizontal grid level on the vertical grid lines. All connection between frame elements were modeled as pin connections. Member end releases were applied to all floor members to release all moment restraints.

Advanced Meshing and Insertion Points Offsets

As mentioned before, the area elements and frame elements must be meshed at equal sizes to achieve the proper composite action. Also the frame elements need to be offset down below the slab to the correct vertical locations as in the real building. The offsets will account for the added stiffness achieved from area at distances away from the neutral axis of the effective cross section. In the case of the existing system 22ft bays are present. Beams and girders are spaced at 11ft. Therefore the area of each 22ftx22ft bay was divided into a main grid of 16x16 and then further subdividing each sixteenth into a 4x4 section of 16.5in square elements. The frame elements were also meshed with maximum length of 16.5in to properly mesh with the area elements. An insertion offset of 4.625in, relative to position 8 (Top Center) was applied to all frame elements to account for the 3in decking plus half of the 3.25in slab thickness. A 3D view of the existing conditions SAP model used in the vibration calculation is shown below in Figure 58.

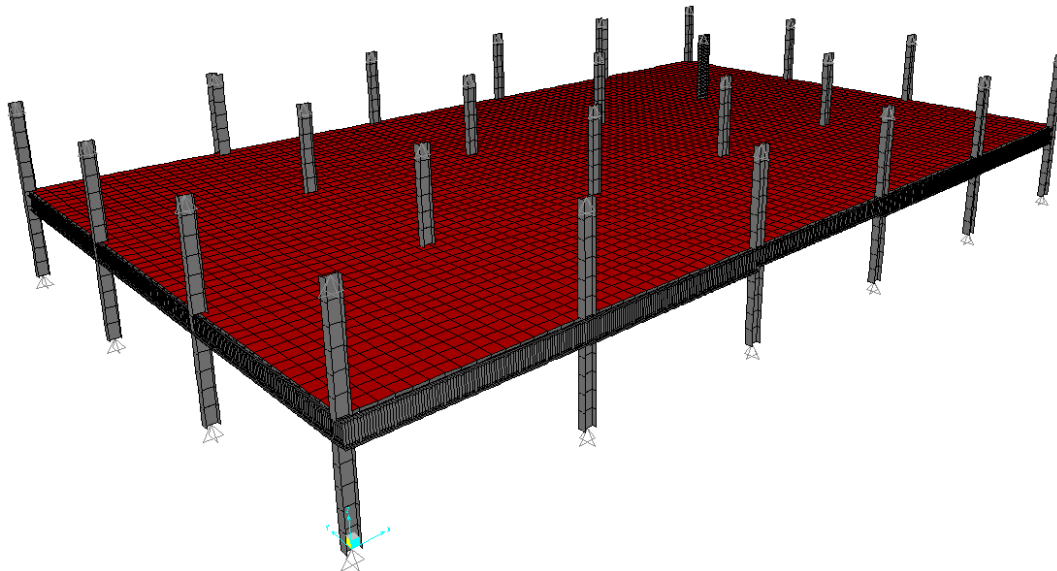


Figure 58: 3D View: Existing Conditions SAP Model, Undeformed Shape

Vibration Model Load Cases

As mentioned before the output data for the center bays will be considered to check for typical vibrational behavior within the existing structure. Three bays in total were considered including: an edge bay (Bay-A), the first interior bay (Bay-B) and the center bay (Bay-C) within the five bay width of the wing. This would show the extent of typical behavior. Therefore three static load cases were created to find the flexibility coefficient, Δp , for each bay. These load cases were named A13, B13, and C7, for the respective bays. To simplify the manipulation of the SAP output, for use in the period of vibration calculation using the Rayleigh method, the major nodes on the main 16x16 grid of each bay were relabeled in a numerical order. The 100K point load for each bay was applied at the nodes that would result in the largest deflection for that bay. These nodes labels were used as the names for the static load case for the individual bays as referenced above. For a summary of the Rayleigh method calculation and output used from the SAP analysis refer to Appendix G. The application of the Rayleigh method in this study incorporates the distribution of weights within each bay, which are lumped together by tributary area into the 25 main nodes, 16 interior and 9 edge nodes. The method uses these weights and the calculated deflections at each of these nodes, due to the static point load case for that particular bay, to calculate the approximate period of that bay.

Additionally a dynamic modal load case was created to automate the period of vibration calculation of the floor system to check against the hand calculation from the Rayleigh method. Three degrees of freedom were used in the dynamic analysis: Uz, Rx, and Ry. Ux and Uy and Rz were not used so as to limit the mode shapes and periods to the vertical period of the bays. If all degrees of freedom were turned on unnecessary modes would show up including translation and torsional modes of the entire floor system, which is not needed. 30 modes were run in the modal analysis and viewed individually one by one to single out the modes in which bay A, B, and C were excited individually. This would hint toward the approximate mode of that bay individually within the floor system. For a summary of the mode shapes for the three typical bays and the respective period of vibrations refer to Appendix G.

Existing Composite Beam System Vibration Analysis Results

Using the flexibility coefficients, Δp determined from the static load cases defined above, the Uv constant of 5500 (lb-HZ²), and the calculated periods from the Rayleigh method, the maximum velocities were calculated for bays A, B, and C. It was determined that for the LS wing the existing composite beam and slab is adequate for use with the given design criteria with a max velocity of 4000ui/s. These results are summarized below in Table 52.

Span/Location	Weight	Uv(lb/sec ²)	Δ_p (in/100kip)	T(sec)	Velocity(ui/sec)
A	27.7	5500	1.115	0.0639	3916
B	27.2	5500	1.004	0.0601	3317
C	26.8	5500	1.138	0.0649	4063

Table 52: Summary of Velocity Calculation For the Existing Composite Beam System

Waffle Slab Vibration Modeling in SAP2000

A similar process and theory as used in the creation of the existing system vibration model was used in the creation of a comparable vibration model for the redesigned concrete waffle slab system. Only a few differences occur due to the change in material, from steel to concrete, and the new layout of floor members. The attempt with the waffle slab vibration model was to simulate as close as possible the same situation developed in the existing conditions model.

The same five bays by three bays layout was used. Similar efforts were needed to achieve composite action between the slab, drop panels, and the ribs and beams. The slabs were modeled with their centroid at the horizontal grid at floor level. The ribs and interior beams were modeled as frame elements with proper frame section definitions and concrete material assignments. Similar area and frame dividing and meshing occurred as well. Slab areas were modeled again as shell elements and divided into a grid defined by the intersection of the ribs, beams, and column locations. The areas defined by these boundaries were further meshed and subdivided into 3x3 squares. The frame elements were meshed with respect to intermediate nodes defined by the area subdivides. The frame elements were modeled at the same grid as the slab shell elements and offset, with respect to Location 8 (Top Center), the same way as with the existing model and equal to half of the slab thickness, 2.25in. A Plan and 3D View of the rib and beam layout is shown in Figures 59-60.

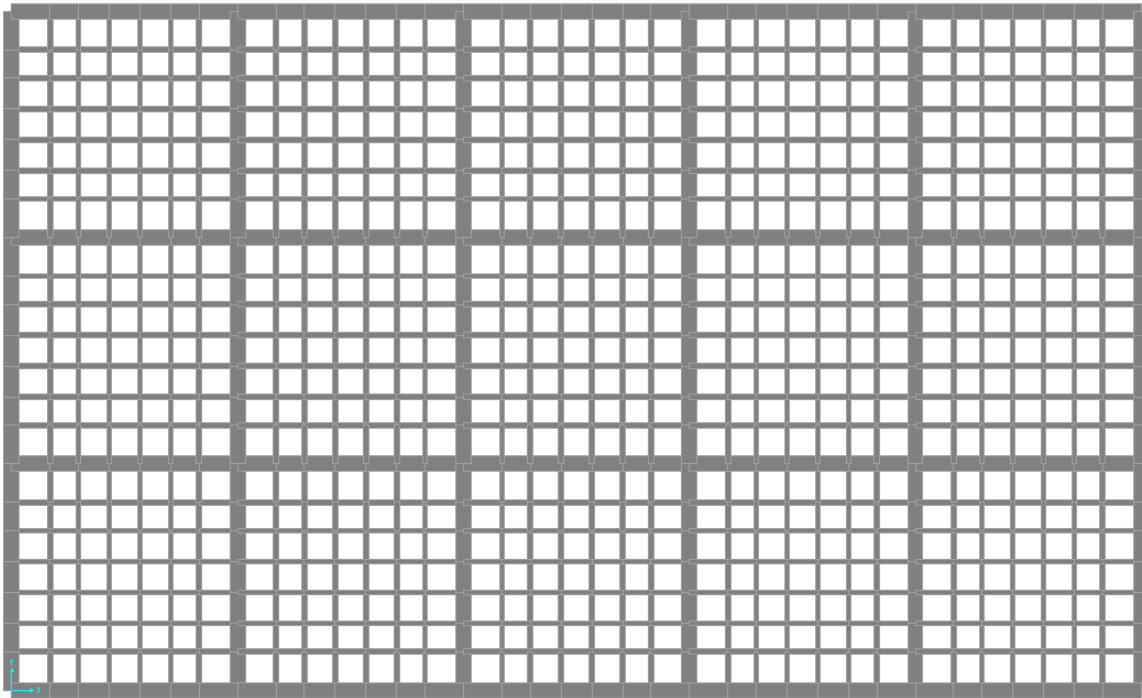


Figure 59: *Plan View: Waffle Slab Vibration SAP Model Rib and Beam Frame Element Layout*

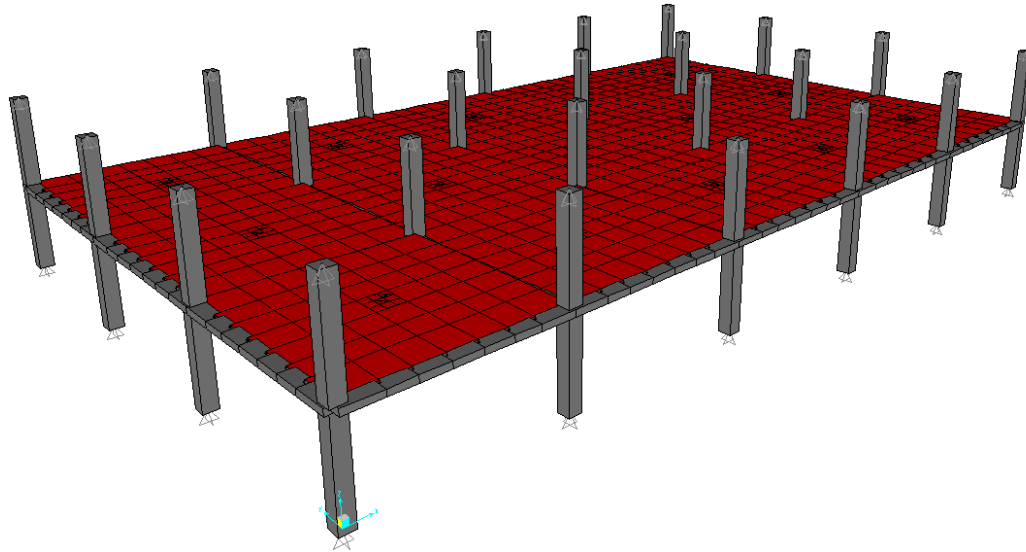


Figure 60: 3D View: Waffle Slab Vibration SAP Model

Waffle Slab Vibration Analysis Results

Based on identical calculations carried out using identical static load cases in bays A, B, and C, identical modal analysis, and the Rayleigh method for calculating approximate period of vibration values, maximum velocities were determined for the three typical bays. It was determined that for the LS wing the redesigned concrete waffle slab is more than adequate for use with the given limiting design criteria with a max velocity of 4000ui/s. These results are summarized below in Table 53.

Span/Location	Weight	Uv(lb/sec2)	Δ_p (in/100kip)	T(sec)	Velocity(ui/sec)
A	46.3	5500	0.500	0.0695	1910
B	46.3	5500	0.463	0.0647	1647
C	46.3	5500	0.462	0.0690	1755

Table 53: Summary of Velocity Calculation for Redesigned Concrete Waffle Slab

The results show that based on purely strength design the waffle slab system was stiff enough even with the added weight to meet the vibrational design requirements. Not only that but it could even be considered too stiff and slightly inefficient, especially for the LS wing of the building. This system may work well in the MS wing for it is even under the 2000ui/s design criteria for that wing. Due to this finding it would benefit the study to consider a slightly less stiff and more efficient concrete floor system. Therefore as proposed, a one-way concrete pan-joist and girder system was also designed and checked as the waffle slab had been done to consider what truly the best alternative concrete floor system was.

One-Way Concrete Pan Joist/Girder Redesign

Based on the results from the vibrational analysis of the waffle slab, a pan joist system was proposed as another potential alternative that could prove adequate for strength, vibrations, and could offer more flexibility within the plenum for coordination purposes, especially considering the mechanical duct redesigns. The pan-joist system would offer the opportunity to run mechanical ductwork laterally between the joists across bays whereas the waffle slab system limits all MEP systems to stay below the bottom of the structural profile. The pan-joist system also offers the opportunity to more easily remove sections of slabs between ribs for potential renovations in the future. A waffle slab system limits any penetrations to the small slab area in the dome areas in between ribs. Design procedures for the pan-joist system include the design of the slab, joists, and girders.

For the slab, joist, and girder design, ACI318-08 was referenced for design methods and required procedures and limitations. For a full design summary and calculations for this system please refer to Appendix G. Slab design was based on fire protection requirements as with the waffle slab. A 4.5in slab was used for this design. For the joist design Table 9.5a was considered for minimum thickness of nonprestressed beams. For one-end continuous the limiting thickness was $l_n/18.5$ which is equal to 14.27in. Therefore 8in pans as used in the waffle slab are no longer adequate. To meet this requirement 10in pans will be the minimum required size. Keeping stiffness requirements in mind for vibration requirements a true pan-joist system was used with 6in wide ribs and 30in clear distance between ribs. For the proposed design and layout these joists meet the minimum requirement to be considered actual joist construction by section 8.13. This title greatly benefits the design requirements for the joist. Moments were calculated based on moment coefficients defined in 8.3.3. Design moments and shear forces were used to design flexural and shear reinforcing. Similar design procedures were used to design the girders, which were sufficiently designed at the same depth as the joists with a 36in width. Bar development length, cut-offs, and anchorage designs were developed according to ACI318-08 chapter 12. Figure 61 shows a plan view of the pan-joist floor system. All elements are 10in deep. Figure 62 shows a typical bay of this design in 3D.

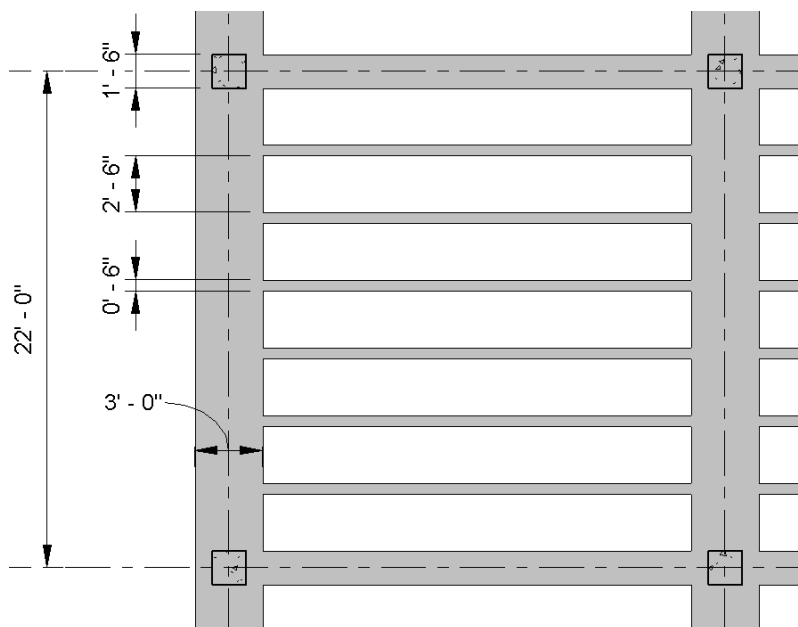


Figure 61: Plan View: Redesigned Pan-Joist System layout



Figure 62: 3D View: Redesigned Pan-Joist System Typical Bay.

Column Redesigns

Initial hand calculation of design loads and floor self-weight distributed to critical columns showed potentials for as small as a 16in square concrete column. Due to layout constraints of the joist spacing the interior beams or larger ribs located on the column lines needed to be 18in. For this reason 18 in columns were assumed adequate in all locations within the wings. Slenderness, sway frame behavior and moment magnification was considered as per ACI318-08 section 10.8 - 10.10. The concrete columns of the wings of MSC were determined to be non-slender in non-sway frames, and non-sway moment magnifiers were less than one. Therefore no moment magnification was considered in the column design moments. A simple 2-dimension gravity frame with columns and beams was analyzed in SAP2000 with calculated column and beam design loads to determine the total axial loads and moment demand on typical columns. These loads were loaded into spColumn and designed. Column Design procedures, loads and final designs with reinforcing are included in Appendix G.

Pan-Joist Vibrations Modeling in SAP2000

To create the vibration model for the redesigned pan-joist in SAP the model used for the waffle slab vibration analysis was easily modified by removing the ribs running in the three bay direction and change the beams on the column lines, in that same direction, to the new 36in wide girders. Frame sections also needed to be modified to reflect the 10in depth instead of the 8in with the waffle slab design. The slab did not need to be modified. The area subdivides and frame meshes were not edited and remained intact. The same static and modal load cases were also preserved. No additional label changes were needed for the nodes either, however, due to the change in weight with the new design the tributary weights needed to be modified to keep the accuracy of the Rayleigh method of calculating the period of vibration for the critical bays. Figure 63 shows a plan view of the new layout of joist, beams, and girders for the pan-joist SAP model and Figure 64 shows a 3D view of the same model. Notice the similarities to the previous two models.

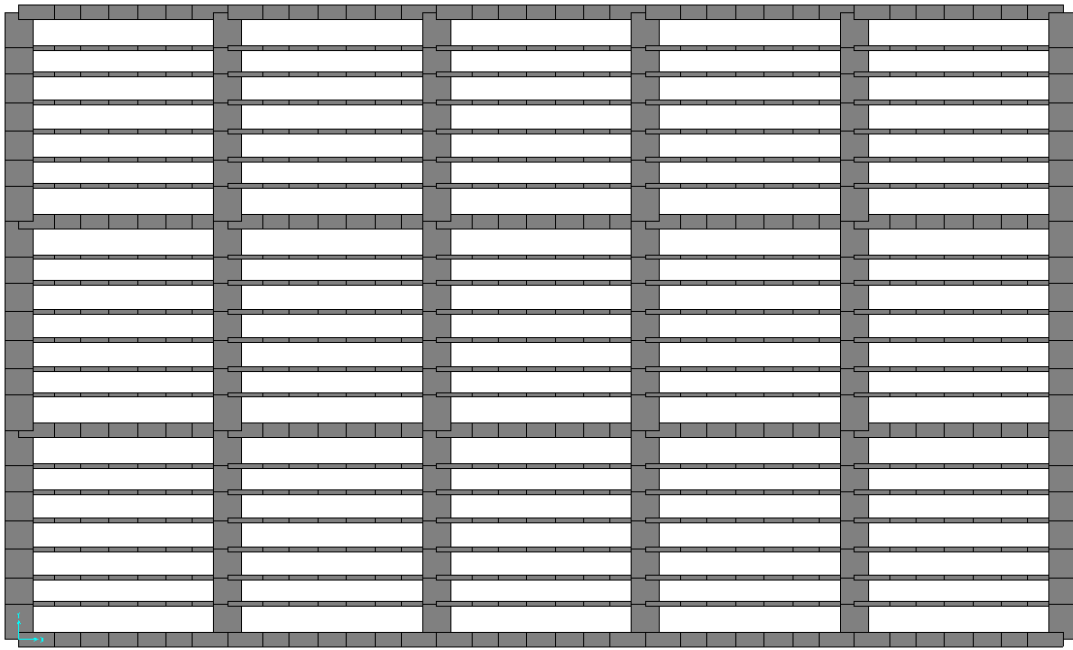


Figure 63: *Plan View: Redesigned Pan-Joist System Layout in SAP2000.*

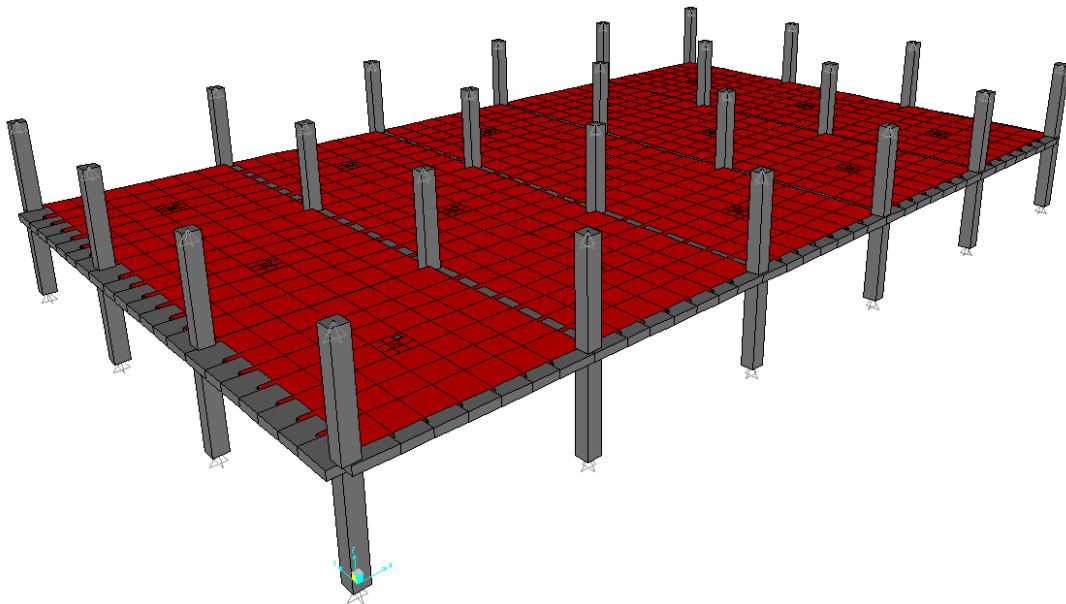


Figure 64: *3D View: Redesigned Pan-Joist in SAP2000.*

Pan-Joist Vibration Analysis Results

Based on identical calculations, as compared to the waffle slab analysis, carried out using identical static load cases in bays A, B, and C, identical modal analysis, and the Rayleigh method for calculating approximate period of vibration values, maximum velocities were determined for the three typical bays. It was determined that for the LS wing the redesigned concrete pan-joist system is more than adequate for use with the given limiting design criteria with a max velocity of 4000ui/s. In fact the results are very similar to the previously discussed waffle slab design. The critical velocity even works for the more stringent 2000ui/s rating in the MS wing. Also the pan-joist is much more efficient and more flexible to mechanical systems and future renovations. These results are summarized below in Table 54.

Span/Location	Weight (kip)	Uv (lb/sec ²)	Δ_p (in/100kip)	T (sec)	Velocity (ui/sec)
A	41.7	5500	0.584	0.0637	2048
B	41.7	5500	0.541	0.0597	1776
C	41.7	5500	0.541	0.0596	1774

Table 54: Summary of Velocity Calculation for Redesigned Concrete Pan-Joist System

Impacts of Gravity System Redesign on Lateral Resisting System

Redesigning the wings as a concrete system affects the methods of lateral resistance within the extents of the concrete system. The concrete system adds mass to the building as well which increases the seismic load demand on the building. Two types of lateral resisting elements exist in the wings currently. On grid lines 15 and V exists 18in shear walls. On grid line 15 the shear wall extends from the first to third floor. A concentric braced frame exists above that extending up to the fourth floor. On grids 20 and M exists concentric braced frames as well. With the proposed pan-joint system these steel braced frames must be changed. Therefore the new proposed lateral system includes a change of all braced frames within the wings to concrete shear walls. The existing 18in shear walls will remain and it will extend to the fourth floor on grid 15. The braced frames at the ends of the wings on grid 20 and M will be replaced with 16in shear walls. To gauge the impact of this change and confirm the adequacy of the new walls an existing check of the lateral system was conducted. Following that study a redesign of the lateral system incorporated the added mass of the new concrete wings and the new shear walls which will replace the concentric braced frames within the wing. Figure 65 shows a plan view of the lateral resisting elements on the first floor. Figure 66 shows the same view with the proposed lateral system redesign. The red overlay shows the extent of the new pan-joint concrete system while the blue overlay shows the part of the building that will remain steel.

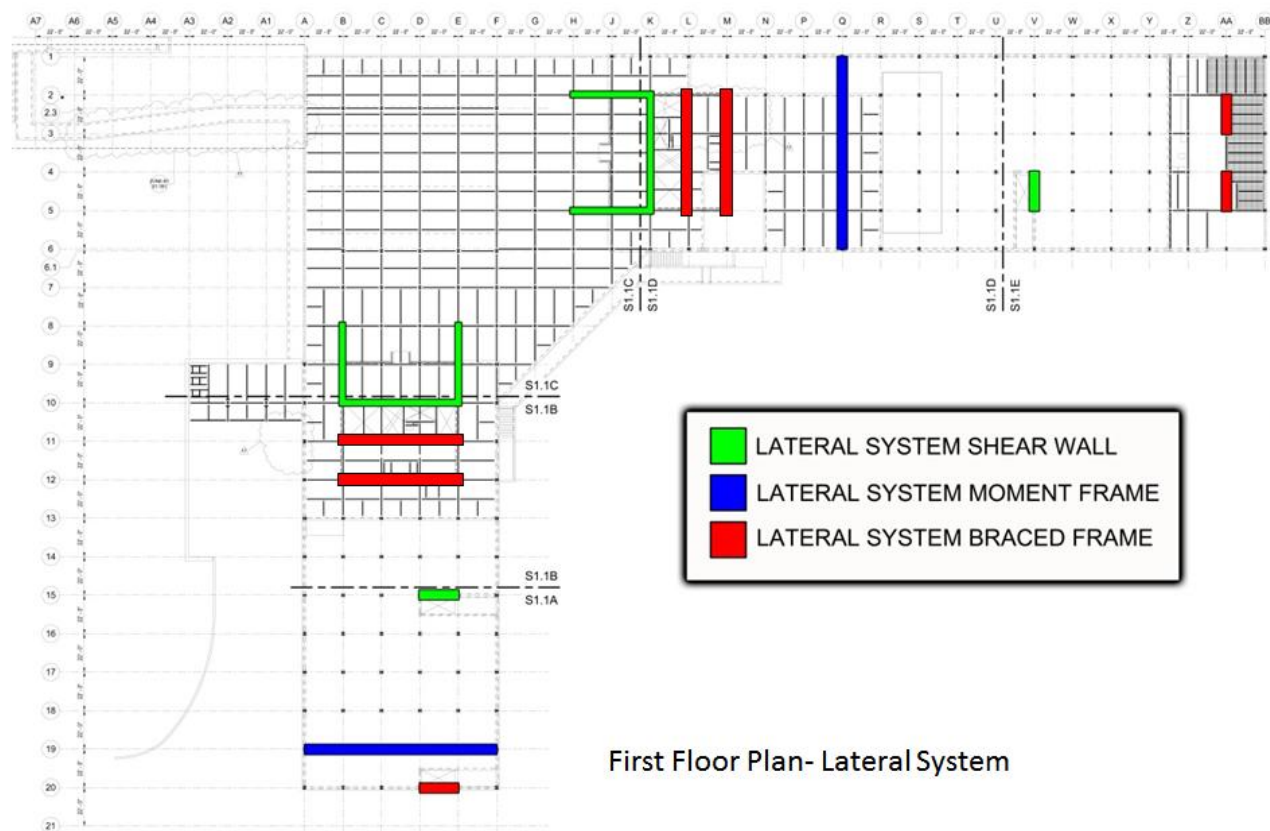


Figure 65: Plan View: Existing Lateral Resisting Elements on First Floor

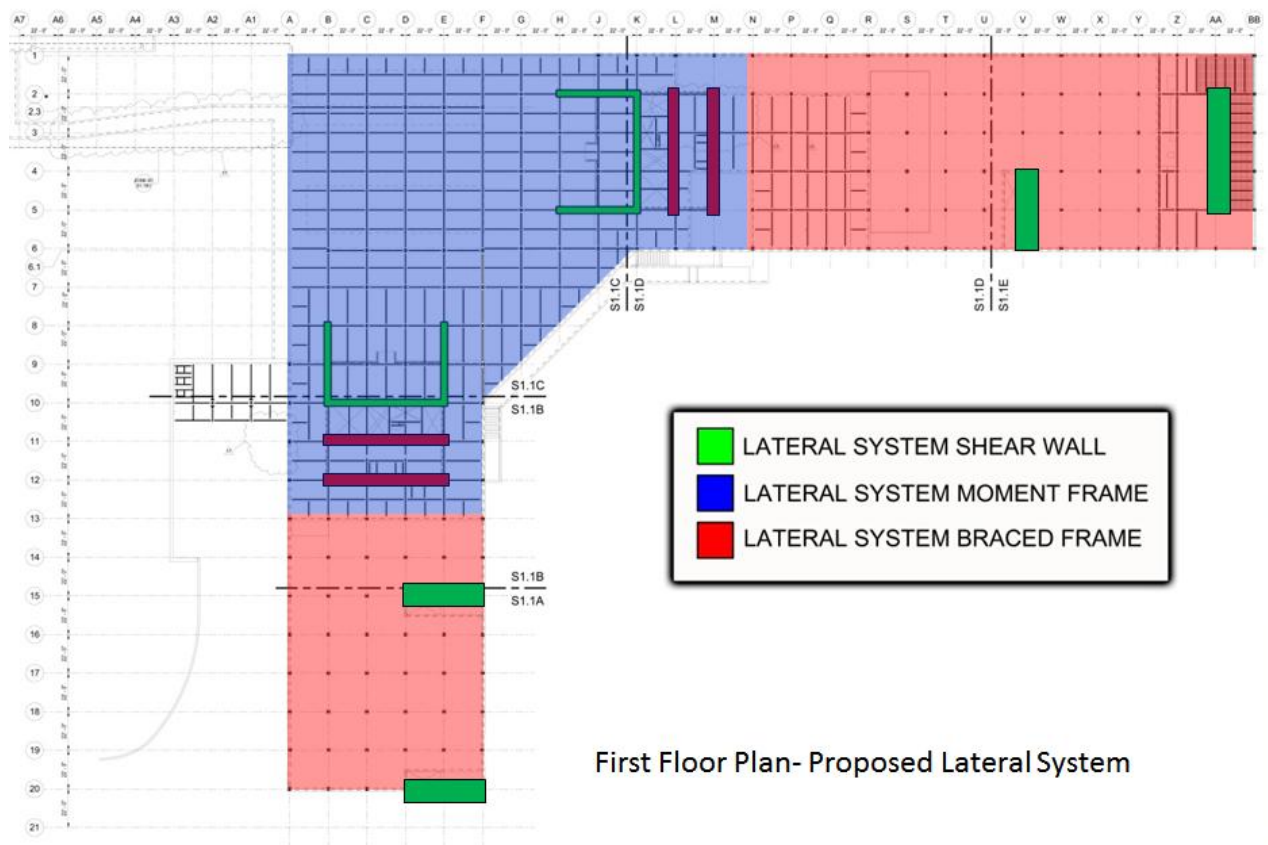


Figure 66: Plan View: New Proposed Lateral Resisting Elements on First Floor

Check of Existing Lateral System

Studying the existing lateral system helps to gauge the impact of any proposed redesign of changes within the structure. For a building of this magnitude and complexity a computer model of the lateral resisting system and the applicable design lateral loads will help to automate the stiffness based lateral distribution of forces to all the lateral resisting elements throughout the building.

Therefore methods were pulled from AE597A to create a properly working ETABS model of the existing lateral resisting elements was created. The model was limited to only the lateral resisting frames, shear walls, and the cantilever truss system, because it adds lateral stiffness to both orthogonal directions. The basement walls were also added to simulate the stiffness of the basement level. Membrane elements were modeled at each floor level connecting each lateral resisting element at that level and reaching to the extents of the actual floor slabs.

Wind and Seismic loads had been calculated previously by hand per ASCE7-05 chapter 6 for wind loadings, and chapters 11 and 12 for seismic loading. The excel calculations for these lateral loads are available in Appendix-G. Proper load case definitions and load combinations were created within ETABS to properly apply the design loads to the structure. Figure 67 shows an image of the existing ETABS lateral model.

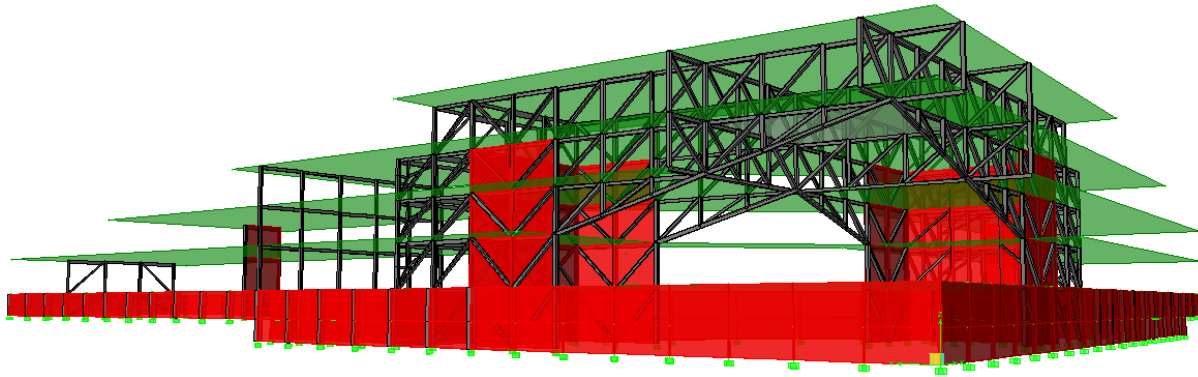


Figure 67: 3D View: Existing ETABS Lateral Model

After the model was run output from the model was reviewed including maximum displacements at roof level, maximum story drifts and overall building drifts, and shear values in walls, columns, and braces. Also modal analysis was reviewed. In all these reviews seismic loads dominated design values as compared with wind loads.

Torsional irregularity was checked per ASCE7-05 section 12.3. Based on the displacement output the building was determined to have torsional irregularity type-1a. Based on our Seismic design criteria, B, certain requirements then must be met. According to Table 12.3-1 we must then abide by sections 12.7.3 and 16.2.2, which define requirements and considerations for the lateral model including modeling cracked section properties and modeling panel zone deformations. These adjustments were made to the model and run again to obtain the adjusted output.

Individual walls, columns, and braces were then checked for strength in certain frames. Due to the large stiffness of the large 30in c-shaped shear walls integrally poured with braced frames a good portion of the lateral loads is concentrated in these walls. One of the side returns of this wall system on grid-2, the back of the c-shaped wall on grid 10, and the shear wall on grid 15. Section cuts were taken at the base of each frame. Forces in the walls, columns, and braces were separated and each set of elements checked individually. No issues arose from these checks. All elements passed for minimum strength. Allowable limits for maximum story and overall drift values were checked as well and were well within the limits for seismic and wind loads. A summary of these calculations are available in Appendix-G.

Lateral System Redesigns

Two main concerns needed to be addressed when redesigning the lateral resisting components within the wing, the change in weight of the new concrete pan-joist floor system in the wings and the potential added stiffness of the lateral system in the wings due to the addition of concrete shear walls. The weight change was considered per floor and the mass assignments to the floor diaphragms in the ETABS model were adjusted accordingly. The weight of an individual bay was calculated for the existing steel and new concrete systems. Based on how many bays were being altered on each floor determined by how much the weight of each floor needed to change. The new masses based on this added weight were calculated and new mass assignments were added to the membrane diaphragms. Also the total floor weights affected the vertical load distribution of seismic forces which were recalculated and the load cases dedicated to seismic loads within the ETABS model were updated accordingly.

The existing braced frames in the wings were then deleted and concrete shear walls were added in these bays. Conceptually this change works because concrete foundation walls, of the proposed thicknesses at these locations, are already present and could simply be continued vertically with the concrete gravity system during construction. The ETABS model was then run again and the newly changed lateral elements were reviewed and checked for strength. A check for minimum strength of the concrete wall on grid 15 was performed. It was determined that the concrete alone could take the shear stress at the base level. Therefore minimum reinforcing for longitudinal and transverse directions were designed for the wall. This was considered a typical design and would apply to all the redesigned shear walls within the wings. Calculations for the weight changes, mass assignments, vertical seismic load distribution, and shear wall designs are available in Appendix-G.

Cost Analysis

Due to time constraints, an investigation of the redesigned lateral systems in the building was not conducted.

Schedule Analysis

Due to time constraints, schedule impacts were not investigated for the redesigned lateral system within the building.

Structural Cost Analysis

The cost of the structure for the Millennium Science Complex provided a very hefty portion of the total cost of the project. As can be seen in the Project Construction Overview, the structure consisted of 17.6% of the project costs, which was just below the cost of the mechanical systems. This is unusual for a typical building, but for the Millennium Science Complex, the structure is far more complex than any normal building. Based on the drastic redesign of the structural system to concrete, a change in the cost of the structure was expected. Building information modeling was utilized in the preparation of the estimates of the existing steel wings, as well as the redesigned concrete wings. Models of the one-way system, as well as the steel, were created in Revit, which were then imported into Quantity Takeoff (QTO). QTO was used to produce takeoffs of the models in preparation for the input of cost data. This was primarily done with the existing steel. The model provided information for the steel beams and columns, as well as the slabs on metal deck, in the portion of the wings that were being redesigned. Once the takeoffs were produced in the program, cost data from RS Means Concrete and Masonry, as well as Walker's Building Estimator's Reference Book, were input to create an estimate of the steel and concrete in the existing structure. This information was combined with takeoffs produced by hand in Excel, once again using RS Means Concrete and Masonry, Walker's Building Estimator's Reference Book, and crane rental data to create an estimate of the existing structure that will change. Table 55 displays a summary of the cost totals for the existing structure.

	Material Cost	Labor Cost
Steel Framing	\$1,722,507	\$341,182
Metal Deck	\$408,606	\$46,170
Concrete	\$421,088	\$163,810
Total	\$2,552,202	\$551,163
Cranes	\$362,500	
Overall Total	\$3,465,865	

Table 55: *Summary Table of Existing Cost of Structure*

The redesign to concrete provided challenges in producing an estimate that was competitive with the existing steel structure. This can be attributed to the steep increase in labor for the concrete system. Labor typically provides a very high portion of the total cost of the construction of concrete structures. Below is a table summarizing the concrete costs of redesign for the Material and Life Science wings. These costs were determined entirely through hand takeoffs done in Excel, using costs data from RS Means Concrete and Masonry and Walker's Building Estimator's Reference Book. In addition, the quantity takeoffs for the volume of concrete in the structure were verified using a Revit model imported into QTO. With the inability to model any other component of the concrete structure, QTO was not able to be further utilized during the estimation process. As can be seen, the concrete structure cost nearly \$1,400,000 more than the steel structure. This represents an increase of nearly 40% over the existing structure. Keeping in mind that the structure was redesigned with the intention to provide more space for the mechanical system, it is possible that a more efficiently designed mechanical system could help repay the increase in costs to the redesigned structure. A more detailed breakdown of how the costs for both the existing estimate and the redesign estimate were produced can be found in Appendix D.

	Material	Labor
Concrete	\$403,758	\$110,791
Rebar	\$277,595	\$187,798
Formwork	\$1,286,819	\$1,787,383
Finishing	\$24,606	\$49,213
Shoring	\$296,521	\$6,477.86
Total	\$2,289,301	\$2,141,664
Cranes	\$402,802	
Overall Total	\$4,833,768	

Table 56: *Summary Table of Redesigned Concrete Structure*

MECHANICAL SYSTEM ANALYSIS

Design Approach

The mechanical redesign of the plenum space will focus on the effects that static pressure losses have on fan energy consumption. The availability and utilization of the vertical height of the plenum will be used to evaluate more efficient duct sizing to produce lifecycle savings.

The existing supply duct for the Materials Science wing will be modeled in Revit MEP 2011, depicted in Figure 68, to produce a baseline static pressure loss, utilizing built in duct sizing capabilities. This will produce a baseline energy model in Trane Trace to analyze the cost of high static pressure. These steps will be repeated, assuming that incremental increases in plenum height are available to be used for increased duct size. As more vertical space is used for duct area, the static pressure will decrease creating potential for energy savings. The final selection of the plenum will allow for an increase in duct size, creating valuable lifecycle energy cost savings.

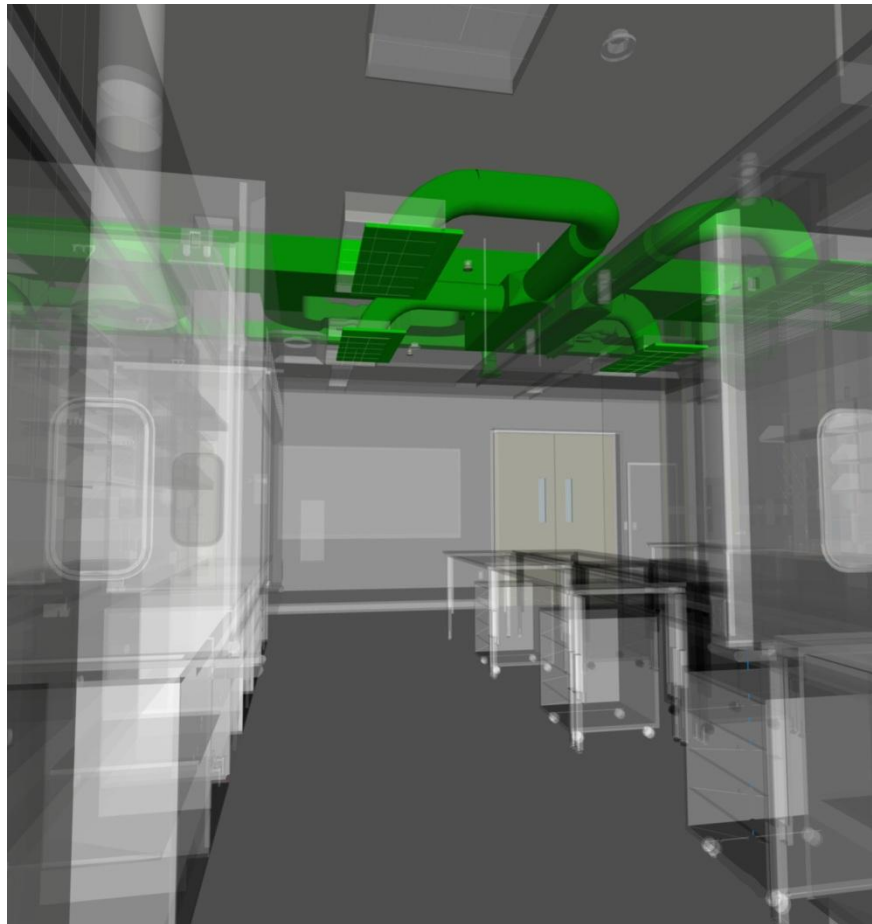


Figure 68: *Render of Laboratory Supply Ductwork in Third Floor Materials Science Lab*

Existing Mechanical System

The existing third floor Materials Science Wing will serve as the basis for all following analysis. As described above the laboratory supply ducts will be evaluated in isolation of the rest of the building to simplify considerations and calculations.

The laboratory supply system manifolds five 100% outdoor air handlers together on the penthouse level. This manifold splits on the penthouse level to serve both the Life and Material Science wings Figure 69. Two duct risers supply laboratory air to the Material Science Wing. One is located in the shaft to the north and the other in the shaft to the south. From the risers, the mains on each level run along the exterior corridors supplying the laboratories Figure 70.



Figure 69: *Laboratory Supply System on Penthouse Level. Manifolds are shown in Red, while the Supply Mains are Green and the Air Handlers are Teal.*



Figure 70: *Laboratory Supply on Third Floor Material Science Wing*

Duct Sizing

The existing duct mains have been sized using the static regain method, creating equal pressure drops for each run of duct. This translates to undersized ducts on the third floor generating high velocities and large pressure drops compensating for the longer runs on the first and second floors. In future analyses, the necessity to match the pressure drops of subsequently mentioned floors will be ignored, allowing for the energy analysis to focus solely on the run from air handler to third floor terminal units.

Fan Selection

Each of the 50,000 cfm laboratory air handlers has a total static pressure of 9 inches water gage. The external static pressure drop is 4.75" wg, and 4.25" wg internally. In future analyses external pressure drop will vary, but the internal pressure drop will be assumed constant, 4.25" wg. In the analysis of the third floor, the total cfm is about 30,000 cfm. A reduction in total brake horsepower for the fan motor from 100 bhp to 70 bhp was calculated using fan laws. The existing third floor will be modeled with a 70 bhp with 9" TSP. As static pressure varies in the analysis, the bhp will vary accordingly using fan laws.

Hand Calculations – Static Pressure Loss

A custom hand calculation spreadsheet was created in excel to evaluate and verify an external pressure drop of 4.75" wg.

The user inputs section run (#), duct accessories (part name), length of run (feet), air flow (cfm), duct dimensions (inch by inch or inches round), and absolute roughness (E) (feet). Using the Huebscher correlation for rectangular ducts, a hydraulic diameter (D) (inches) is calculated equating the rectangular duct to a standard round duct size. Once area is calculated, air velocity (V) (fpm) is found from the relationship of area and airflow. Velocity and diameter are the most integral parameters for calculating losses in duct runs and accessories.

Absolute roughness is input from ASHRAE 2009 Fundamentals Table 1 Duct Roughness Factors. 0.005 E ft. will be used for ducts of average roughness, while flex ducts will experience a roughness factor of 0.01 E ft. Relative roughness (E/D) is calculated. Kinematic Viscosity and Density are assumed constants at 60 degrees at $1.58 \times 10^{-4} \text{ ft}^2/\text{s}$ and $0.075 \text{ lb}/\text{ft}^3$ respectively. A Reynolds number (Re) is calculated.

In order to expedite calculations the Swamee-Jain Equation, Figure 71 will be used to approximate the friction factor. The accuracy of this equation was tested by manual checks and proves to be reliable. Pressure drop (in wg) will be calculated from ASHRAE 2009 Fundamentals equation 18.

$$f = \frac{0.25}{\left[\log_{10} \left(\frac{\epsilon}{3.7D} + \frac{5.74}{\text{Re}^{0.9}} \right) \right]^2}$$

Figure 71: Swamee-Jain Equation Used to Approximate Friction Factor.

For lengths of duct run pressure drop (in wg) will be calculated from ASHRAE 2009 Fundamentals equation 18. For accessories pressure drop will be found from the product of velocity pressure and a corresponding loss coefficient from ASHRAE 2009 Fundamentals Fitting Loss Coefficients.

To find total static pressure, the losses due to duct runs and accessories will be summed at the termination of components. A copy of the excel template can be found in the Appendix F.

Existing – Static Pressure Loss

The existing laboratory supply duct pressure loss was calculated for the third floor Materials Science wing. Values for length, duct size, and airflow were input, along with any components and accessories. Pressure drops for components like diffusers, heating coils, and supply venture valves were found in the construction documents and assumed as constants. For every other component and accessory, the pressure loss was calculated as described above using velocity pressure and loss coefficients. To compensate for only considering third floor airflow, the duct sizes in the penthouse were resized to match the pressure loss per 100 feet of ductwork of the existing system, while having the flow of just the third floor.

The effectiveness and accuracy of the hand calculation spreadsheet was confirmed when a total external static pressure was given as 4.81" wg, only 2% different than the specified 4.75" wg.

Duct Sizing Effects – Static Pressure Loss Alternatives

Using the calculation for the existing duct system, iterations of different duct sizes were analyzed for their effects on static pressure and fan energy. A decrease in height of 2" and increases in height of 2", 4", 6" and 8" were analyzed. By changing the area of the duct, the velocity in the duct is changed. A decrease in velocity correlates to a decrease in losses per length and losses per component. The effects of this analysis can be seen in Table 57. This table also uses fan laws to approximate adjusted fan horsepower. The exponential relationship of decreasing duct size to total static pressure can be seen in Figure 72.

	<i>Decrease 2 Inches</i>	<i>Existing</i>	<i>Increase 2 Inches</i>	<i>Increase 4 Inches</i>	<i>Increase 6 Inches</i>	<i>Increase 8 Inches</i>
External Static Pressure (in wg)	6.6	4.81	3.8	3.09	2.7	2.34
Total Static Pressure (in wg)	10.85	9.06	8	7.34	6.9	6.59
Fan HP	95	70	60	55	50	45

Table 57: Duct Sizing Effects on Fan Selection

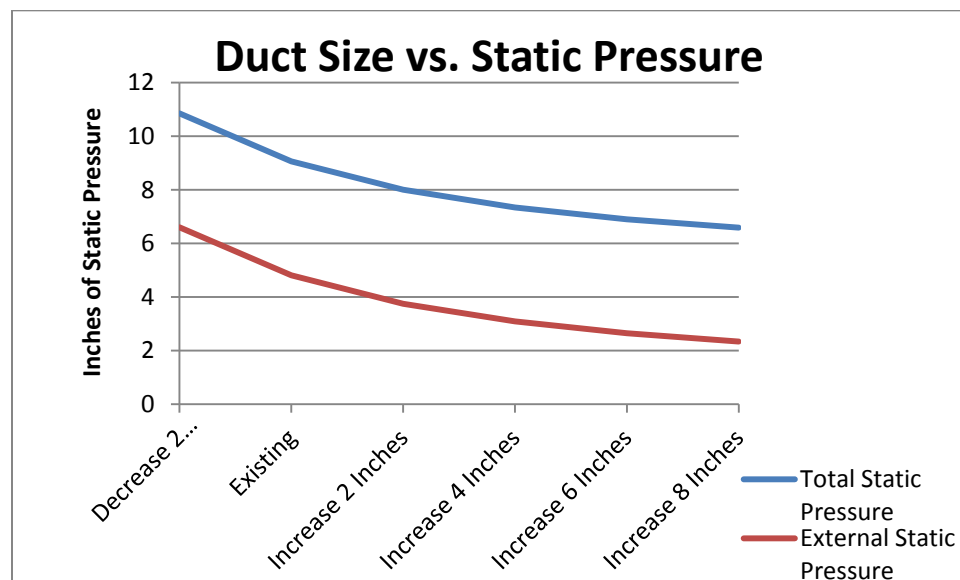


Figure 72: Exponential Relationship of Duct Size and Static Pressure

Energy Modeling – Static Pressure Loss Alternatives

The effects of changing the duct system were modeled in Trane Trace. By changing the duct system, the supply air fan experiences varying total static pressure losses and a corresponding change in fan horsepower. These are the two variables adjust in the model. Trane Trace was selected to perform this analysis to take advantage of the interdependencies of supply air systems. Duct pressure and fan operation add heat to the supply air. This can be seen in the requirement of varying cooling and heating energies to meet the constant room load of all cases. An increase in horsepower and static pressure requires less reheat energy, but more cooling energy. The ability of Trace to use utilization and operation schedules also enhances its accuracy in predicting the total effects on energy usage. The chart below analyzes the effects of static pressure on whole building energy consumption and costs, Table 58.

	<i>Decrease 2 Inches</i>	<i>Existing</i>	<i>Increase 2 Inches</i>	<i>Increase 4 Inches</i>	<i>Increase 6 Inches</i>	<i>Increase 8 Inches</i>
<i>Building Energy Consumption (kbtu/ft2-yr)</i>	141.4	138.1	136.9	135.9	135.2	134.7
<i>Source Energy Consumption (kbtu/ft2-yr)</i>	237.6	231.9	230.2	228.7	227.3	226.5
<i>Electricity (kWh)</i>	620,285	600,535	594,847	589,705	584,753	582,131
<i>Yearly Electricity Cost</i>	\$62,028.50	\$60,053.50	\$59,484.70	\$59,870.50	\$58,475.30	\$58,213.10
<i>Purchased Steam (therms)</i>	17,291	17,496	17,625	17,711	17,766	17,805
<i>Steam Yearly Cost</i>	\$37,435.00	\$37,878.84	\$38,158.13	\$38,344.32	\$38,463.39	\$38,547.83
<i>Purchased Chilled Water(therms)</i>	24,126	23,153	22,675	22,332	22,099	21,934
<i>Chilled Water Yearly Cost</i>	\$44,231.00	\$42,447.17	\$41,570.83	\$40,942.00	\$40,514.83	\$40,212.33
<i>Total Yearly Operating Costs</i>	\$143,694.52	\$140,379.51	\$139,213.66	\$138,256.82	\$137,453.52	\$136,973.26

Table 58: Energy and Cost Analysis of Changing Duct Size

Construction/Installation Costs of Alternate Duct Systems

With a change in ductwork comes a change in the cost of the mechanical system. In order to properly analyze the benefits of this change to the mechanical system, costs for the increase and decrease in size of ductwork must be established. In addition to the material cost of ductwork, the material cost of insulation around the ductwork must be considered due to the increase or decrease in surface area. Labor was not considered for this analysis due to the negligible effect it would have on the cost.

Based on RS Means Mechanical Cost Data, the following costs for the third floor were determined for the change in ductwork. These costs are based on four total runs of 22 gauge ductwork on the third floor, each totaling 250 feet in length. The cost for ductwork provided by RS Means was based on a cost per pound. Based on typical weights for metal ductwork, a weight per linear foot, and correspondingly a total weight per section of duct, was determined. This was then used to determine the cost for the runs of ductwork. A more detailed breakdown can be found in Appendix D.

Ductwork Size Change	Cost of Ductwork for Third Floor	Change in Insulation Cost from Existing
6 in. Increase	\$33,131	\$2,130
4 in. Increase	\$32,076	\$1,418
2 in. Increase	\$31,021	\$710
Existing	\$29,966	\$0
2in. Decrease	\$28,911	\$-710

Table 59: Construction Costs of Changing Duct Size

Schedule Impacts

Due to the negligible impacts on labor based on the changes to the ductwork, the schedule impacts were not thoroughly investigated. A change in the size of the ductwork, as referenced above, would not add additional time to labor. The change in labor for the increase or decrease in insulation would not provide significant increases to the time required for installation. It is assumed that the additional time could be done without impact to the schedule.

Life Cycle Cost Analysis

Analyzing the life cycle cost effects of manipulating duct size will help to select the most economical size for the supply duct system. In the Figure 73 below, varying duct size changes are evaluated. Both yearly operating costs and installed costs are relative values compared to the existing design. As duct size increases the installed cost increases linearly, while operating costs experience diminishing returns and eventually will converge on a value. This relationship implies that at some point the added increase in installed cost will not produce a correlated increase in operational savings. From Figure 73 below, an increased duct size of 6 inches will be selected, just as operating costs begin experiencing diminishing returns.

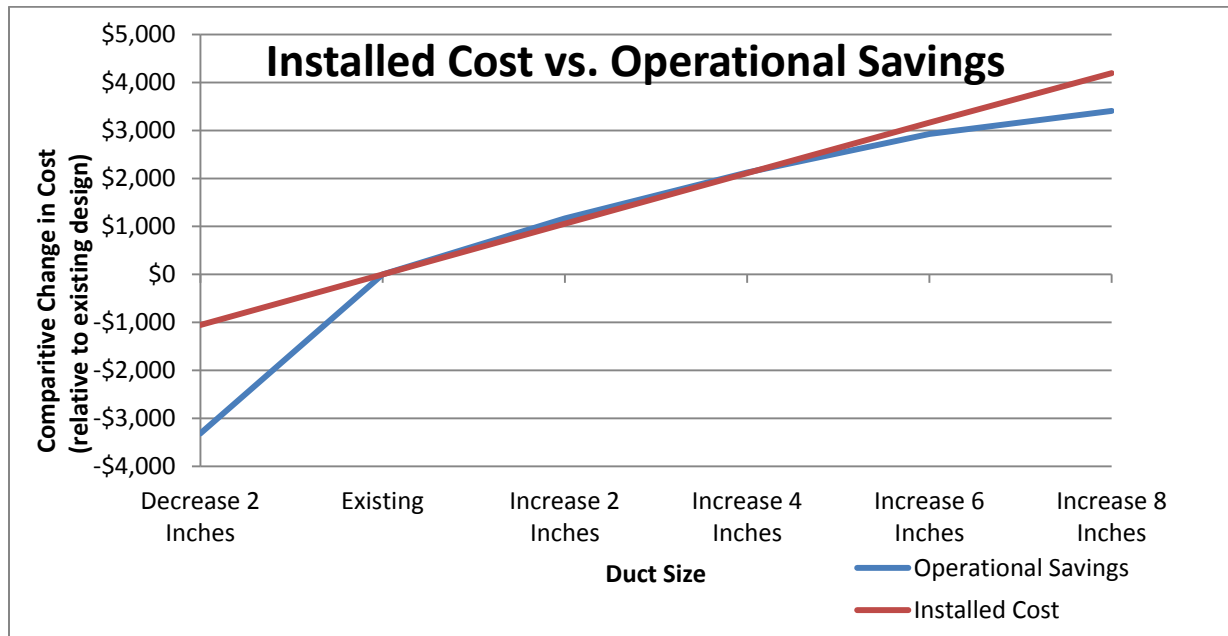


Figure 73: Comparison of Installed and Operational Costs

To confirm the value in saving yearly operational costs, a full life cycle cost analysis was performed. The following Table 60 comparatively shows the cost effects of changing duct size.

	Decrease 2 Inches	Existing	Increase 2 Inches	Increase 4 Inches	Increase 6 Inches	Increase 8 Inches
Total Yearly Operating Costs	\$143,694	\$140,379	\$139,213	\$138,256	\$137,453	\$136,973
Installed Cost	\$28,911	\$29,966	\$31,021	\$32,076	\$33,131	\$34,161
30 yr Life Cycle Cost	\$3,732,024	\$3,647,648	\$3,618,659	\$3,595,055	\$3,575,409	\$3,564,062

Table 60: Life Cycle Cost of Duct Size Alternatives

CONSTRUCTION SCHEDULE AND LOGISTIC IMPACTS OF FINAL SELECTION

Site Logistics and Planning

A change to a concrete structural system from steel provides significant changes to how the construction of a building is approached. For a steel building such as the Millennium Science Complex, proper site planning is important to coordinate the delivery of steel, and coordinate the location and use of mobile cranes for erection of the structure. In addition, the limited space on site provided challenges for the construction team to overcome. Congestion among the different trades on site was high, but Whiting-Turner did a great job at designing an effective and safe site for construction. Whiting-Turner's site plans can be found in Appendix D.

With the redesign of the wings to concrete, this adds to the congestion that could occur on site. Both steel erection and concrete pours are occurring on site, and sufficient room must be provided for each trade in order to effectively construct the building. In addition, safety is of the utmost importance when considering site planning. Proper planning must be done in order to minimize safety concerns on site, and provide a safe atmosphere for the workers on site. As will be seen later, both the steel and concrete will be occurring simultaneously with the goal to accelerate the overall construction of the building. Using Whiting-Turner's site plans as a reference, it was concluded that little modification would be necessary in order to adjust their logistics plans for the change to concrete in the wings. For the construction of the cantilever portion, the location of the 400-ton crane at the inner intersection of the two wings, as well as the 275-ton crane located between the areaway and Eisenhower Parking Garage, would be unnecessary to change. With the lessened area of steel, these two cranes would need to move less within their respective locations, reducing the potential congestion that could occur from the relocation of the cranes during erection. Lay down areas for steel would not change drastically for these areas, either. During the erection of the cantilever, the areaway slab was used as a lay down area. Prefabricated steel members were brought in, and trusses were bolted and welded on the ground on this slab. This allowed for easier welding, which occurred on the ground as opposed to on scaffolding 60-80 feet in the air. In addition, it allowed for easier erection of the cantilever, as it was erected in larger pieces rather than one piece at a time. The existing structure used concrete pump trucks in order to pour the concrete slabs within the building. During the construction of the wings, these concrete pumps were located on the north side of the Material Science wing, and the east side of the Life Science wing. These pump trucks moved up and down these designated locations as the concrete slabs were poured. With this in mind, the location of concrete pump trucks will be the same for the redesigned concrete wings. From these two locations, the pumps will be able to reach all locations of the concrete wings without issue.

One addition to the pouring of concrete that the steel structure did not have was dedicated cranes for the lifting and moving of rebar, formwork and equipment. Because it can't be assumed that other cranes on site could be used for these activities, two 55-ton mobile cranes were included in the estimate for the construction of the concrete wings. As such, the location and path of travel must be taken into account during site planning. The locations of these mobile cranes will be similar to the concrete pump trucks, following a similar path of travel, depending on where materials and equipment need to be moved. Another concern that can appear is the constant appearance of concrete trucks on site. A full concrete structure will require much more concrete than just slab on deck, and therefore, will require a greater quantity of concrete trucks brought to the site. With the constant student and vehicle traffic going through this area, careful planning must take place in order to not impede this traffic with the increased need for concrete trucks. However, even with this increase, the locations in which they are

brought onto the site will not change. Both the main access point on Bigler Road, as well as the secondary access point north of the main access point on Bigler will be utilized for the concrete trucks.

An adjusted site plan, which takes into account the changes to the structure, can be found in Appendix D.

Schedule Analysis

As mentioned in the Project Construction Overview section of this report, preconstruction began in March of 2008, with construction beginning on August 12, 2008. According to a schedule provided by Whiting-Turner, substantial completion is due to be May 12, 2011, with building turnover on July 7, 2011. This presents a schedule that is one week behind, as the expected dates for both of these milestones are the previous week in each case. Whiting-Turner maintains that the project will be delivered on June 30, 2011, as expected, even with the challenges that have had to face through the construction of the Millennium Science Complex. One of the key challenges faced by the construction team was the issue of weather. The structure of the building was scheduled to be constructed during the winter months. Snow is often a concern, and an aspect that project team is expected to plan for in the event weather does not permit work. However, during the winter of 2009-2010, the snowfalls were greater than expected, reaching higher amounts in State College than has been seen in recent years. This caused serious concerns for the schedule of the project, delaying steel erection and affecting the numerous quantity of welding that needed to occur. However, Whiting-Turner did an excellent job of controlling any schedule impacts that may have occurred due to these setbacks, and still maintains that the project will be delivered on time on June 30, 2011.

Whiting-Turner's schedule for the Millennium Science Complex was created with the key concept that the structural system was steel. All work was sequenced based on the sequencing of the steel. It is clear that the driving force of their schedule was the steel erection, and rightfully so as the structure is typically part of the critical path in a CPM schedule. In addition, the schedule was sequenced in a vertical fashion, where the steel was erected upwards, then horizontally. This is typical of a steel structure, and fully makes sense for this building. However, this is in high contrast to a concrete building. The driving force for a concrete building often starts with the foundation and slab on grade, which immediately extends into the concrete framing of the building. In addition, a concrete building is typically sequenced horizontally first, pouring a single level at a time, before moving vertically.

With all this in mind, a full analysis of the existing schedule needed to occur, starting from the beginning with excavation and foundation work. Because the existing schedule was heavily driven by the steel erection, it was clear that the schedule had to be entirely reworked into order to work for the addition of concrete. In order to properly analyze Whiting-Turner's schedule, the schedule tasks and starting dates were brought into Microsoft Project. It was assumed that the given durations in the schedule were the original, expected durations for each task. These durations were applied to the tasks to understand what the schedule could have looked like without giving additional time to tasks. Once the sequencing of the existing schedule was understood, the tasks related to the erection of the steel in the wings were removed, and the substructure was re-sequenced for a concrete building. Tasks for the construction of a concrete framing structure were created, and durations were determined based on information in Whiting-Turner's schedule, as well as data from RS Means Concrete and Masonry. Based on the restructuring of the existing schedule, these tasks were inserted and sequenced for the new structure.

The goal of creating the new schedule was not only to produce a schedule to match the changes to the structural system, but to determine a way to accelerate the schedule. This was to be done through proper sequencing of the redesigned concrete wings in combination with the construction of the steel cantilever. Based on conversations with a representative of Thornton Tomasetti, and structural analysis, it was determined that the prominent cantilever at the intersection of the Material and Life Science wings could stand on its own as long as the steel remained intact through the braced frames extending into the wings. Using this information, it was decided that the steel of the cantilever and braced frames would be erected simultaneously with construction of the concrete wings. Concrete pours began at the ends of the wings, and moved towards the cantilever to the designated column line. Starting dates were determined based on the restructuring of the existing schedule, which led from the adjustment of the substructure and foundation. In addition to the structure, the precast panels needed to be adjusted to account for the change in schedule. Erection of the precast panels begins when the mechanical level concrete is being constructed. This was done to ensure proper concrete strength at the time of erection, as well as avoid overly congesting the access roads where both the precast cranes and concrete trucks would need to be. Below is a summary of the construction of the redesigned structure, as well as the cantilever and precast panels. A full schedule of the existing structure, as well as the redesigned structure, from excavation through the precast erection, can be found in Appendix D.

Task	Duration (Days)	Start	Finish
Material Science Wing Concrete	98	7/29/09	12/11/09
Life Science Wing Concrete	63	8/11/09	11/12/09
Cantilever Steel/Shear Walls	114	8/10/09	1/14/10
Precast Panels	67	12/7/10	3/4/10

Table 61: *Schedule Summary of Redesign*

Concrete Pours

An important aspect of the construction of a concrete building, as well as the preparation of a schedule for a concrete structure, is the pouring of concrete. Based on labor data in RS Means Concrete and Masonry, as well as Walker's Building Estimator's Reference Book, it was determined that a logical pour size for the floor system would be three full bays across the building, which is approximately 7000 square feet. This required three formwork crews and one rebar crew to prepare a pour of this size, and keep the schedule within a reasonable time frame. It is also important to choose pour breaks wisely in order to reduce cracking in unwanted locations in the slab. Based on moment diagrams produced for the floor system, the location of pour breaks were placed where the moment is zero. This location occurred between the first and second joist, approximately four feet passed the column line. Figure 74 provides a visual of the approximate typical pour. Placing the pour break at this location allows cracking to occur at a location where it is less detrimental to the integrity of the concrete slab. This same setup is used for all pours through the wings of this building. Three bays are typical except at the intersection of the steel and concrete, where the

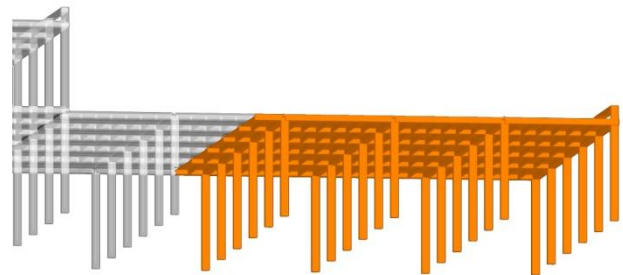


Figure 74: *Visual of Concrete Pour*

pours become either one or two bays in length. In all typical pours, the break is set at the same location following the last column line between the first and second joist.

Crane Analysis

This investigation involved the potential for using the minimum cranes for steel erection and using tower cranes for precast erection and concrete placement. An initial investigation into the use of tower cranes on this project revealed several impracticalities for this building. Tower cranes are not often used on buildings of only four stories in height. This is because it is more effective to use pump trucks when it is possible for them to reach the height required of the building. In addition, one of the goals was to be able to use these tower cranes for the erection of the precast. Based on capacity diagrams and the corresponding max reach of tower cranes investigated, it would have been impossible to obtain the capacity required to erect the precast panels, as well as reach all locations of the wings from a single centralized location. Based on practicality, the choice to use tower cranes on this type of project was illogical. Based on conversations with industry professional about the topic, a similar opinion was obtained that it would be impractical to use a tower crane on a project such as the Millennium Science Complex. A more in-depth investigation was not conducted due to the above reasons. Therefore, it was determined that using pump trucks with additional small mobile cranes was a more practical choice for the construction of the concrete.

4D Modeling

In order to fully understand the existing schedule for the Millennium Science Complex, Revit models were used to provide visualizations of the structure. While a full existing 4D model was not created, parts of the schedule were analyzed in Navisworks to understand the exact order in which items were constructed. This included the foundation, as well as the existing steel. Part of the analysis of the schedule, and the creation of a new schedule, included the development of a 4D model for the redesigned building. This was meant as a visual way to incorporate a key BIM tool into the schedule work. The 4D model provides a clear picture of the schedule, as well as helps highlight the sequencing that occurs between the concrete wings, steel cantilever and the precast panels.

COORDINATION AND MODELING OF SYSTEMS

Revit Modeling of Duct Systems

The modeling of third floor Material Science Wing ductwork will create the opportunity to test automatic duct sizing and static pressure calculations as well as evaluating the benefits of a redesigned structural system. Shown below in Figure 75 the laboratory and office supplies were modeled in Revit along with the office return. Laboratory exhaust and office branch ducts were not modeled and were not analyzed in this report. A picture of the existing Navisworks model from Whiting Turner, including all mechanical duct components, can be found in Appendix F.

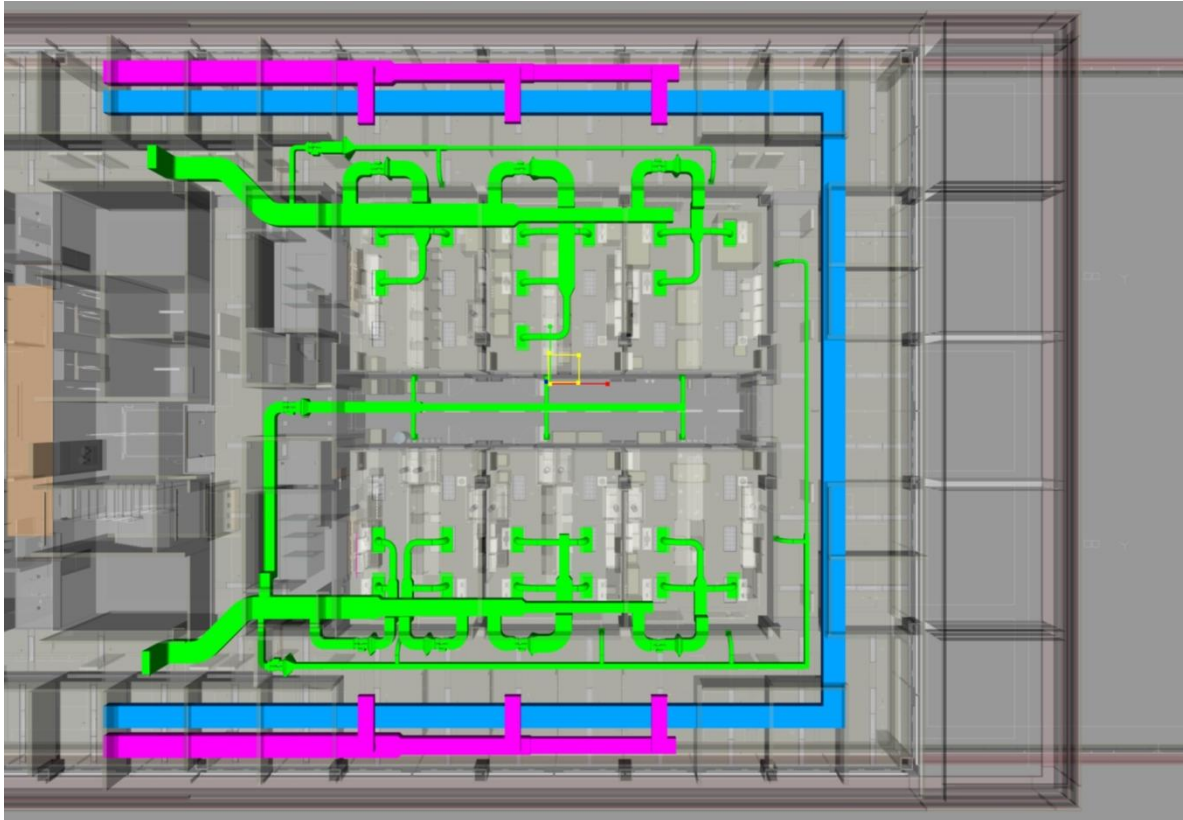


Figure 75: Navisworks Model of Third Floor Duct Systems.
Lab Supply–Green, Office Supply–Blue, Office Return–Pink.

Building Information in Duct Systems

The automatic resizing function in Revit potentially can be a useful tool to help design duct layouts. The tool is meant to adjust the size of the duct based on parameters such as velocity and/or static pressure loss per 100'. In this manner, valuable information becomes inherent in the duct, making it a smart object. Ducts will have an associated airflow, air speed, and pressure loss. Every time the duct is resized these values are calculated and transferred to the next duct or piece of equipment. In theory, a duct system will be able to verify its total airflow and pressure loss. These values could be tracked and exported, helping to properly select a fan. In Revit, these values could be read by a mechanical fan object and automatically update this information in the construction document fan schedule. By modeling the duct systems correctly, the duct model can become a design calculation tool.

Limitations of Building Information in Duct Systems

In theory the above section describes how information could become a part of the mechanical duct model, but in practice these results are difficult to attain. In order to build the duct model accurately, the MSC duct model lost the ability to communicate duct information reliably.

In order to transfer data from component to component there needs to be a good connection. During the modeling of flexible duct between supply diffuser and branch duct, the good connection was broken. The loss of this good connection, created a "bad connection", defined by Revit. This bad connection disabled the ability of Revit to calculate total system airflows and pressure losses. After a whole system has been created, the time investment to correct this mistake early in the design process negates any time saving benefits in using the building information.

In designing the laboratory supply, depicted in Figure 76, a unique system was used incorporating uncommon pieces of mechanical equipment. Most supply systems use a VAV box to monitor and condition air, but the high performing laboratory system uses a combination of phoenix control valves and heating coils. Revit has a specific way that it requires duct information to be analyzed and transferred through an object. The system was unable to transfer airflow information from component to component, effectively breaking the system. The system was capable of transferring data through one object, but unable to accurately transfer information between two components. A learning curve accounted for the extra time spent trying to understand how Revit uses connectors and family parameters to communicate information through an object, but this knowledge couldn't be translated to the transfer between two component families. The online knowledge base, which is often very helpful, was unable to offer any concrete suggestion other than "Guess and Test". Due to lack of knowledge and case studies, the transfer of data between the heating coils and supply valves was abandoned. This lack of transfer disabled the ability to calculate airflow and static pressure loss through the duct system.

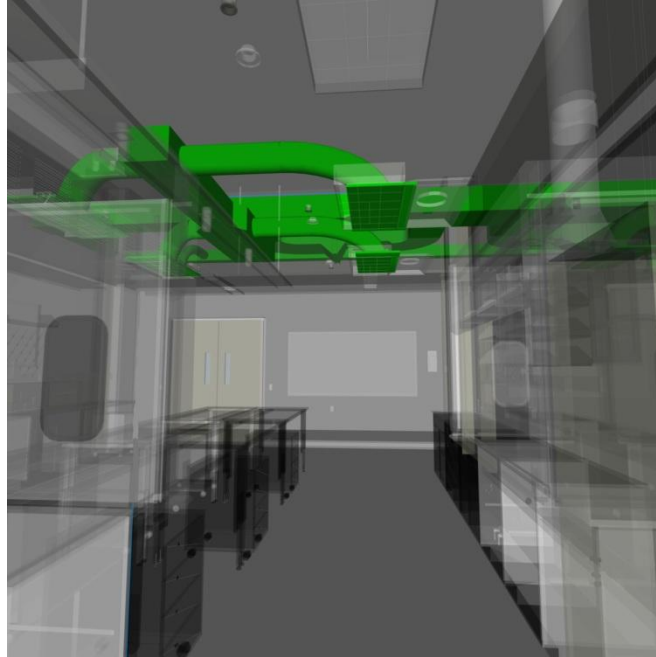


Figure 76: *Render of Laboratory Supply Ductwork in Third Floor Materials Science Lab*

Once the existing duct model was created, the automatic duct sizing tool was used to model varying duct sizes as described in the static pressure section above. Using this automatic tool caused numerous errors in the duct systems, invalidating the transfer of information. The transitions between ducts would not automatically resize. They would create mismatches, causing the connections to become broken or unable to resize. In other cases, automatically resizing the duct would cause the airflow direction to change, invalidating the system connections. Using the automatic duct sizing tool became a hassle trying to get Revit to do what was intended. The information inherent in ducts became a hindrance in simply trying to manipulate duct sizes.

The usefulness of building information in duct systems was lost in every case tested. The process to correctly and efficiently transfer information needs to be developed and well communicated to the user base. Without an understanding of how Revit requires things to be modeled, the user base will never be able to use the functions that are being developed. The added information actually slowed the modeling process and no information was able to be extracted from the model.

Revit Modeling of Structural Systems

An existing structural model was provided to BIMception by Whiting Turner Construction and was modeled by RVA. This model served as a good base model for coordination purposes, modeling alternative design options, creating schedules and material take-offs, and producing quality images of new design options.

Modeling of the proposed one-way concrete pan-joint system was carried out in this Revit model as a “Design Option.” Revit has a unique modeling framework for simultaneously modeling multiple design options. The main structural model includes the entirety of the cantilever area with all structural steel that will be retained as the existing design. All existing structural steel in the LS and MS wing, from grid line 13 to 21 and N to BB, respectively, was moved from the main model to its own design option called “Existing Steel.” Another design option was made and named “New Concrete Design.” Within this design option the fully designed pan-joint system was modeled. Thus, both the existing steel wings and the new concrete wings could be present in the same model without interacting and or overlapping. By assigning the concrete option as the “primary” design option in the model the concrete pan-joint system was then automatically inserted in place of the existing steel option when the main model is viewed. The existing steel wings can also easily be viewed by switching to its respective design option. An image of this change is shown below in Figure 77. Other images of the existing steel structure are present in Appendix-G.

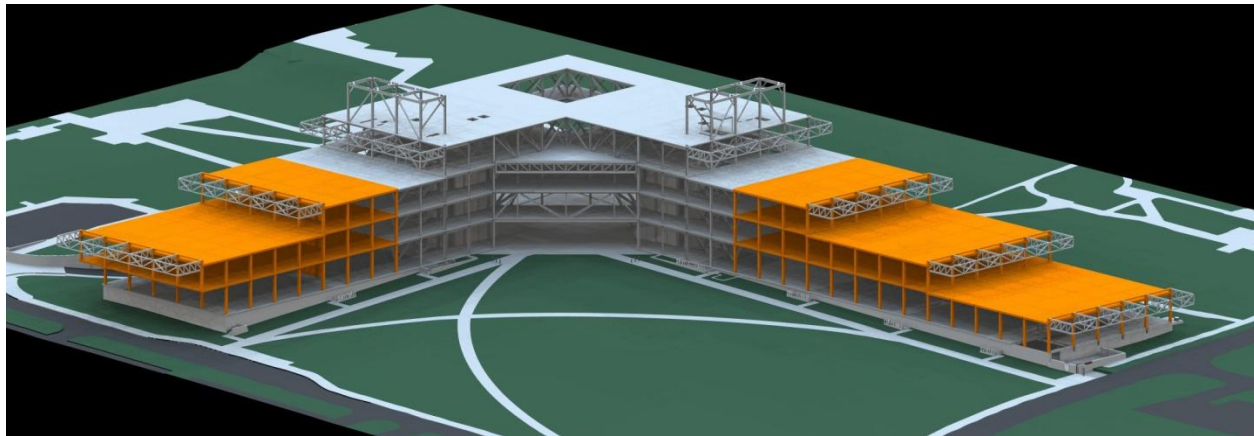


Figure 77: Render of Structural Concrete Wing Alternative

Building Information in Structural Systems

Including the existing and new design options in the same Revit model poses multiple benefits and uses when attempting material take-offs and for coordination modeling. Multiple schedules can be created within the one model and filtered to reveal specific information about the model. Revit schedules pull information from all design options. By keeping the concrete elements on a separate workset named “New Concrete Design” the schedules can be filtered to only show these elements. Quantities such as areas, volumes, and grand totals can be automatically calculated by the schedule. The entire schedule can then be exported to Excel and used by the construction manager to integrate with all relevant cost analyses and take-offs from other models.

Initial 3D coordination between the mechanical redesigns and structural redesigns were accomplished by inserting each model into one another as a Revit link. This is an easy way to spot collisions and design flaws early in the design process. Structural Coordination Models can easily be created from 3D views within the Revit model as well to be used in Navisworks to find final collision detections and for 4D modeling. Section boxes within a 3D view can be used to limit the amount of elements that are exported. For more information on Structural coordination view the Coordination section of the Plenum Investigation.

Limitations of Building Information in Structural Systems

Proposed Structural BIM processes within BIMception’s BIM Execution Plan included Structural Design Authoring. In this BIM process the new concrete gravity system was to be modeled entirely in ETABS for design iterations and analysis. When the system was approved and met all performance requirements it was to be exported through the ETABS-Revit link and imported into Revit to be used as a design option within the entire structural model. This link is intended to be two-way to allow the designer to make changes in either program. By importing/exporting through the link the same model in the other program will be updated automatically. This is an ideal description of how the process should work, however many issues with this process have been encountered.

The link was originally developed for the 2010 version of Revit and had been used by BIMception’s Structural Engineer in BIM Studio in 2010 to link an ETABS analytical Model to the Revit coordination model. An initial concept model was created in Revit around the proposed architecture and then exported to ETABS. Issues were seen when running the model with gravity and lateral loads. The program showed warnings with respect to lack of stiffnesses and losses of accuracy within the analytical results. Due to the fact that Computer Structures INC (CSI), the producer of ETABS and SAP, and Autodesk, the producer of Revit, are not affiliated CSI is responsible for the production of the link. Although they work with Autodesk to understand how to produce the link the process is relatively new and there are inherent issues with the link. Also with the upgrade to Revit 2011 a new link needs to be created to keep up with the new Revit updates. Unfortunately this takes time and was not available with the release of the new version of Revit. It was expected that it would eventually be available in time to use within the time constraints of this thesis, however, upon the conclusion of this thesis project the link is still not available and the process cannot be completed.

Extent of Modeling for Etabs-Revit Link

Analytical models created in ETABS are generally created with a different goal than a Revit coordination model. To successfully use the link feature project team members must decide not only the extent of what need be modeled for coordination purposes in the Revit model, but also what is necessary for an analytical model, in this case using ETABS. If the link is used both models will include the same components. Therefore if the entirety of the building structure is needed to integrate with the other building systems, the entire structure must be included within the ETABS model. This can pose some issues for the analytical model, those of which have been realized through this plenum investigation.

For a floor system analysis using gravity loading, unless the floor system changes drastically throughout the structure it benefits the designer to model a small section of the structure with typical member sizes to obtain general knowledge about the structural performance. The entire floor structure need not be modeled. For a lateral system analysis, ASCE7-05 allows the modeling of only lateral resisting elements within an analytical model connected with rigid diaphragms to simplify the modeling process. Using the ETABS-Revit link would essentially force the combination of the gravity and lateral analytical models. This is possible and ETABS is set up to be able to keep gravity and lateral loads as separate load cases and can be run separately. This issue arises with the size of the model.

The larger the model the longer the analysis run time and the more likely that analytical errors will occur. Even though this process would force the creating of a more complicated model it would prevent the task of modeling elements twice, once in each model, and could prevent differences between the models. However, as in the case of modeling MSC, the potential complication of a model due to the amount of structural elements within the overall structure outweighed this benefit. The fact that the link was never available ended up being the capstone and the end to this BIM process regardless of the modeling process.

Coordination of Mechanical Supply Duct and Structure 1

In the Figure 78 below, the existing structure is shown coordinated with the existing mechanical laboratory supply. The supply mains run just below the deepest girders restricting their height, so that branch ductwork can run perpendicular underneath. The large supply phoenix valves and reheat coil can be seen. The enlarged reheat coil is mounted in the center of the duct and takes advantage of wasted plenum volume above the supply main.

The Figure 79 depicts the redesigned structure integrated with the existing mechanical system. The increase in useful plenum volume is clearly noticeable in the increased distance between the top of the supply duct and lowest structural member. The waffle ribs in the structure allow for the reheat coil to extend into the smaller volume of wasted plenum space.

A redesigned duct system is shown in Figure 80 taking advantage of the increased plenum volume of the redesigned concrete pan-joint structure. There is still wasted space above the duct system that could be analyzed in future studies with the potential to shrink the floor to floor height, reroute mechanical systems, raise the ceiling, or perform better coordination.

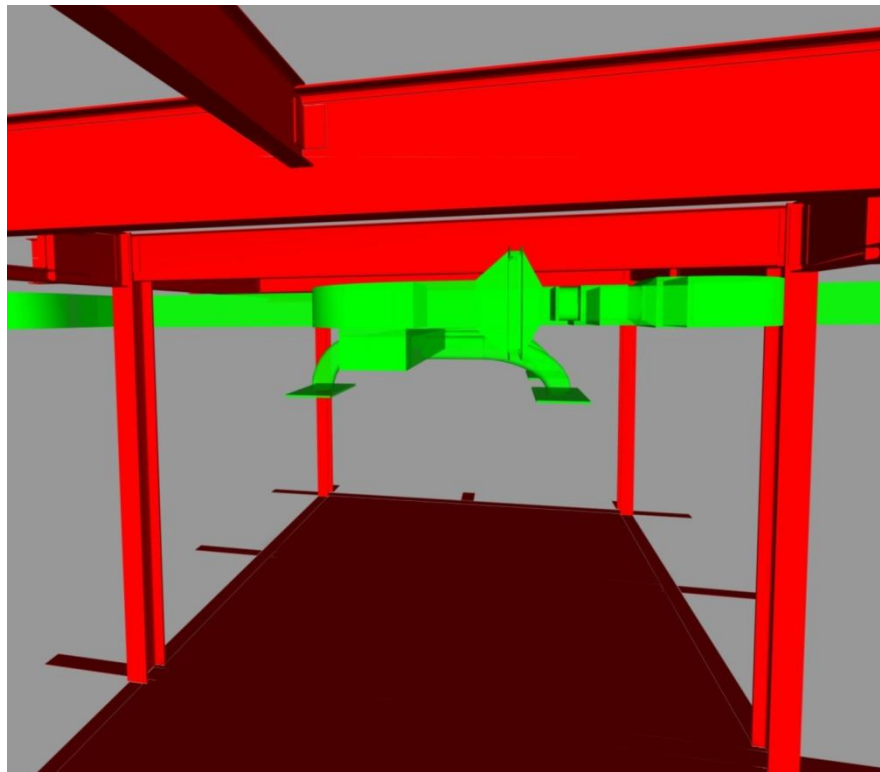


Figure 78: Existing Coordination of Laboratory Supply and Structure

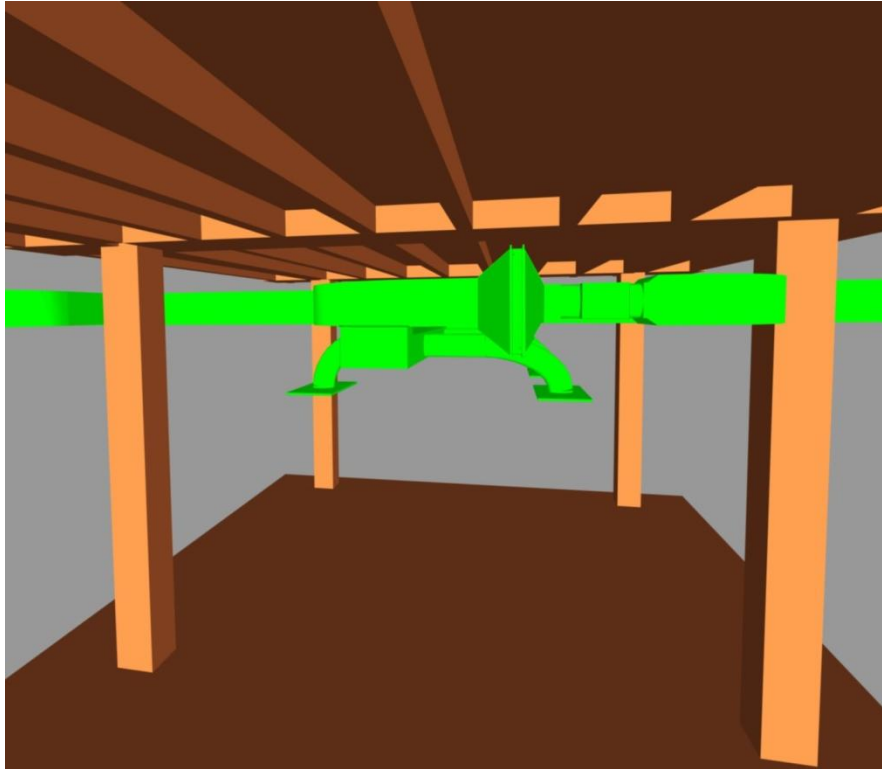


Figure 79: *Coordination of Laboratory Supply and Alternate Structure*

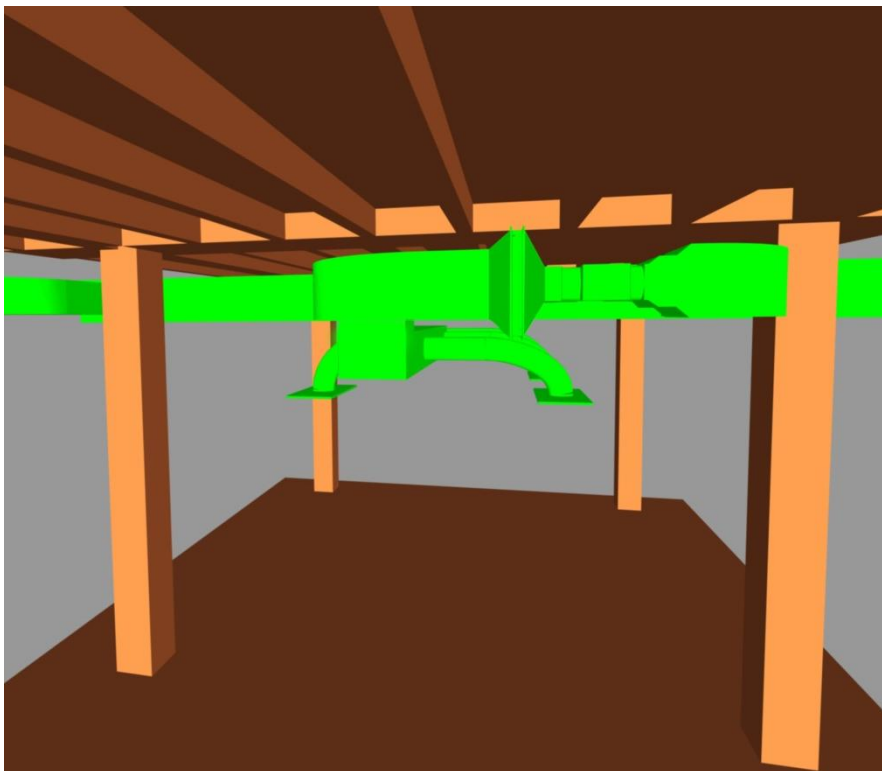


Figure 80: *Coordination of Alternate Laboratory Supply and Alternate Structure*

Coordination of Mechanical Supply Duct and Structure 2

In the Figure 81 below, the existing structure is shown coordinated with the existing mechanical laboratory supply. The supply duct runs tightly under the existing structure not allowing for flexibility in sizing.

Figure 82 shows the plenum space advantages of the redesigned structure. Removing the deep girders, allows for greater duct/structure clearances and an increasing in useful plenum volume.

An increase in duct height utilizes the extra plenum space created by the structural redesign, saving operational energy, shown in Figure 83.

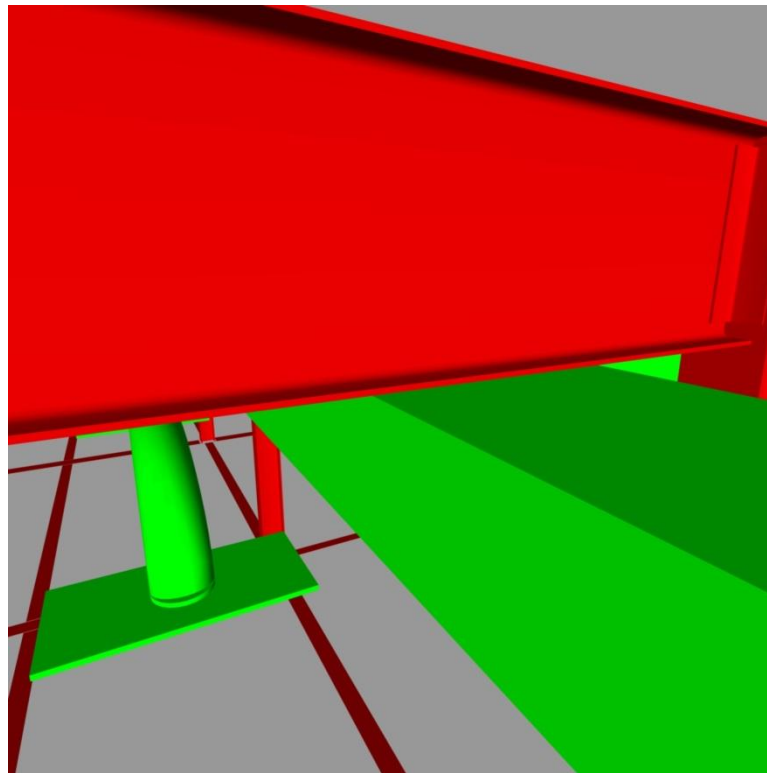


Figure 81: Existing Coordination of Laboratory Supply and Structure

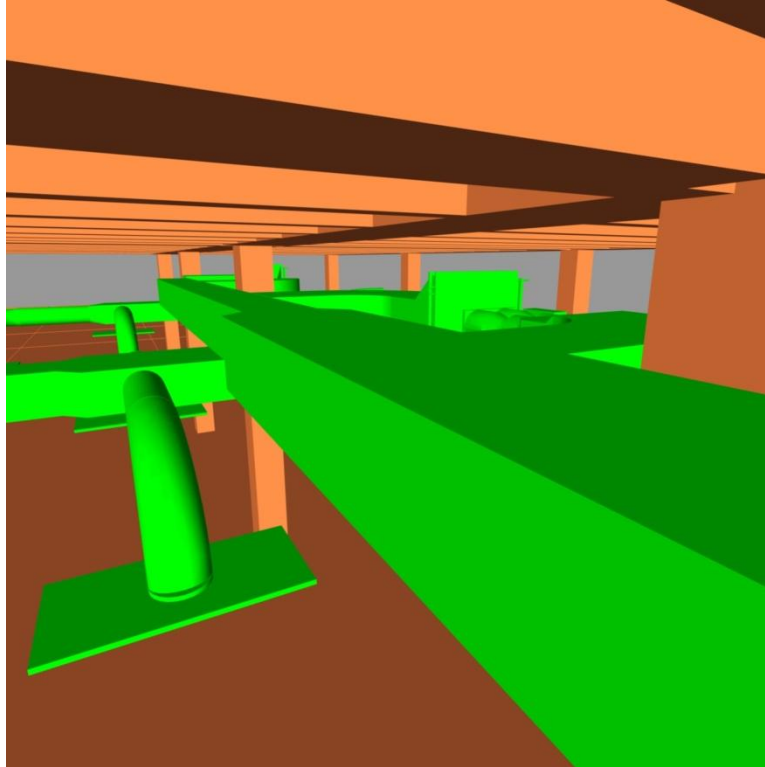


Figure 82: *Coordination of Laboratory Supply and Alternate Structure*

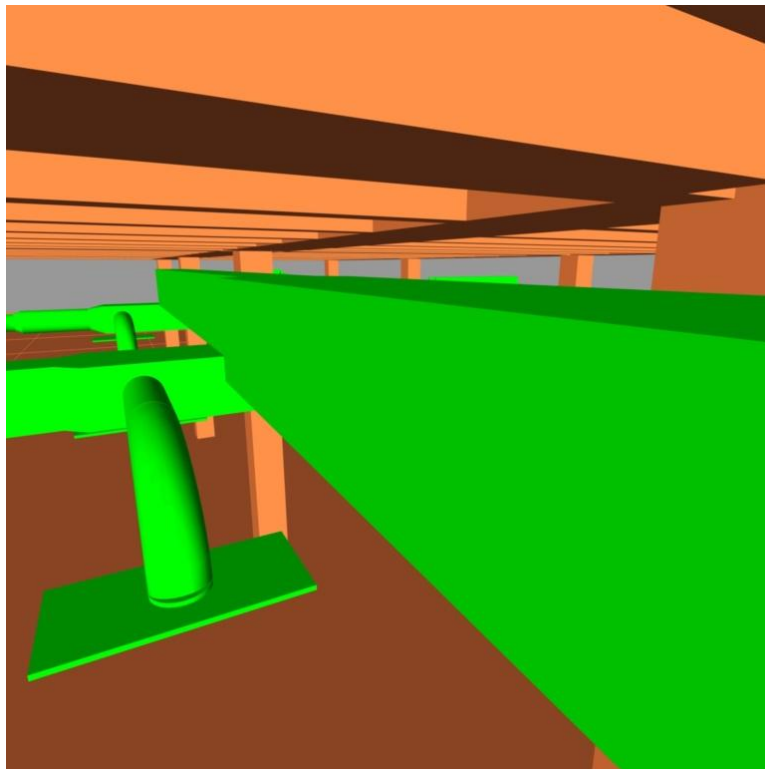


Figure 83: *Coordination of Alternate Laboratory Supply and Alternate Structure*

Coordination of Mechanical Supply Duct and Structure 3

In the Figure 84 below the existing mechanical and structural systems are coordinated. In order to fit in the plenum the office supply shown in blue must divert around the office return shown in pink. The office supply effectively uses the extra plenum space left by the depth of structural girders. This diversion, however, creates a significant source of static pressure loss.

A redesigned structure and redesigned mechanical solution, Figure 85, show an alternative to addressing this coordination issue. While the ribs do not allow for the supply duct to divert over the return, they do provide a horizontal chase in which the return branch can run. As seen in previous examples, the redesigned structure creates more usable plenum space, including room for horizontal chases. Due to system effects, it is difficult to predict which mechanical alternative creates the best opportunity for energy savings and therefore is not evaluated.

In Figure 86, the mechanical alternative is shown with the existing structure highlighting the collision of the branch duct and structural member. The coordination of mechanical and structural systems is imperative to creating a feasible alternative.

The 3D building section in Figure 87 better shows the close integration of the mechanical and structural systems as the branch duct runs down a chase created by the redesigned structure.

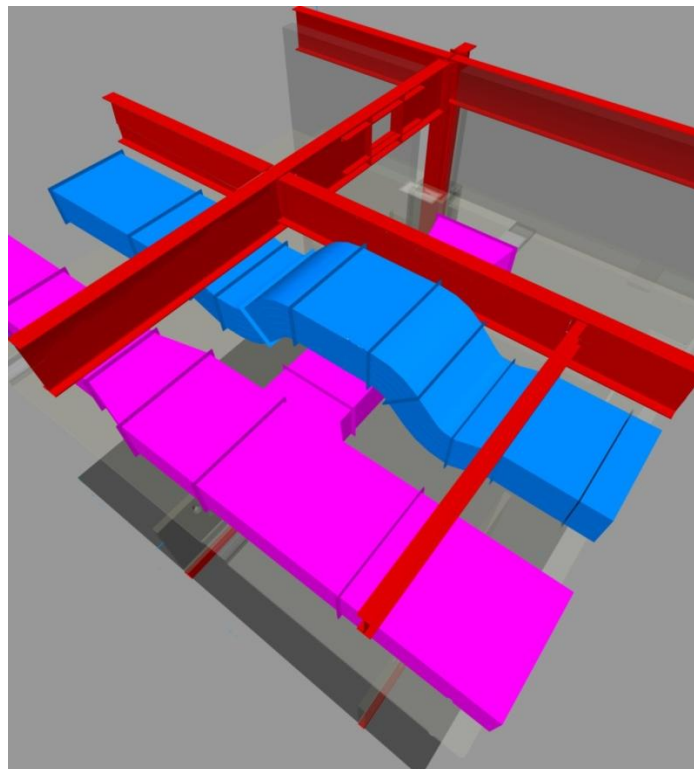


Figure 84: *Existing Coordination of Office Ductwork and Structure*

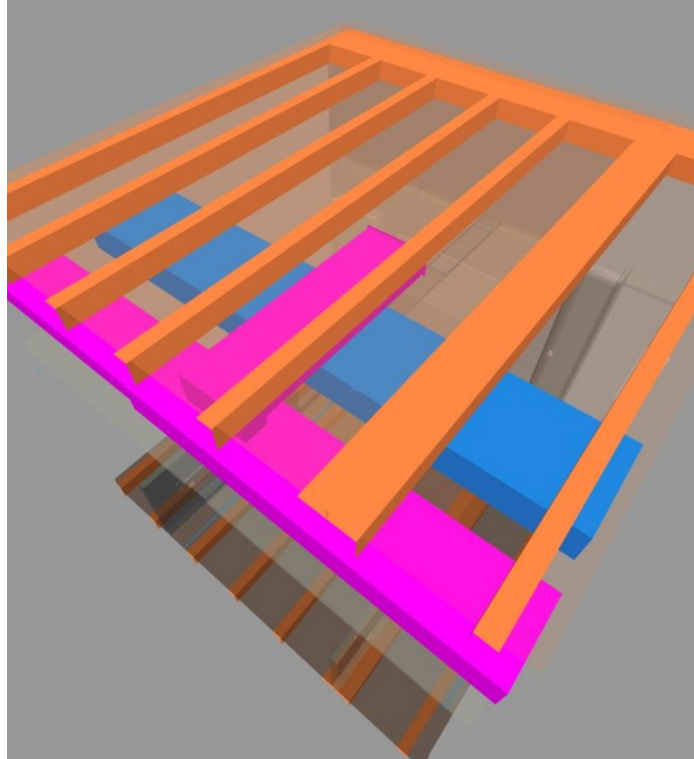


Figure 85: *Coordination of Alternate Office Ductwork and Alternate Structure*

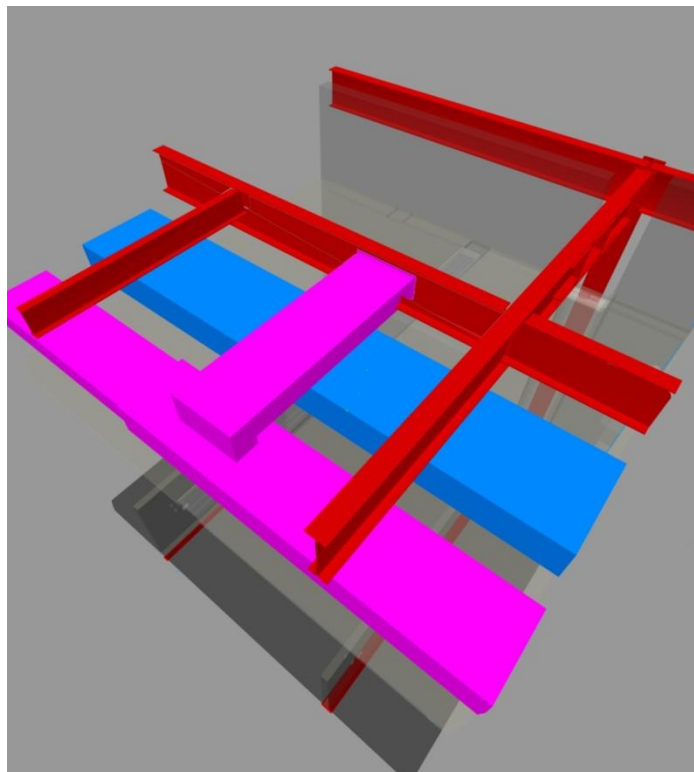


Figure 86: *Collision of Alternate Office Ductwork and Existing Structure*

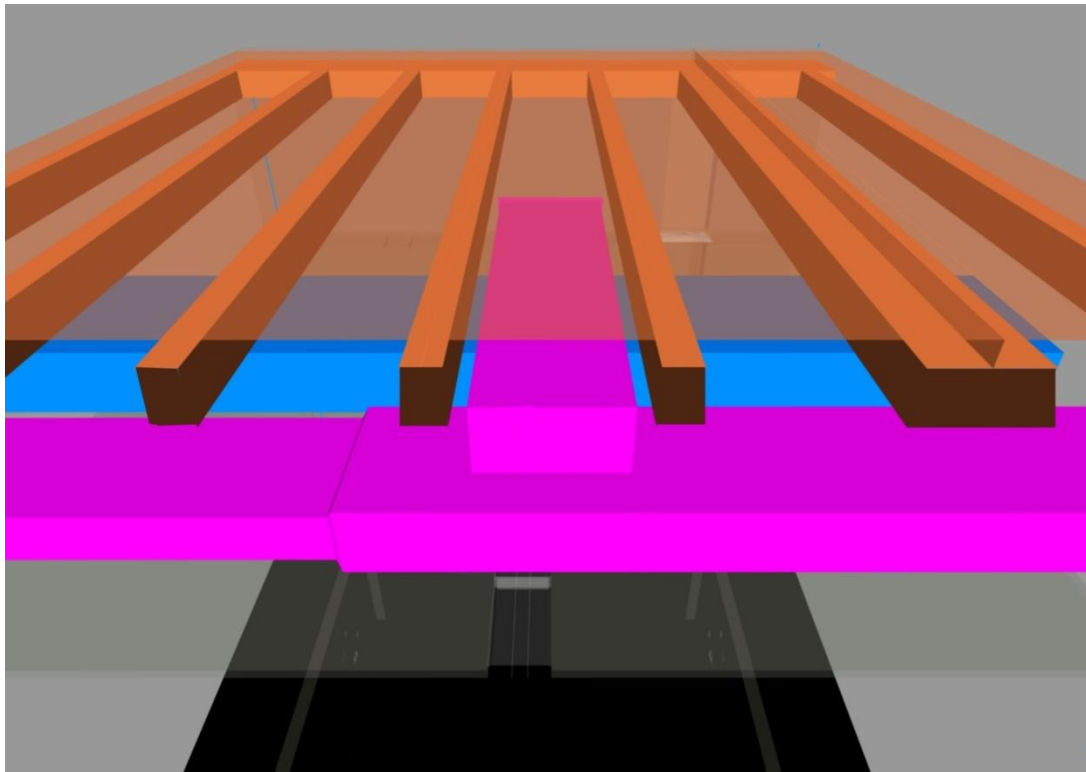


Figure 87: *3D Section of Coordinated Alternate Office Ductwork and Alternate Structure*

Coordination of Mechanical Drainage Pipe and Structure

In Figure 88 the drainage system from the green roof above penetrates the existing structure. Running above all other components in the plenum, the drainage system runs directly through the structure. While this is not a field collision, the design creates unique field work-arounds to accommodate the sloping pipe. This collision has created more design work for the structural engineer and more labor within the fabrication process to cut these holes and weld the web stiffeners in place before delivery to the site.

To allow the drainage pipes to run the length of the building, structural beams are cut and their members supported with flanges, Figure 89.

A redesigned structure in Figure 90 allows the drainage pipe to fit directly underneath the structure, preventing collisions with beams and other components in the plenum. No collisions were detected between the existing drainage pipes and the redesigned floor structure.

The render, Figure 91, highlights the numerous penetrations of drainage pipe through the structure, while Figure 92 shows the drainage pipe fitting snugly under the redesigned structure.

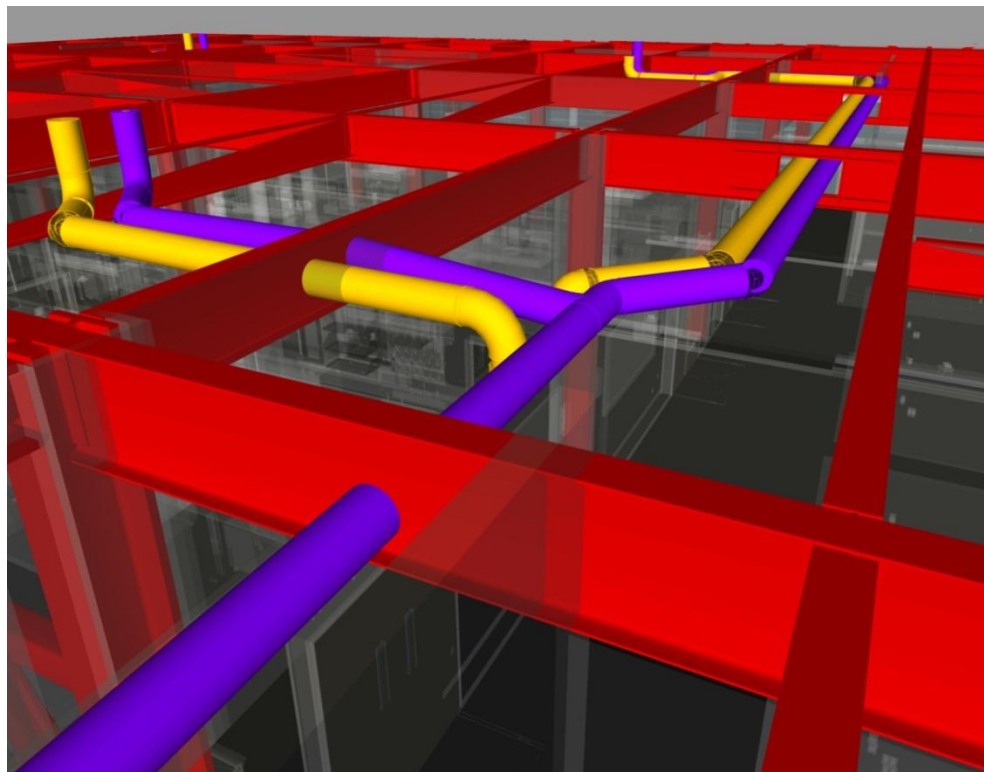


Figure 88: *Existing Coordination of Drainage Piping and Structure*

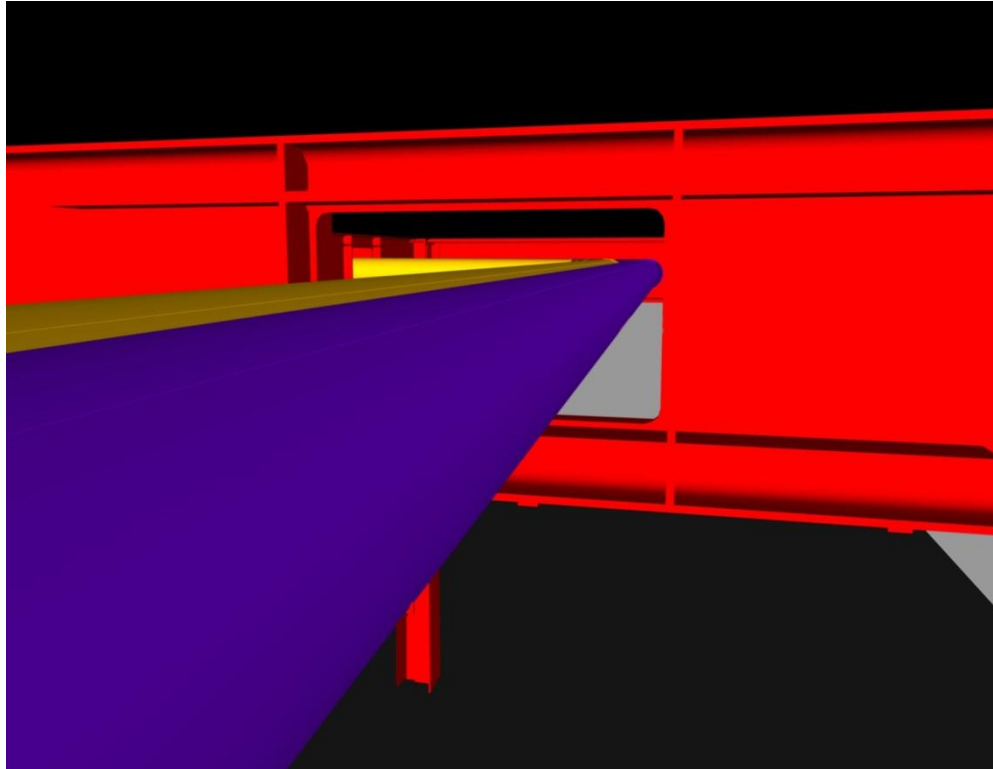


Figure 89: *Existing Coordination of Drainage Piping and Structure*

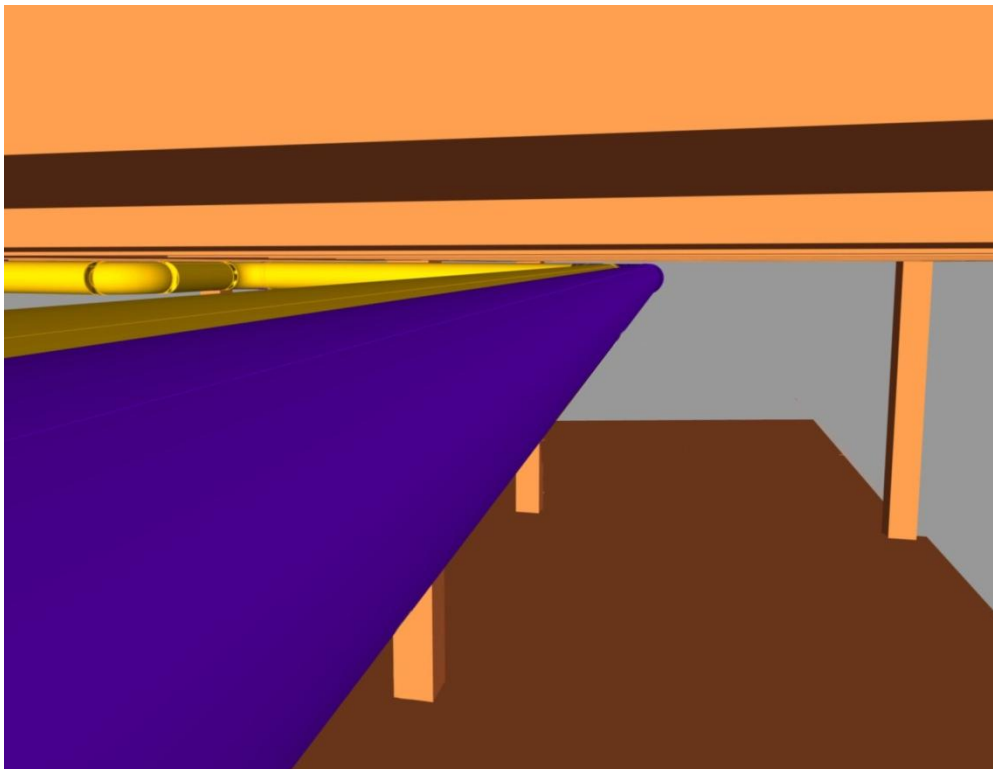


Figure 90: *Coordination of Drainage Piping and Alternate Structure*

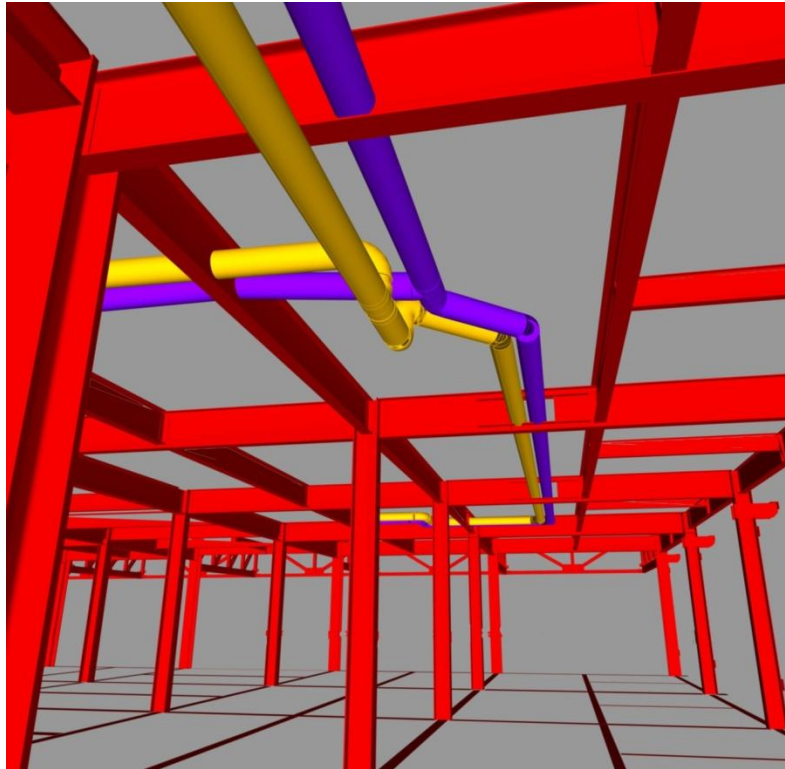


Figure 91: *Existing Coordination of Drainage Piping and Structure*

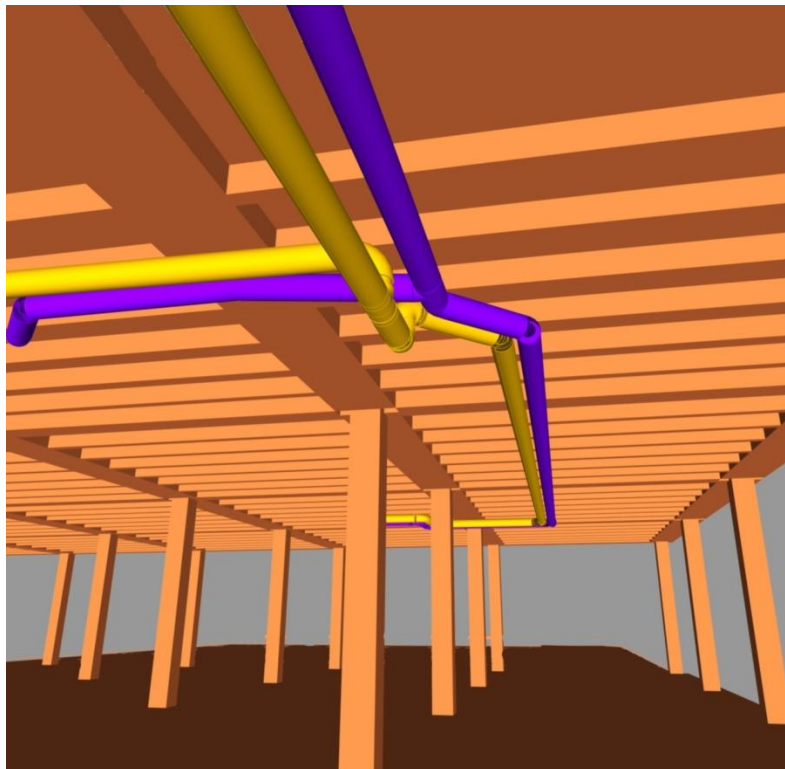


Figure 92: *Coordination of Drainage Piping and Alternate Structure*

PLENUM CONCLUSION

The alternative concrete structure adequately meets all strength and vibration criteria while reducing structural depth. This reduction in depth allows for an additional 14" of useful plenum space. A 6" increase in laboratory supply duct size produces nearly three thousand dollars of savings, immediately offsetting first costs. The alternative concrete system improves mechanical coordination by reducing collisions and adding flexibility. Scheduling and site logistics have also been improved.

	<i>Existing Design</i>	<i>Alternative Façade Design</i>	<i>Savings</i>
<i>Total Yearly Operating Costs</i>	\$140,379	\$137,453	\$2,926
<i>Installation Costs</i>	\$29,966	\$33,131	\$-3,165
<i>30 yr Life Cycle Cost</i>	\$3,647,648	\$3,575,409	\$72,239

Table 62: Duct Redesign Life Cycle Cost Analysis

Cantilever Plaza Redesign

DESIGN APPROACH

The Millennium Science Complex cantilever plaza creates a large architectural statement integrated with strong engineering. The plaza contains the main entrance to the MSC and brings together the Material and Life Science wings as one cohesive building. Beneath the plaza lie vibration sensitive nanotechnology laboratories. The vibration requirements play a large role in the structural system of the 150' laterally cantilever. Due to the stringent vibration requirements the plaza contains a serpentine to discourage foot traffic above the labs. *Bimception's* focus on the cantilever plaza is to enforce the key architectural features of this plaza while retaining the overall themes of a floating horizontality.

The cantilever structural design requires an innovative design solution. The existing system incorporates two orthogonal truss systems, each consisting of an interior and exterior truss, reaching out and upward from each wing toward the shared corner. Each of the trusses intersects each of the trusses extending from the opposite wing. Member sizes and orientations within the trusses are based on stiffness to control deflection in the cantilever. The current structural design deflects four inches under self-weight with an additional allowance of two inches for live loads.

The cantilever plaza landscape attempts to reduce pedestrian traffic above the nanotechnology labs with the winding serpentine pathway. This presents conflicting illumination goals. While the pathway creates a unique space it's essential to divert people towards the entrances and not the landscaped plaza. In order to achieve this, illuminance ratios were utilized bringing focus towards the entrance canopies, yet the pathway still needs adequate illumination to create a visually appealing space for those who venture from the main sidewalks. Fixture placement along the sidewalk edges helps create a line of light directed away from the pathway and towards the entrance. To highlight the architecture of the cantilever the absence, or void was illuminated along with the side walls in the entrance canopy.

STRUCUTRAL TRUSS ALTERNATIVE

The investigation of the cantilever will attempt to move toward a more strength controlled truss design that will allow the use of more efficient tension members. This will be accomplished by the addition of shear wall panels extending into the cantilever from the existing shear walls. This can reduce the effective length of the cantilever reducing flexural deformations and increase usable shear area within the concrete walls to reduce shear deformations due to racking in the truss. The hope is that this effort can relax the stiffness demand on the diagonal braces so that the orientation of the braces can be changed to be acting in tension and then can be downsized to a level controlled by strength.

Increases in stiffness due to the addition of concrete shear wall panels will directly affect the relative stiffnesses of each lateral resisting element within the building, specifically the concrete shear walls within the wings. Another design alternative will investigate the potential of simultaneously adding depth to the truss at the steel-concrete wall interface and reducing the effective length of the cantilever with added braces and concrete shear into the cantilevered section.

Existing Truss Designs

Truss Layout

Massive is the best word to describe the truss system that supports the 155ft building cantilever at the intersection of the two wings of MSC. An interior and exterior truss, 66ft apart, extend out from each wing. The two interior trusses intersect 66ft into the cantilever and then each intersects the exterior truss from the opposite wing an additional 66 ft from the first intersection. The exterior trusses intersect the interior truss from the opposite wing 66ft into the cantilever and then intersect each other another 66ft out from there, toward the tip of the cantilever. Each of these trusses supports one another and the multiple gravity frames between them within the cantilever. Also the space in between the truss intersections helps to define the square window opening above the cantilever plaza.

Design Theory- Balance of Stiffnesses

Both the interior and exterior trusses are designed similarly although slightly different in overall shape due to the sloped profile angles of the cantilever. These four trusses needed to be designed together due to the fact that they essentially support each other. Engineers at Thornton Tomasetti took special care in balancing the stiffnesses of the two different trusses so that the exterior trusses hung from the interior trusses or vice versa. The overall stiffnesses of each frame are roughly the same resulting in heavier members in the smaller exterior trusses and lighter members within the larger interior truss. Figure 93 and Figure 94 on the following pages show the existing truss designs and the member sizes.

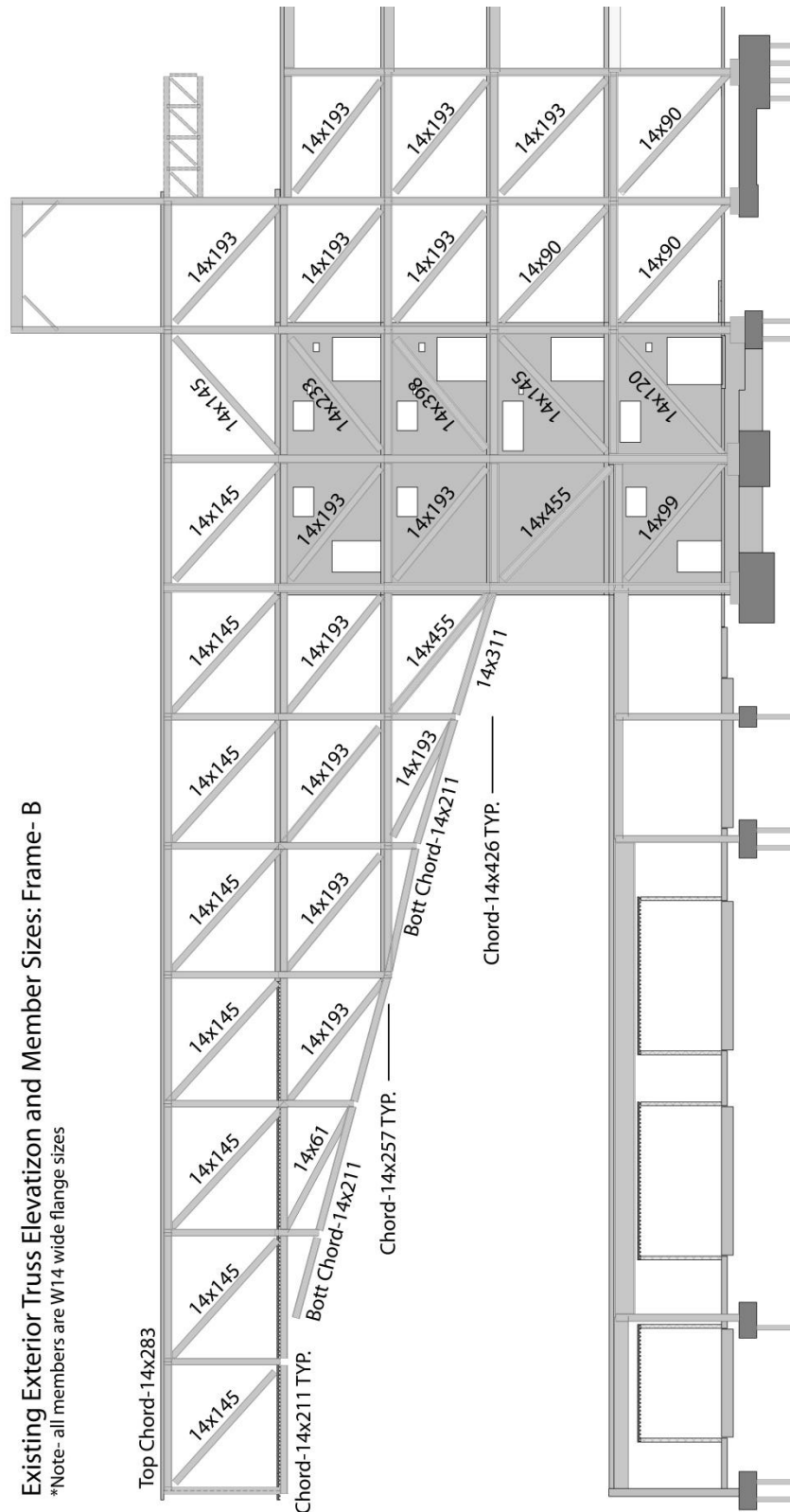


Figure 93: Existing Exterior Truss on Frame- B



Thomas Villacampa

Total stiffnesses of the combined truss system were primarily governed by the serviceability requirements defined by the code and adjusted by the structural engineer. The code limit for the deflection at the tip of a cantilever is $L/180$. Over the 155ft cantilever length this would equate to slightly over 10in. This was considered unacceptable for the construction of MSC for façade panel installation, occupant comfort and exterior aesthetics of the building. Therefore the service load deflection was limited to a total of 6in. The designed structure was determined to deflect 4in under self-weight alone and the live load deflection was limited to 2in. To account for the self-weight deflection all steel members within the truss system were cambered so that when installed a deflection of approximately zero inches. Truss stiffnesses were then designed to only allow an extra 2in of deflection due to live load. Although the total deflection during construction was 6in the overall deflection below the horizontal is only the 2in live load deflection, which is negligible to human perception.

To accomplish the extreme stiffness requirements to limit the deflections a customized load path was created through the truss to transfer gravity loads back to the shear wall and down to the foundations. All braces within the cantilevered portion of the trusses are oriented in compression. This orientation, along with the increasing width of the truss toward the shear walls, creates a system of compression chords passing gravity loads to specific locations and focusing them downward toward the foundation. This creates the shortest and most efficient load path. Also considering the high stiffness requirements buckling was not an issue with the brace design. Also for constructability reasons and for added stiffness all intersections of braces, columns, and braces were moment connected with full penetration welds. Figure 95 shows the highlighted compression load paths, in blue, from the tip of the cantilever back to the shear wall, highlighted in red.

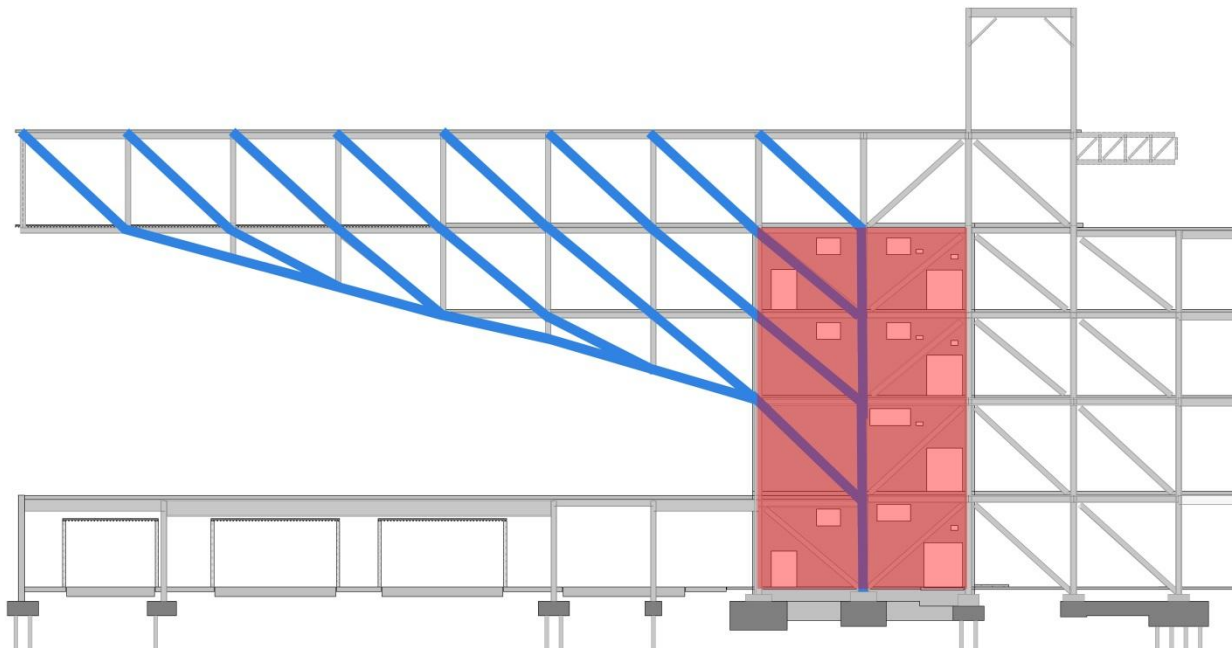


Figure 95: *Exterior Truss with Efficient Compression Load Paths Highlighted in Blue*

Truss Alternatives

Challenges arise with the proposed truss design in relation to the stiffness requirements. Switching to tension members can be a good idea, especially if concrete is introduced to reduce the effective length of the shear; however, the efficient load paths created by the compression members are interrupted. The first step in the redesign process was to properly model the truss system and all relevant loads in SAP2000.

Cantilever Modeling in SAP2000

Pulling again from knowledge gained in AE 597A, the existing and all redesigned truss alternatives were modeled in SAP2000 to adequately compare deflections and stiffnesses of the whole cantilever system. Two sets of models were created. The first were a set up models strictly used to compare the stiffnesses of the interior and exterior trusses as well as the stiffnesses of any redesigns with the model of the existing design. Figure 96 shows the stiffness comparison model of the existing truss configurations with the correct member sizes, shear wall sizes, material definitions, and adequate meshing of the wall and frame elements surrounding the walls. A point load of 1000 kips was added to the end of each truss. Using a linear static analysis in the model, the resulting deflections are proportional to load applied through the overall stiffness of the truss. Therefore comparing these deflections is an adequate representation of the comparison of stiffness values. The deflections of the exterior truss, frame-B, and the interior truss, frame-E, in this existing stiffness model were 5.7335in and 5.8725in, respectively.

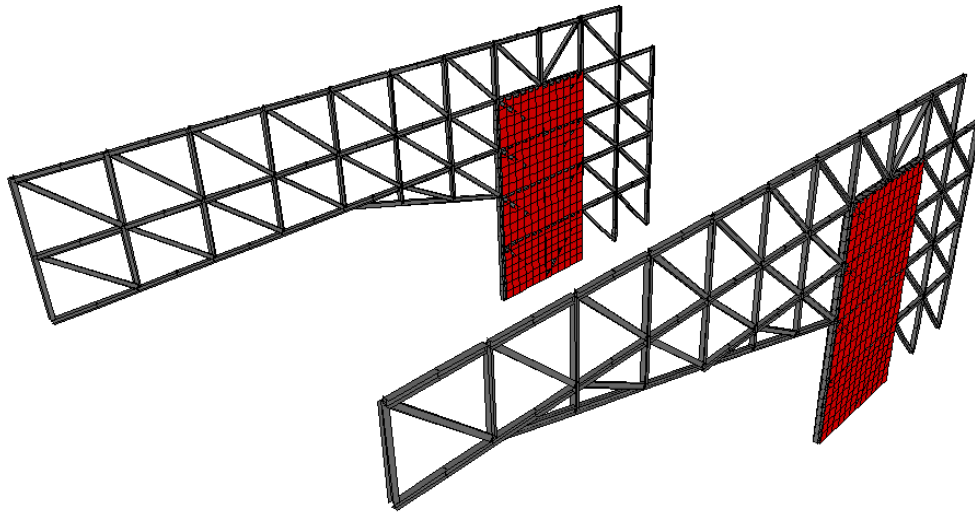


Figure 96: *SAP2000 Model of Existing Truss Configurations*

In attempt to recreate the ideal conditions of the existing cantilever system a larger SAP2000 model was created incorporating all four trusses, as well as all gravity frames transferring gravity loads onto the trusses. Frame elements were used for all steel columns, beams, and braces. Shell elements were modeled at the floor levels. A process of area dividing and frame meshing was used, as explained in the vibration analysis section of the floor system redesign previously, to mimic the existing composite steel beam floor system. Design loads including dead, live, superimposed dead, and façade panel loads were modeled in the proper locations. The extent of the model was exclusive to the area surrounding the cantilever plaza area, including all floor levels, roof, and all lateral resisting elements from girds one to 12 and from A to M for both wing directions. Figure 97 shows an image of the secondary model of the

existing system. The service load deflection for Model-2 with the existing condition was a total of 5.233in, 0.9201in being strictly live load deflection. This is well within the defined limits and confirms the accuracy of the modeling process. Although this output may be close to the ideal conditions of the real structure to focus of this study will be the comparison of this design criteria with the same criteria calculated for all new design iterations.

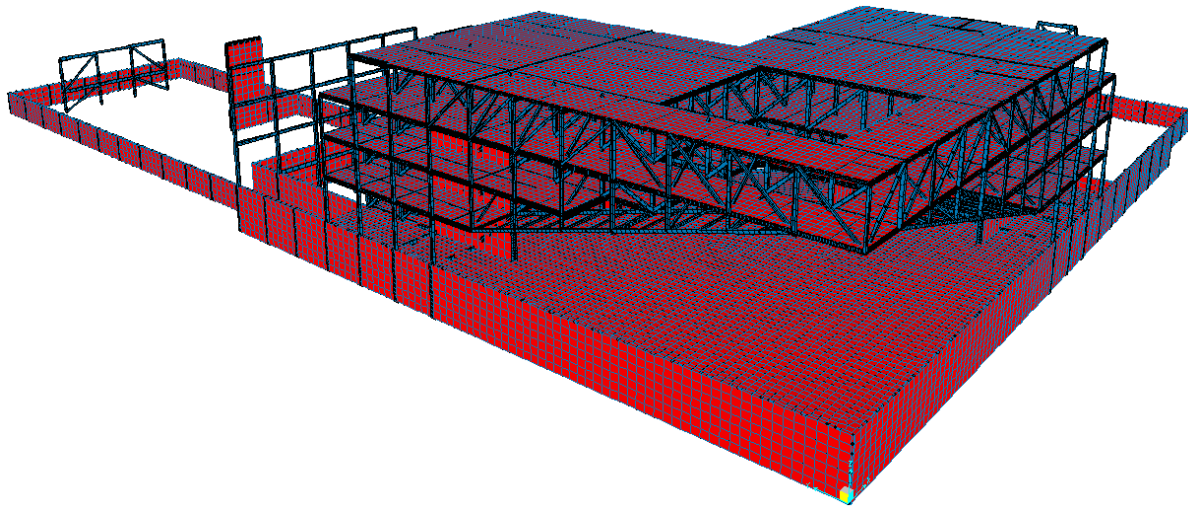
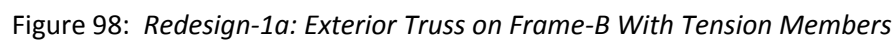


Figure 97: SAP Model of Entire Cantilever Support System With Supported Gravity Systems

Cantilever Redesign 1- Tension Members

In preparing the first alternative truss designs two goals must be accomplished including the overall stiffness of the trusses as well as the strength of the members. As a first step the orientation of all compression members from the existing design were switched to a tension orientation. Initial size changes were made in attempts to keep the truss stiffnesses intact, yet assign members appropriately for a tension dominated truss. Stiffness Model-1 was then run to gauge the impact of this change. The resulting deflections were larger than the existing design. Therefore as initial design critical members were sized larger than necessary to eventually result in slightly lower deflection on both frames as compared to the existing stiffness model. This new layout was then modeled in the large Model-2 to see if these equivalent stiffnesses carried over into a model with the real loads.

Design Loads based a load combination of 1.2D+1.6L as per ASCE7-05 were calculated in the SAP model to obtain design axial loads and moments in each brace and chord member within the truss. SAP frame element member loads were used to calculate minimum sizes of braces and chord members based on the combined axial load and moment using the combined loading tables and equations from chapter 6 in AISC Steel Construction. These minimum sizes were incorporated in the Model-2 SAP model. When the analysis had been run the service deflection was noted to be 9.336in. This is testament to the efficiency of the compression load path shown earlier. Not only was the overall truss stiffness much less, but the member sizes had already been increased through stiffness analysis using Model-1. The critical member sizes were then increased to eventually match the overall stiffness in Model-2 with the design loads. The results show a potential design alternative with tension members, yet no extra efficiency is granted from this design, in fact this design is much less efficient than the existing system. Figures 98-99 show the final design solutions of the exterior and interior frames for design iteration-1.



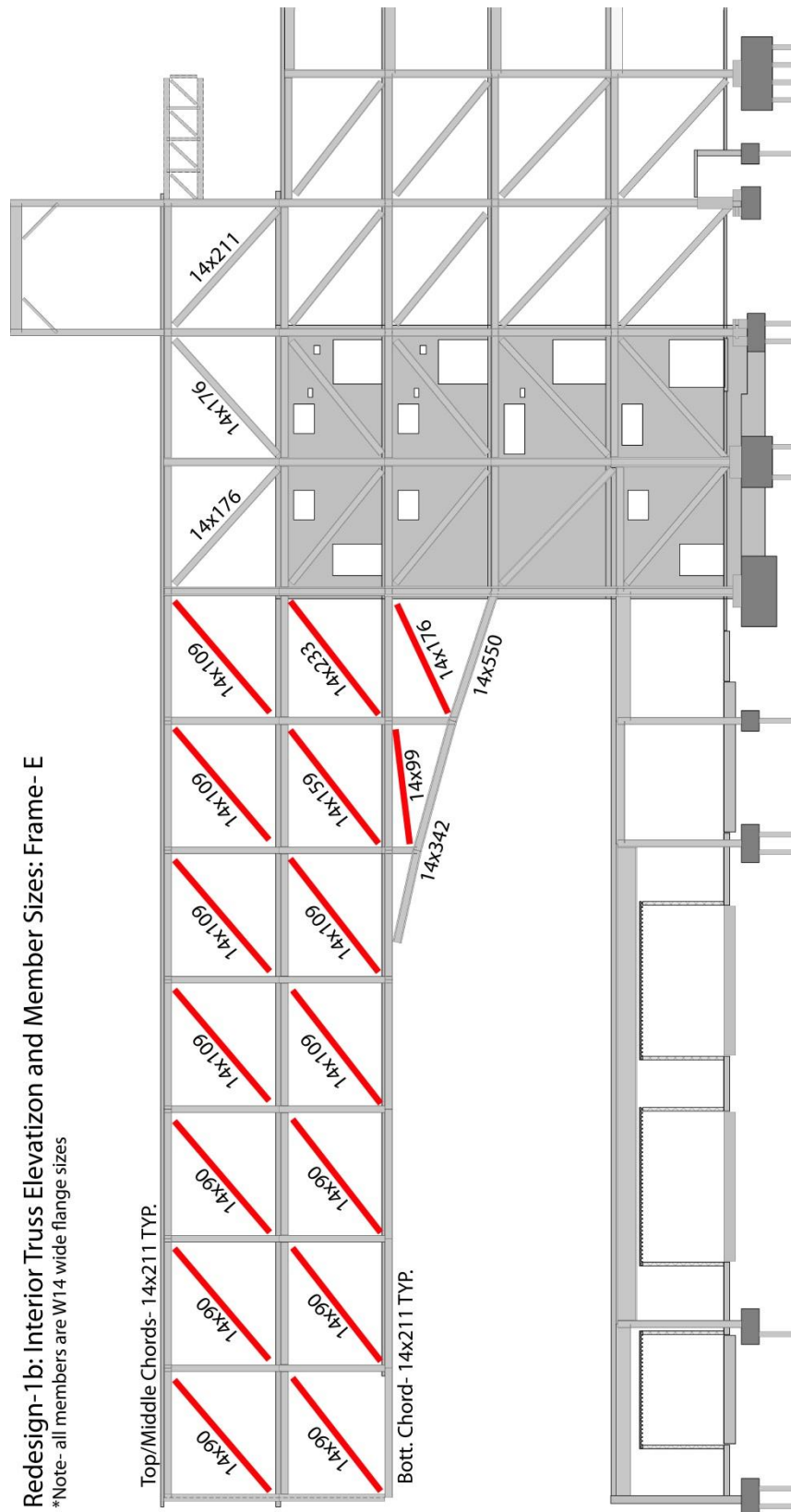


Figure 99: Redesign-1b: Interior Truss on Frame-E With Tension Members

To improve the truss redesigns incorporating tension members concrete shear walls were introduced into the cantilever to attempt to reduce the effective length of the cantilever and improve the shear stiffnesses. The one large issue with the tension member redesign-1 was the concentration of most of the chord compression force through only one member in the bottom chord thus the reason for the need of a W14x655 in the exterior truss. This is not an issue with the existing truss due to the multiple compression chords helping to distribute the large gravity loads. Therefore to help with the compression forces and increase stiffness, the shear wall was extended two bays into the cantilever for both truss configurations. An example of this addition is shown in Figure 100.

Truss Redesign-1+: Additional Shear Wall

When the shear walls were introduced into the stiffness Model-1 the deflections from redesign-1, which had been approximately equal to the existing model with larger sizes, the deflections dropped well below the target values by 17%. This was a large improvement, however, once again the same cannot be said when the same change was incorporated into Model-2. Even with the additional shear wall the members needed upsizing to meet the deflection requirements. Therefore the redesigns using tension members were becoming more and more inefficient. Adding size to the brace and chord members as well as extra concrete to even match the existing system is illogical and another alternative should be considered.

Redesign-1a+: Exterior Truss Elevatizon and Member Sizes: Frame- B

*Note- all members are W14 wide flange sizes

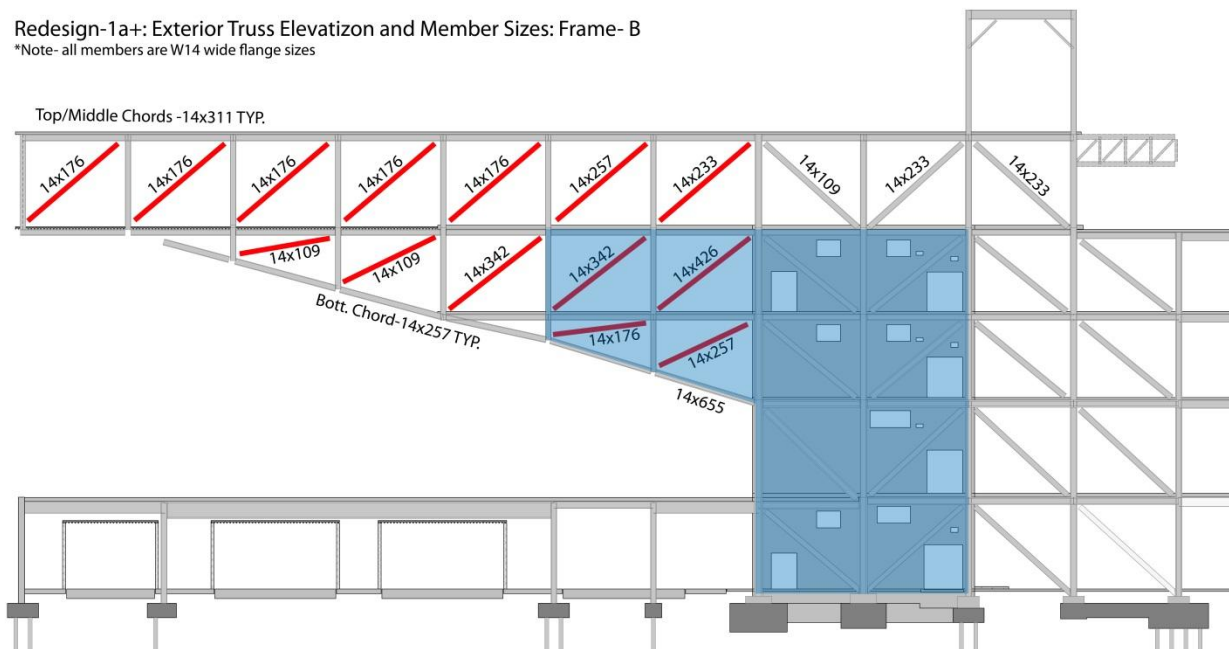


Figure 100: Redesign-1a+: Additional Shear Wall Within Truss Configuration

Truss Redesign- 2: Additional Bracing

Truss redesign-1 and 1+ showed that for the existing truss layout the efficient load path exhibited by the bracing members oriented in compression shows much more potential than a similar layout with compression members. Also additional concrete shear walls seemed to help with the individual stiffness of each frame, but with the entire system and all service loads applied member sizes still needed increasing to meet the existing deflections. It is then worthwhile to attempt to modify the existing truss configuration incorporating potential improvements to the already efficient system.

Reducing effective span and increasing usable depth in a cantilever will always yield a more efficient design. While additional shear wall with the existing configuration potentially reduced the effective span of the cantilever, it does not add any extra depth to the truss. A new idea proposed to improve this aspect with the existing truss was to add an additional brace to connect another compression load path. The proposed additional brace was added in the first bay of the cantilever plaza adjacent to the shear wall, between the first and second floor.

Initial designs for this option were formulated by adding the new brace with a similar size to the bottom compression chord at the lowest part of the cantilever. This brace was added to Model-2 at each truss and the design load case was analyzed through SAP. Axial loads and moments were once again output from the program and new minimum sizes were calculated for all braces and chords based on combined axial and moment loading. These minimum sizes were modeled in stiffness Model-1 including the new braces. After a few iterations of upsizing similar members were determined for most brace sizes as compared to the existing design, however, the critical compression members with large loads near the shear walls were reduced in size and the chord members also dropped in size. Overall more efficient truss configurations were designed overall. Figures 101-102 summarize the new member sizes in the exterior and interior trusses and show the added braces.



Thomas Villacampa

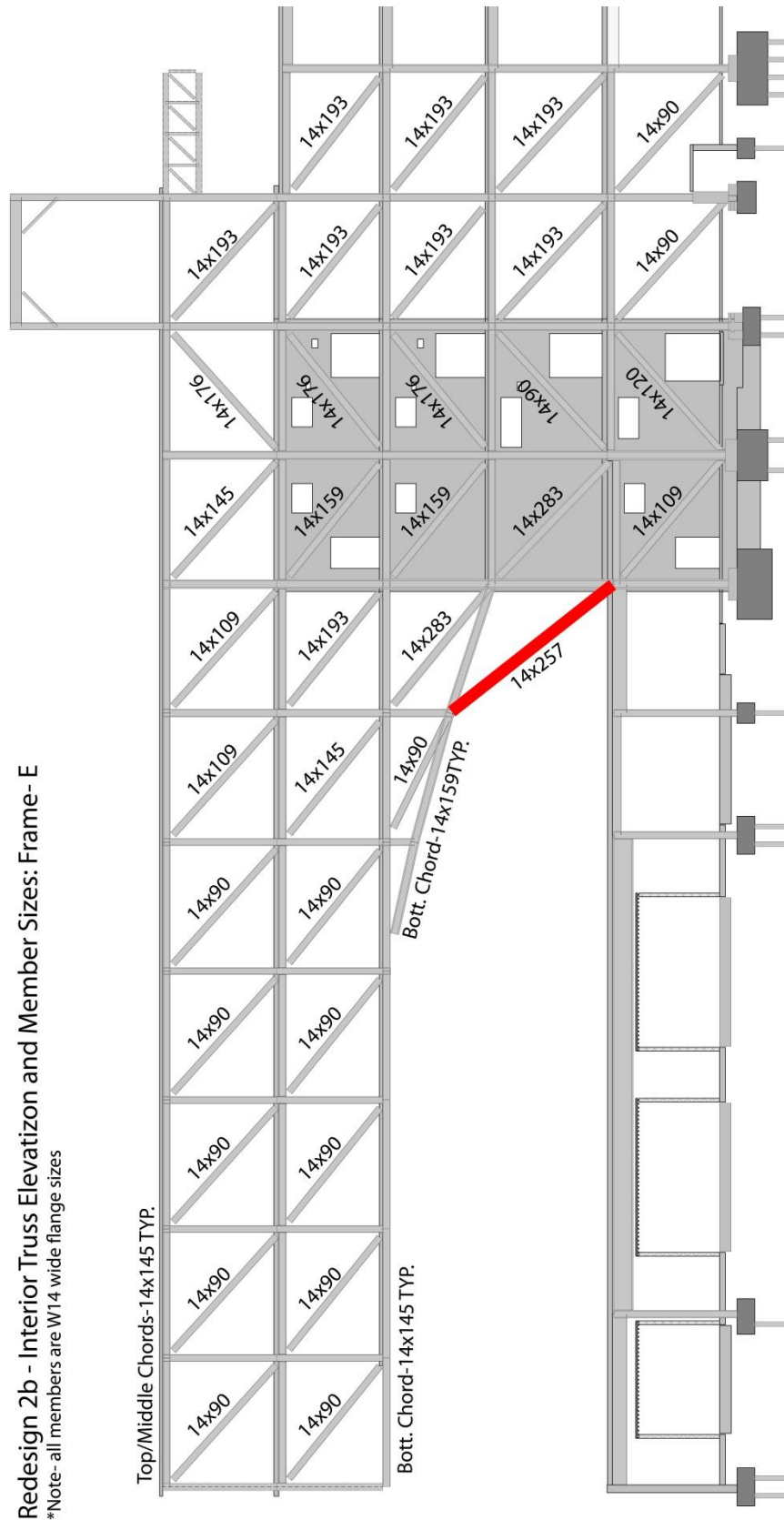


Figure 102: Redesign-2b: Interior Truss on Frame-E With Added Brace

Truss Redesign Conclusions

The added brace poses the best benefit of all the redesign options for the cantilever truss system. To compare the full potential with the previous designs shear wall was also extended a full two bays into this design as well. Once again the savings could not outweigh the input of materials and labor. When modeled in the stiffness Model-1 only 5% of the previous deflection, just with the additional brace, was removed. When incorporated with the entire gravity system in Model-2 the added wall did have a similar impact on the deflection, however, through only changing one or two brace sizes in the last two bays of the cantilever, that deflection savings was relinquished. This would have only saved roughly \$2000 in steel cost while adding the cost of additional concrete and labor alone would cost more than the savings. However, redesign-2, shown in Figure 103, with the additional brace greatly reduces the amount of steel necessary in the horizontal chords and the additional brace reduced the demand and the sizes of the critical compression braces at the lower sections of the cantilever. In all the size reductions amount a savings in excess of \$50,000, just in steel material costs between the four trusses, which makes it the most efficient structural option and the most cost effective option, between the existing and the redesign options presented above.

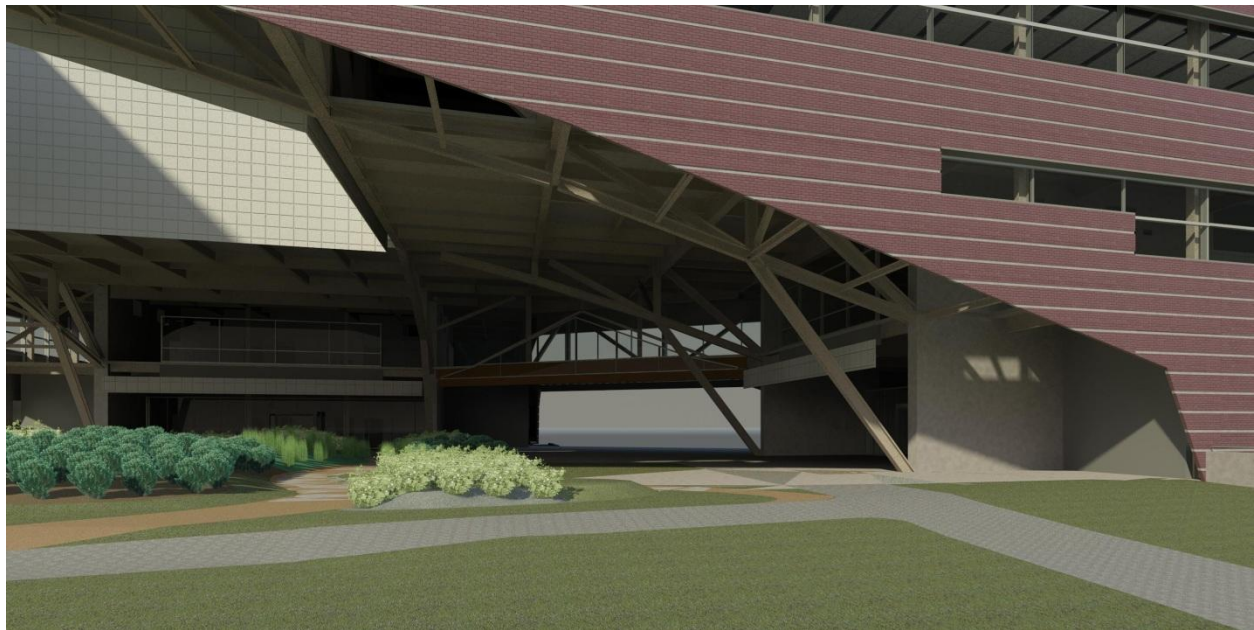


Figure 103: *Cantilever Plaza BIMception's Structural Changes*

Cost Analysis

Due to time constraints, an in-depth analysis of the structural changes to the cantilever was not conducted. However, a quick takeoff was produced for the changes to the beams within the trusses. Based on this takeoff, there was a savings of \$52,991 for the reduction in steel tonnage for the downsized beams. Changes to labor were not investigated. However, the expectation is that labor would not change drastically as the number of steel members did not change, nor did the welded connections. A detailed takeoff can be found in Appendix G.

Schedule Analysis

Due to time constraints, schedule impacts were not investigated for the change to the structural framing within the cantilever.

ARCHITECTURAL

BIMception's overall architectural goal for the Millennium Science Complex was to maintain Raphael Vinoly's vision of a floating horizontal building. The structural changes to the cantilever truss resulted in architectural changes to the Millennium Science Complex. However the changes to the entrance canopy (seen in Figure 104) doesn't infringe upon the hierarchy of the design. The entrance canopy's side walls encase the structural trusses, creating a seamless integration between the structure, cantilever profile, and building entrance.

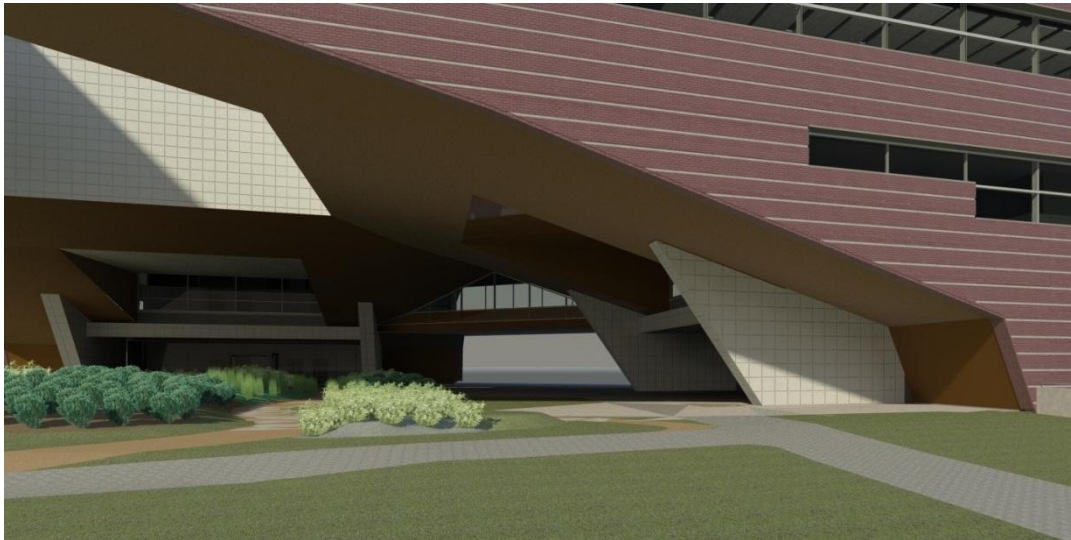


Figure 104: *Cantilever Plaza BIMception's Architectural Changes*

When assessing the architectural changes within the cantilever plaza it's important to look at the building as a whole. The new angled entrance canopy creates a progression of angles from ground level up to the tip of the cantilever. Figure 105 shows that from any point in the plaza the eye follows vertically along the angles towards the huge architectural statement of the cantilever.

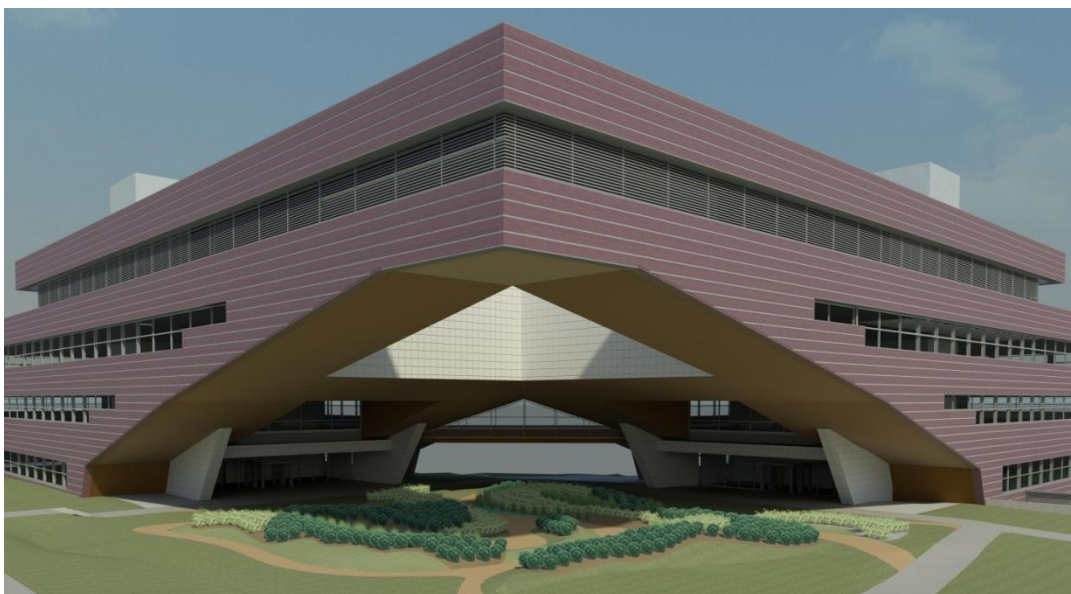


Figure 105: *Cantilever Plaza BIMception's Architectural Changes*

LIGHTING REDESIGN

Space Description

The cantilever plaza is located at the main entrance of the building, and brings together the two wings of the Millennium Science Complex. Located below the plaza are vibration sensitive laboratories. Due to this there is a serpentine pathway intended to limit foot traffic. BIMception's redesign of the entrance canopy ties in with the angled nature of the cantilever structure.



Figure 106: Cantilever Plaza Site Plan

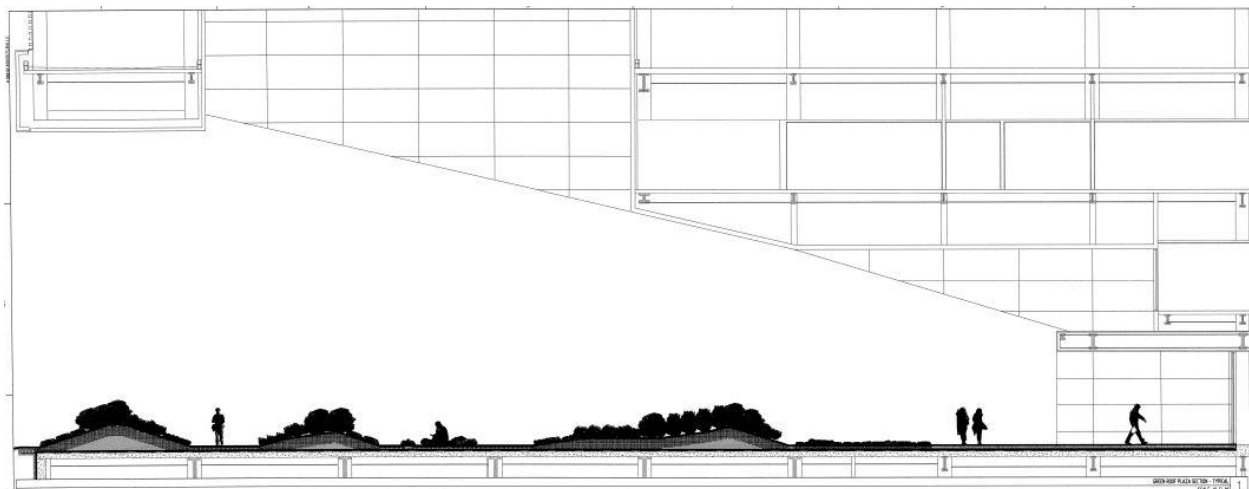


Figure 107: Cantilever Plaza Section

Materials – Cantilever Plaza	
Surface	Reflectance Value
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	

Table 63: Cantilever Plaza Material Properties

Design Criteria

IESNA Illuminance Recommendations

Building Entrance	Illuminance 5 fc Horizontal
Prominent Structures	Illuminance 5 fc Horizontal
Garden Pathways	Illuminance 1 fc Horizontal 0.3 fc Vertical

ASHRAE 90.1 Lighting Power Density

Building Walkways (<10' wide)	1.0 W/Linear Foot
Building Walkways (>10' wide)	0.2 W/SF
Canopies & Overhangs	1.25 W/SF
Building Façade	1.25 W/SF

Plaza Considered under ASHRAE 90.1 LPD Classification of Canopies and Overhangs, This allowing 1.25W/SF. Total available connected watts 35,528 W.

Design Considerations

Very Important

Appearance of Space and Luminaires (*IESNA*)

When dealing with a prominent structure and building entrance, it's important to address the appearance of the space. This can help direct occupants throughout the space; this is a key theme to this space to limit foot traffic above the laboratories.

Glare (*IESNA*)

When designing an exterior space it's important to avoid glare. Glare can cause discomfort for the occupants entering the building. This can be addressed in fixture selection and location.

Light Pollution/Light Trespass (*IESNA*)

Light pollutions and light trespass can have a large effect on adjacent properties. In this space this issues aren't as important since Pennsylvania State University owns all of the adjacent property.

Modeling of Faces or Objects (*IESNA*)

For safety and comfort reasons it's important for occupants of an exterior space to be able to identify their surroundings.

Points of Interest (*IESNA*)

This space contains a large structural icon in the cantilever and void so it will be important to address this in design.

Luminaires

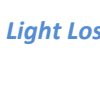
Luminaire Schedule								
Fixture Type	Image	Description	Mounting	Lamp	Voltage	Ballast	Wattage	Notes
X1		Louis Poulsen Kipp Post Cutoff. Pole Mounted Fixture, White Spun Aluminum Diffuser, Black Injection Molded ASA Top Shade, Clear Polycarbonate Enclosure, Black Die Cast Aluminum Frame Catalog #: KIP-1-70W-CMH-T6 G12	Pole Mounted 27'-0"	(1) 70W CMH CCT 3000K CRI 90	277V	Electronic Advanced Transformer	79W	
X2		Louis Poulsen Kipp Bollard. Pole Mounted Fixture, Injection Molded White Opal Acrylic Diffuser, Injection Molded Clear Polycarbonate Enclosure, Black Die Cast Aluminum Frame. Catalog #: KIB-1-39W-CMH-T6 G12	Pole Mounted 4'-3"	(1) 39W CMH CCT 3000K CRI 90	277V	Electronic Advanced Transformer	45W	
X3		Winona Lighting Spirit. Black Painted Aluminum, 18" Stem, Area Light. Catalog #: SP-0-12V-BKS-18-SM-STD	Surface 18" Stem	(1) 35W MR8 CCT 3000K CRI 100	12V	--	35W	Provide Series TMI 600 Ingrade Transformer
X4		Invue Entri LED Triangle Reveals. Black One Piece Die-Cast Aluminum, Injection Molded AccuLED Optical System. Catalog #: ENT-A01-E1-BL4-BK	Wall Mount	(1) LED Bar 4000K CRI >70	277V	Integrated Driver	26W	Wall mounted at 10' 0"
X5		Lightolier Calculite 6" Recessed Downlight. Array of High Brightness Royal Blue LED's, Phosphory Lens Assembly Converts Blue Light to White. Catalog #: C6L20-DL-30-M-CL-P	Recessed	LED CCT 3000K CRI	277V	Integrated Driver	39W	
X6		Lightolier Calculite 6" Recessed Wallwasher. Array of High Brightness Royal Blue LED's, Phosphory Lens Assembly Converts Blue Light to White. Catalog #: C6L20-WW-30-M-CL-P	Recessed	LED CCT 3000K CRI	277V	Integrated Driver	39W	
X7		Bega Floodlight. 3"x4' Floodlight. Black Die-Cast Aluminum Extruded Housing. Catalog #: 7593P.537BLK-28	Wall Mount	(1) 28W T5HO CCT 3000K CRI 85	277V	Electronic Advanced Transformer	31W	Mount Parallel to underside of cantiliver void.
X8		MP Lighting. Black Anodized Aluminum Housing, Polycarbonate Lens. Catalog #: L36-3.5W-W30S-BA	Surface	LED CCT 3000K CRI	12V	Remote Driver	3.5W	Provide Remote TLDDL60W5000 Driver

Table 64: Cantilever Plaza Luminaire Schedule

Light Loss Factors

Light Loss Factors - Corridor/Study Area				
Fixture Type	LDD	LLD	BF	Total LLF
X1	0.88	0.88	1.00	0.77
X2	0.88	0.88	1.00	0.77
X3	0.88	0.92	1.00	0.81
X4	0.75	0.92	1.00	0.69
X5	0.75	0.92	1.00	0.69
X6	0.75	0.92	1.00	0.69
X7	0.80	0.92	1.05	0.77
X8	0.75	0.92	1.00	0.69
*Using new IESNA guidelines for Clean Environment based on 12 month cleaning interval				

Table 65: Cantilever Plaza Light Loss Factors

Control Scheme

The cantilever plaza lighting is controlled through Eaton lighting control panel Pow-R-Command 1000 (LCP-1). See Table 66 for control zones, and Appendix E for LCP cutsheet.

Lighting Control Panel Schedule (LCP-1)	
Control Time Period	Zones
Dusk to Dawn	9,11,13,19,20,21,22,24,26,29,30,31,32,33,31,
Dusk to 11:00 PM	3, 6

Table 66: *Cantilever Plaza Lighting Control Hours of Operation*

Lighting Plan

Lighting plans found in Appendix E.

Renderings



Figure 108: *Cantilever Plaza Perspective Rendering*



Figure 109: *Cantilever Plaza Perspective Rendering*



Figure 110: *Cantilever Plaza Perspective Rendering*

Design Performance

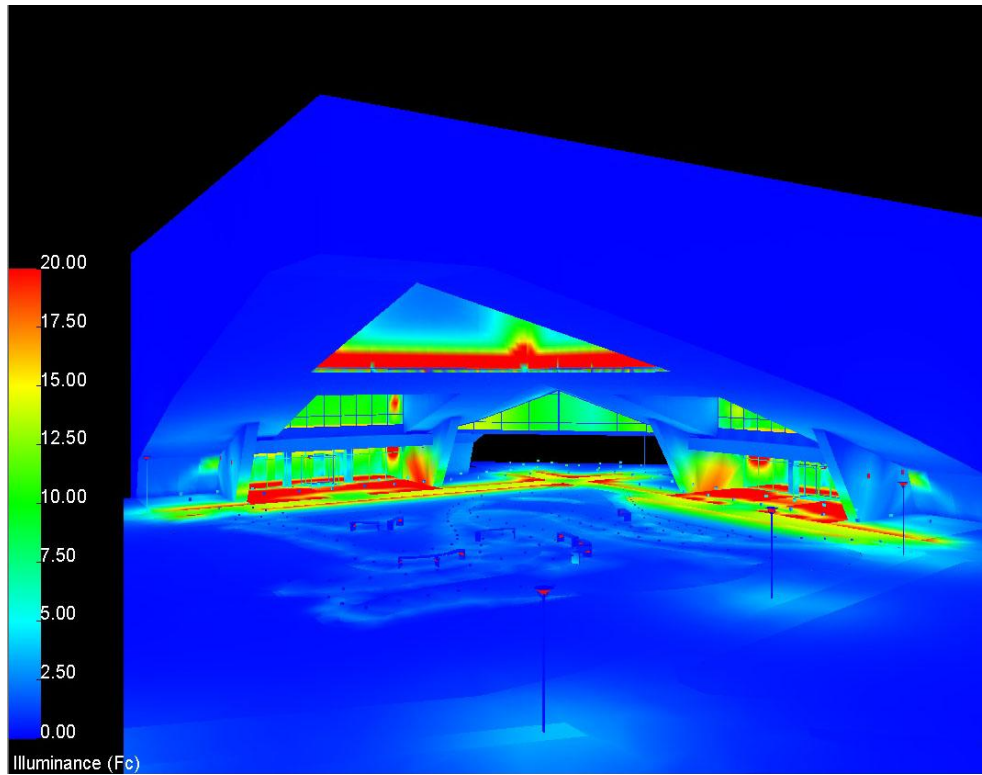


Figure 111: *Cantilever Plaza Pseudo Color*

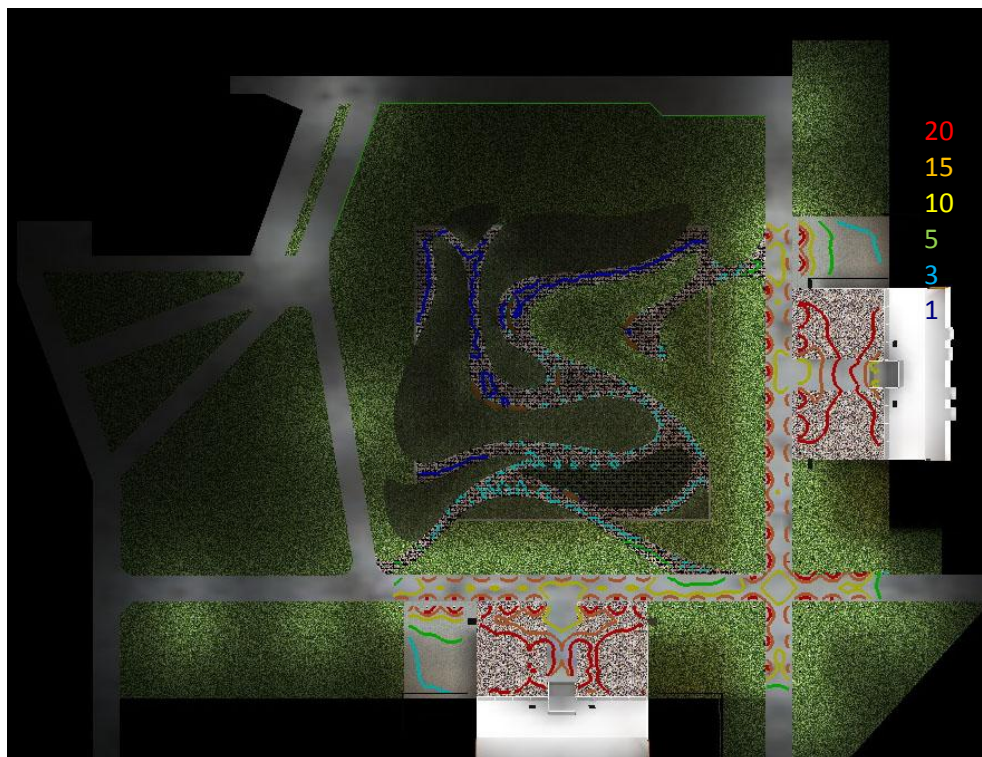


Figure 112: *Cantilever Plaza Pseudo Color*

Pathway Illuminance (FC)	
E _{average}	2.32
E _{Maximum}	6.1
E _{Minimum}	0.7

Table 67: Pathway Illuminance Values

Sidewalk Illuminance (FC)	
E _{average}	12.38
E _{Maximum}	32.2
E _{Minimum}	2.9

Table 68: Sidewalk Illuminance Values

SkyGlow Illuminance (FC)	
E _{average}	5.1

Table 69: Sidewalk Illuminance Values

Lighting Power Density

35W * 139 Fixtures = 4865W
 45W * 55 Fixtures = 2475W
 79W * 9 Fixtures = 711W
 26W * 4 Fixtures = 104W
 39W * 32 Fixtures = 1248W
 39W * 32 Fixtures = 1248W
 62W * 31 Fixtures = 1922
 3.5W * 18 Fixtures = 63W
 12636W/28,426SF = 0.44W/SF

Performance Summary

The lighting design for the cantilever plaza highlights the void in the cantilever. There is also a prominent focus on the building entrance. The bollards along the main sidewalks help direct occupants towards the entrance and away from the serpentine pathway. Illuminance requirements are exceed, but this was done to create contrast ratios between different portions of the space. The higher values on the sidewalk help to prevent a large contrast from the interior lobby space. There are some issues with sky glow, and in order to address this issue the cantilever void lighting can be set to turn off after hours.

Cost Analysis

Due to time constraints, an investigation of the redesigned exterior lighting systems in the areaway below the cantilever was not conducted.

Schedule Analysis

Due to time constraints, schedule impacts were not investigated for the change to the exterior lighting system within the areaway under the cantilever.

CANTILEVER CONCLUSION

The additional bracing added in redesign-2 reduced the amount of steel in the horizontal chords, and reduced the size of the critical compression braces in the lower portion of the cantilever. The reduction of sizing saved \$50,000, but the architectural changes that resulted from redesign enhance the cost savings. The redesigned structure created a new entrance canopy that blends with the cantilever plaza creating a progression of angles. The cantilever plaza serves as the Millennium Science Complex main entrance and focal point that ties the Material and Life Science wings together. The progression of angles created by the redesign creates a fusion of the spaces that helps enhance the overall architectural theme of a floating building. The use of lighting design in the cantilever plaza further reinforces the architectural theme. The architectural statement of the cantilever is highlighted with light by showcasing the void. The lighting design uses illuminance ratio to guide occupants towards the building entrance and away from the serpentine path. The combination of structural and lighting redesigns serve to enhance Raphael Vinoly's vision for the Millennium Science Complex Plaza.

Electrical Work

LIGHTING CIRCUIT REDESIGN

Affected Panelboards

PANELBOARDS					
Panel Tag	Voltage	System	Study Area	Office	Courtyard
HL-3D	480Y/277V, 3P, 4W	N	x	x	
HLE-3D	480Y/277V, 3P, 4W	N/E	x		
HLE-1B	480Y/277V, 3P, 4W	N/E			x
LCP1	480Y/277V, 3P, 4W	N			x

Table 70: Panelboards Affected by Lighting Redesign

Student Area

Description of Lighting Redesign

The lighting design for the Millennium Science Complex perimeter student areas is comprised of pendant and under cabinet luminaires. Pendant luminaires are 277V while the under cabinet luminaires are 120V plug loads.

Control Scheme

Pendant luminaires will be controlled by ceiling mounted low voltage occupancy sensor and photosensor. Low voltage switches receive 24VDC power from WattStopper BZ150 Power Pack. Under cabinet luminaires are controlled utilizing integrated on/off switches. The under cabinet luminaires are plug loads.

Lighting Plan

See Appendix E.

Existing Panelboards

BRANCH CIRCUIT PANELBOARD SCHEDULE													
Panel Name: HL-3D		Mounting:	Surface:		X	Main Lugs Only:		.	Amp Main CB		200		
277/480, 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	Load	TRIP	KVA/Phase			Poles	Poles	KVA/Phase			TRIP	Load	CKT
No.		(Amp)	A	B	C			A	B	C	(Amp)		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/OFFICE 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 LIGHTING	20		1.23		9	10		1.32		20	CONFERENCE RM LIGHTING	10
11	DRAY LAB, MISC COM. LIGHTING	20			1.28	11	12			1.52	20	CONFERENCE RM LIGHTING	12
13	CORRIDOR LIGHTING	20	1.60			13	14				20	SPARE	14
15	CORRIDOR LIGHTING	20		1.54		15	16				20	SPARE	16
17	CORRIDOR LIGHTING	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						60.00 %			Demand Factor	
			Phase B: 7.59 kVA						13.99 kVA			Demand Load	
			Phase C: 7.98 kVA						17.48 kVA			Load x 1.25	
Total Connected Load:			23.31 kVA						21.05 A			AMP	

Figure 113: Existing Panelboard Schedule HL-3D

BRANCH CIRCUIT PANELBOARD SCHEDULE																				
Panel Name: HLE-3D			Mounting:		Surface:		X		Main Lugs Only:			.		Amp Main CB		200				
277/480, 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: XXX%			Number of Poles:				42		TVSS:			.		Isolated Ground Bus		.				
CKT		Load			TRIP	KVA/Phase			Poles		Poles		KVA/Phase			TRIP	Load			CKT
No.					(Amp)	A	B	C			A	B	C	(Amp)	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		1.45		20	STAIR N-1 LIGHTING			4		
5		OFFICE 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		PANEL LE-3D VIA			50 3P	4.94			37	38				20	SPARE			38		
39		XFMR 'TRE-LE-3D'					3.80		39	40				20	SPARE			40		
41		(SOC)						3.80	41	42				20	SPARE			42		
Subtotals (kVA):					5.04	5.96	6.10								Subtotals (kVA)					
Total Loads:					Phase A: 6.06 kVA					60.00 %					Demand Factor					
					Phase B: 7.41 kVA					11.74 kVA					Demand Load					
					Phase C: 6.10 kVA					14.68 kVA					Load x 1.25					
Total Connected Load:					19.57 kVA					17.68 A					AMP					

Figure 114: Existing Panelboard Schedule HLE-3D

Panelboard Worksheets

PANELBOARD SIZING WORKSHEET										
Panel Tag----->					HL-3D	Panel Location:		Elec. Closet 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 LTG	3		0.83	KVA	1.00	830	830	
2	A	Staff and Facult LTG	3		1.7	KVA	1.00	1700	1700	
3	B	Electroactive Poly LTG	3		1.6	KVA	1.00	1600	1600	
4	B	Student Area/Private Office LTG	3		0.59	KVA	1.00	590	590	
5	C	Organic Elec. & PH LTG	3		1.6	KVA	1.00	1600	1600	
6	C	Student LTG	3		1.9	KVA	1.00	1900	1900	
7	A	Dry Lab A&B, Staff LTG	3		1.41	KVA	1.00	1410	1410	
8	A	Staff LTG	3		2.2	KVA	1.00	2200	2200	
9	B	Staff Admin. Kitchen LTG	3		1.23	KVA	1.00	1230	1230	
10	B	Conference RM LTG	3		1.32	KVA	1.00	1320	1320	
11	C	Dry Lab, Misc. Comp. LTG	3		1.28	KVA	1.00	1280	1280	
12	C	Conference RM LTG	3		1.52	KVA	1.00	1520	1520	
13	A	Corridor LTG	3		0.87	KVA	1.00	870	870	
14	A	Spare			3.55	KVA	1.00	3550	3550	
15	B	Corridor LTG	3		1.54	KVA	1.00	1540	1540	
16	B	Spare			3.55	KVA	1.00	3550	3550	
17	C	Corridor LTG	3		1.68	KVA	1.00	1680	1680	
18	C	Spare			3.55	KVA	1.00	3550	3550	
19	A	Spare			3.55	KVA	1.00	3550	3550	
20	A	Spare			3.55	KVA	1.00	3550	3550	
21	B	Spare			3.55	KVA	1.00	3550	3550	
22	B	Spare			3.55	KVA	1.00	3550	3550	
23	C	Spare			3.55	KVA	1.00	3550	3550	
24	C	Spare			3.55	KVA	1.00	3550	3550	
25	A	Spare			3.55	KVA	1.00	3550	3550	
26	A	Spare			3.55	KVA	1.00	3550	3550	
27	B	Spare			3.55	KVA	1.00	3550	3550	
28	B	Spare			3.55	KVA	1.00	3550	3550	
29	C	Spare			3.55	KVA	1.00	3550	3550	
30	C	Spare			3.55	KVA	1.00	3550	3550	
31	A	Spare			3.55	KVA	1.00	3550	3550	
32	A	Spare			3.55	KVA	1.00	3550	3550	
33	B	Spare			3.55	KVA	1.00	3550	3550	
34	B	Spare			3.55	KVA	1.00	3550	3550	
35	C	Spare			3.55	KVA	1.00	3550	3550	
36	C	Spare			3.55	KVA	1.00	3550	3550	
37	A	Spare			3.55	KVA	1.00	3550	3550	
38	A	Spare			3.55	KVA	1.00	3550	3550	
39	B	Spare			3.55	KVA	1.00	3550	3550	
40	B	Spare			3.55	KVA	1.00	3550	3550	
41	C	Spare			3.55	KVA	1.00	3550	3550	
42	C	Spare			3.55	KVA	1.00	3550	3550	
PANEL TOTAL								117.1	117.1	Amps= 140.9
PHASE LOADING										
PHASE TOTAL			A					39.0	39.0	33% 140.6
PHASE TOTAL			B					38.2	38.2	33% 138.0
PHASE TOTAL			C					39.9	39.9	34% 144.2
LOAD CATEGORIES										
				Connected				Demand		
						DF			PF	Ver. 104
1	receptacles			0.0	0.0		0.0	0.0		
2	computers			0.0	0.0		0.0	0.0		
3	fluorescent lighting			21.3	21.3	1.00	21.3	21.3	1.00	
4	HID lighting			0.0	0.0		0.0	0.0		
5	incandescent lighting			0.0	0.0		0.0	0.0		
6	HVAC fans			0.0	0.0		0.0	0.0		
7	heating			0.0	0.0		0.0	0.0		
8	kitchen equipment			0.0	0.0		0.0	0.0		
9	unassigned			95.9	95.9		95.9	95.9	1.00	
Total Demand Loads							117.1	117.1		
Spare Capacity					0%		0.0	0.0		
Total Design Loads							117.1	117.1	1.00	Amps= 140.9
Default Power Factor =				1.00						
Default Demand Factor =				100 %						

Figure 115: Panelboard Worksheet HL-3D

PANELBOARD SIZING WORKSHEET										
				HLE-3D		Panel Location:		Elec. Clost. N-P347		
Neutral Voltage----->				277		Phase:		3		
Phase Voltage----->				480		Wires:		4		
Pos	Ph.	Load Type	Cat.	Location	Load	Units	L. PF	Watts	VA	Remarks
1	A	Exit Sign			0.1	KVA	1.00	100	100	
2	A	Stair N-1 LTG	3		1.02	KVA	1.00	1020	1020	
3	B	Toilet & Corridor LTG	3		1.1	KVA	1.00	1100	1100	
4	B	Stair N-1 LTG	3		1.45	KVA	1.00	1450	1450	
5	C	Office LTG	3		2.3	KVA	1.00	2300	2300	
6	C	Spare			3.55	KVA	1.00	3550	3550	
7	A	Spare			3.55	KVA	1.00	3550	3550	
8	A	Spare			3.55	KVA	1.00	3550	3550	
9	B	Spare			3.55	KVA	1.00	3550	3550	
10	B	Spare			3.55	KVA	1.00	3550	3550	
11	C	Spare			3.55	KVA	1.00	3550	3550	
12	C	Spare			3.55	KVA	1.00	3550	3550	
13	A	Spare			3.55	KVA	1.00	3550	3550	
14	A	Spare			3.55	KVA	1.00	3550	3550	
15	B	Spare			3.55	KVA	1.00	3550	3550	
16	B	Spare			3.55	KVA	1.00	3550	3550	
17	C	Spare			3.55	KVA	1.00	3550	3550	
18	C	Spare			3.55	KVA	1.00	3550	3550	
19	A	Spare			3.55	KVA	1.00	3550	3550	
20	A	Spare			3.55	KVA	1.00	3550	3550	
21	B	Spare			3.55	KVA	1.00	3550	3550	
22	B	Spare			3.55	KVA	1.00	3550	3550	
23	C	Spare			3.55	KVA	1.00	3550	3550	
24	C	Spare			3.55	KVA	1.00	3550	3550	
25	A	Spare			3.55	KVA	1.00	3550	3550	
26	A	Spare			3.55	KVA	1.00	3550	3550	
27	B	Spare			3.55	KVA	1.00	3550	3550	
28	B	Spare			3.55	KVA	1.00	3550	3550	
29	C	Spare			3.55	KVA	1.00	3550	3550	
30	C	Spare			3.55	KVA	1.00	3550	3550	
31	A	Spare			3.55	KVA	1.00	3550	3550	
32	A	Spare			3.55	KVA	1.00	3550	3550	
33	B	Spare			3.55	KVA	1.00	3550	3550	
34	B	Spare			3.55	KVA	1.00	3550	3550	
35	C	Spare			3.55	KVA	1.00	3550	3550	
36	C	Spare			3.55	KVA	1.00	3550	3550	
37	A	Panel LE-3D via XFMR			4.94	KVA	1.00	4940	4940	
38	A	Spare			3.55	KVA	1.00	3550	3550	
39	B	Panel LE-3D via XFMR			3.8	KVA	1.00	3800	3800	
40	B	Spare			3.55	KVA	1.00	3550	3550	
41	C	Panel LE-3D via XFMR			3.8	KVA	1.00	3800	3800	
42	C	Spare			3.55	KVA	1.00	3550	3550	
PANEL TOTAL								139.2	139.2	Amps= 167.5
PHASE LOADING										
E TOTAL								A		
E TOTAL								B		
E TOTAL								C		
LOAD CATEGORIES								Connected	Demand	
								kW	kVA	DF
1 Spectacles								0.0	0.0	0.0
2 Computers								0.0	0.0	0.0
3 Ambient lighting								5.9	5.9	1.00
4 Lighting								0.0	0.0	0.0
5 Accent lighting								0.0	0.0	0.0
6 AC fans								0.0	0.0	0.0
7 Heating								0.0	0.0	0.0
8 Equipment								0.0	0.0	0.0
9 Unassigned								133.3	133.3	1.00
Demand Loads								139.2	139.2	
Design Capacity								0%	0.0	0.0
Design Loads								139.2	139.2	1.00
										Amps= 167.5
Default Power Factor =								1.00		
Default Demand Factor =								100 %		

Figure 116: Panelboard Worksheet HLE-3D

Revised Panelboard Schedules

PANELBOARD SCHEDULE												
VOLTAGE: 480Y/277V, 3PH, 4W			PANEL TAG: HL-3D			MIN. C/B AIC: 14K						
SIZE/TYPER BUS: 150A			PANEL LOCATION: Elec. Closet N-P347			OPTIONS: PROVIDE FEED THROUGH LUGS						
SIZE/TYPER MAIN: 150A/3P C/B			PANEL MOUNTING: SURFACE			FOR PANELBOARD 111B						
DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS. NO.	A	B	C	POS. NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION
Student LTG		830	20A/1P	1	*			2	20A/1P	1700		Staff and Faculty LTG
Electroactive Poly LTG		1600	20A/1P	3		*		4	20A/1P	590		Student Area/Private Office LTG
Organic Elec. & PH LTG		1600	20A/1P	5			*	6	20A/1P	1900		Student LTG
Dry Lab A&B, Staff LTG		1410	20A/1P	7	*			8	20A/1P	2200		Staff LTG
Staff Admin. Kitchen LTG		1230	20A/1P	9		*		10	20A/1P	1320		Conference RM LTG
Dry Lab, Misc. Comp. LTG		1280	20A/1P	11			*	12	20A/1P	1520		Conference RM LTG
Corridor LTG		870	20A/1P	13	*			14	20A/1P	3550		Spare
Corridor LTG		1540	20A/1P	15		*		16	20A/1P	3550		Spare
Corridor LTG		1680	20A/1P	17			*	18	20A/1P	3550		Spare
Spare		3550	20A/1P	19	*			20	20A/1P	3550		Spare
Spare		3550	20A/1P	21		*		22	20A/1P	3550		Spare
Spare		3550	20A/1P	23		*	*	24	20A/1P	3550		Spare
Spare		3550	20A/1P	25	*			26	20A/1P	3550		Spare
Spare		3550	20A/1P	27		*	*	28	20A/1P	3550		Spare
Spare		3550	20A/1P	29			*	30	20A/1P	3550		Spare
Spare		3550	20A/1P	31	*			32	20A/1P	3550		Spare
Spare		3550	20A/1P	33		*		34	20A/1P	3550		Spare
Spare		3550	20A/1P	35			*	36	20A/1P	3550		Spare
Spare		3550	20A/1P	37	*			38	20A/1P	3550		Spare
Spare		3550	20A/1P	39		*	*	40	20A/1P	3550		Spare
Spare		3550	20A/1P	41			*	42	20A/1P	3550		Spare
CONNECTED LOAD (KW) - A Ph.		38.96							TOTAL DESIGN LOAD (KW)		117.12	
CONNECTED LOAD (KW) - B Ph.		38.23							POWER FACTOR		1.00	
CONNECTED LOAD (KW) - C Ph.		39.93							TOTAL DESIGN LOAD (AM)		141	

Figure 117: Panelboard Schedule HL-3D

PANELBOARD SCHEDULE												
VOLTAGE: 480Y/277V, 3PH, 4W			PANEL TAG: HLE-3D			MIN. C/B AIC: 14K						
SIZE/TYPER BUS: 175A			PANEL LOCATION: Elec. Closet N-P347			OPTIONS: PROVIDE FEED THROUGH LUGS						
SIZE/TYPER MAIN: 175A/3P C/B			PANEL MOUNTING: SURFACE			FOR PANELBOARD 111B						
DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS. NO.	A	B	C	POS. NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION
Exit Sign		100	20A/1P	1	*			2	20A/1P	1020	0	Stair N-1 LTG
Toilet & Corridor LTG	0	1100	20A/1P	3		*		4	20A/1P	1450	0	Stair N-1 LTG
Office LTG	0	2300	20A/1P	5			*	6	20A/1P	3550	0	Spare
Spare		3550	20A/1P	7	*			8	20A/1P	3550		Spare
Spare		3550	20A/1P	9		*		10	20A/1P	3550		Spare
Spare		3550	20A/1P	11			*	12	20A/1P	3550		Spare
Spare		3550	20A/1P	13	*			14	20A/1P	3550		Spare
Spare		3550	20A/1P	15		*		16	20A/1P	3550		Spare
Spare		3550	20A/1P	17			*	18	20A/1P	3550		Spare
Spare		3550	20A/1P	19	*			20	20A/1P	3550		Spare
Spare		3550	20A/1P	21		*		22	20A/1P	3550		Spare
Spare		3550	20A/1P	23		*	*	24	20A/1P	3550		Spare
Spare		3550	20A/1P	25	*			26	20A/1P	3550		Spare
Spare		3550	20A/1P	27		*	*	28	20A/1P	3550		Spare
Spare		3550	20A/1P	29			*	30	20A/1P	3550		Spare
Spare		3550	20A/1P	31	*			32	20A/1P	3550		Spare
Spare		3550	20A/1P	33		*	*	34	20A/1P	3550		Spare
Spare		3550	20A/1P	35			*	36	20A/1P	3550		Spare
Panel LE-3D via XFMR	0	4940	—	37	*			38	20A/1P	3550		Spare
Panel LE-3D via XFMR	0	3800	50A/3P	39		*	*	40	20A/1P	3550		Spare
Panel LE-3D via XFMR	0	3800	—	41			*	42	20A/1P	3550		Spare
CONNECTED LOAD (KW) - A Ph.		45.11							TOTAL DESIGN LOAD (KW)		139.21	
CONNECTED LOAD (KW) - B Ph.		45.40							POWER FACTOR		1.00	
CONNECTED LOAD (KW) - C Ph.		48.70							TOTAL DESIGN LOAD (AMPS)		168	

Figure 118: Panelboard Schedule HLE-3D

[illegible]

Wiring with Occupancy Sensor

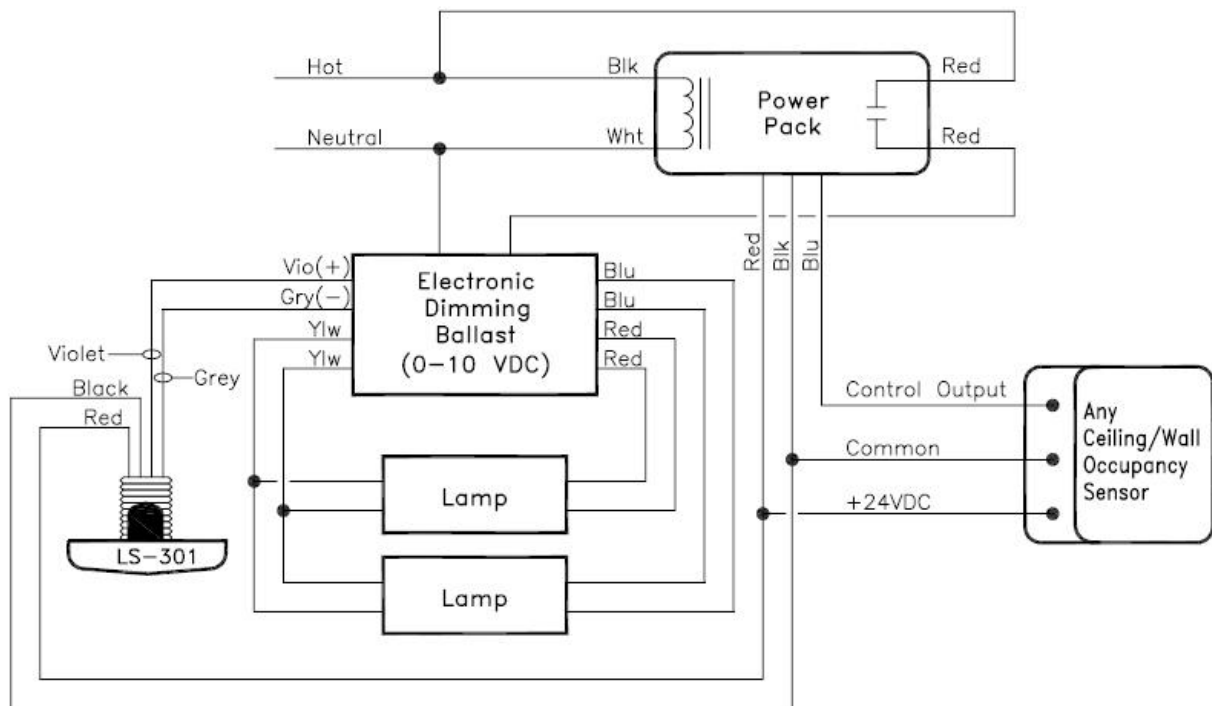


Figure 120: *Student Area Wiring Diagram*

Feeder Sizing

Panel HL-3D Feeder Sizing	
Voltage	277
Design Load kVA	117
Power Factor	1
Design Load Amps	141
Circuit Break Size	150 A
Number of Sets	1
Phase Conductors	(3) #1/0
Neutral Conductor	(1) #1/0
Ground Conductor	(1) #6
Conduit	1-1/2"
Run Length	207'
Voltage Drop	7.1V
Percent Voltage drop	2.6%

Table 71: Feeder Sizing for Panelboard HL-3D

Panel HLE-3D Feeder Sizing	
Voltage	277
Design Load kVA	139.21
Power Factor	1
Design Load Amps	168
Circuit Break Size	175 A
Number of Sets	1
Phase Conductors	(3) #2/0
Neutral Conductor	(1) #2/0
Ground Conductor	(1) #6
Conduit	2"
Run Length	207'
Voltage Drop	0.8V
Percent Voltage drop	0.3%

Table 72: Feeder Sizing for Panelboard HLE-3D

Private Office

Description of Lighting Redesign

The lighting redesign for the Millennium Science Complex perimeter office utilizes pendant Luminaires. The pendant Luminaires operate on 277V.

Control Scheme

The pendants are controlled using a wall mounted occupancy sensor, and ceiling mounted photosensor. Photosensor lighting control will switch fixtures off enough daylight is present. Wiring diagram will be provided showing power pack for low voltage switch. The photosensor and occupancy sensors receive 24VDC from Wattstopper BZ100 Power Pack.

Lighting Plan

See Appendix E.

Existing Panelboards

See Existing Panelboards for student area.

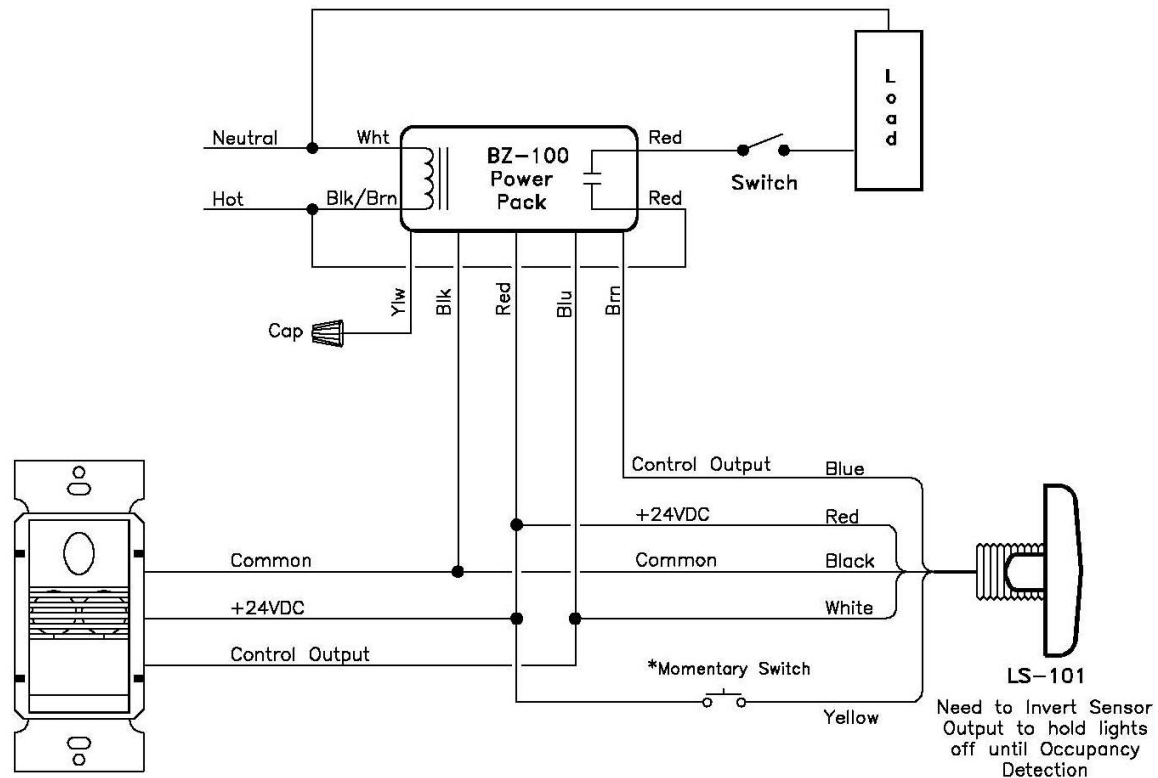
Panelboard Worksheets

See Panelboard Worksheets for student area. Office is circuited on HL-3D circuit 4 along with the student area.

Revised Panelboards

See Revised Panelboards for student area. Office is circuited on HL-3D circuit 4 along with the student area.

Wiring Diagram



Single Low Voltage Switch
For use with DW-100-24,
PW-100-24, and UW-100-24.

Operation

* Switch lets you turn load On for 1 hour.

Occupancy sensor signals BZ-100 power pack based on detection.

If lighting level is above the LS-101 set point, LS-101 will send 24 VDC to force BZ-100 off. During the off condition, pushing the momentary switch will turn lights on for one hour.

If lighting level is below LS-101 set point, LS-101 will release force off and allow occupancy sensor to control BZ-100.

Figure 121: Private Office Wiring Diagram

Feeder Sizing

See Feeder Sizing for student area. Office is circuited on HL-3D circuit 4 along with the student area.

Cantilever Plaza

Description of Lighting Redesign

The lighting redesign for the cantilever plaza consists of ceramic metal halide, halogen, and LED fixtures. The CMHs run at 277V, the halogens run on 12V with an in grade transformer, and the LEDs have an in grade remote driver.

Control Scheme

The cantilever plaza lighting is controlled through Eaton lighting control panel Pow-R-Command 1000 (LCP-1). See Table 73 for control zones, and Appendix E for LCP cutsheet.

Lighting Control Panel Schedule (LCP-1)	
Control Time Period	Zones
Dusk to Dawn	9,11,13,19,20,21,22,24,26,29,30,31,32,33,31,
Dusk to 11:00 PM	3, 6

Table 73: *Cantilever Plaza Lighting Control Hours of Operation*

Lighting Plan

See Appendix E.

Existing Panelboards

BRANCH CIRCUIT PANELBOARD SCHEDULE															
Panel Name: LCP-1			Mounting:		Surface:	X	Main Lugs Only:			.	Amp Main CB			.	
277/480, 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	Load		TRIP	KVA/Phase			Poles	Poles	KVA/Phase			TRIP	Load		CKT
No.			(Amp)	A	B	C			A	B	C	(Amp)			No.
1	ZONE 1 LOBBY LIGHTING		20	0.42			1	2				20	SPARE		2
3	SPARE		20				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 LIGHITNG		20			1.25	11	12				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				20	SPARE		16
17	ZONE 9 EXTERIOR LIGHTING		20			1.40	17	18			0.40	20	ZONE 26 SITE LIGHTING		18
19	SPARE		20				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 LIGHTING		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 LGITHING		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				37	38				20	SPARE		38
39	SPARE		20				39	40				20	SPARE		40
41	SPARE		20				41	42				20	SPARE		42

Subtotals (kVA):	4.30	5.11	6.92
Total Loads:	Phase A: 5.59 kVA		
	Phase B: 6.95 kVA		
	Phase C: 8.45 kVA		
Total Connected Load:	20.99 kVA		

1.29	1.84	1.53	Subtotals (kVA)
80.00 %			Demand Factor
16.79 kVA			Demand Load
20.99 kVA			Load x 1.25
25.28 A			AMP

REMARKS: * - DENOTES PROGRAMMABLE REMOTE CONTROL BREAKER

Figure 122: Existing Panelboard Schedule LCP-1

BRANCH CIRCUIT PANELBOARD SCHEDULE																													
Panel Name: HLE-1B			Mounting:		Surface:		X		Main Lugs Only:			.		Amp Main CB		100													
277/480, 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		Load			TRIP		KVA/Phase			Poles		Poles		KVA/Phase			TRIP		Load			CKT							
No.					(Amp)		A B C							A B C			(Amp)					No.							
1		PERIMETER CORRIDOR LIGHTING			20		1.60					1		2		1.02						20		ELEC, TEL, LAB LIGHTING			2		
3		EXIT LIGHTS			20				0.04			3			4								20		SPARE			4	
5		CORRIDOR LIGHTING			20				1.31			5			6								20		SPARE			6	
7		STAIR- W2, W3 LIGHTING - (B. MEZZ.)			20		0.50					7			8								20		SPARE			8	
9		SPARE			20							9			10								20		SITE LIGHTING (XP0-1)			10	
11		SPARE			20							11			12								20		EL-5 (EMERGENCY)			12	
13		SPARE			20							13			14		0.63						20		EXTERIOR CANOPY LIGHTING			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					1.36			20		HEAT TRACE			42	
Subtotals (kVA):						2.10		0.04		1.31				1.65		0.00		1.36				Subtotals (kVA)							
Total Loads:				Phase A: 3.75 kVA								60.00 %				Demand Factor													
				Phase B: 0.04 kVA								3.88 Kva				Demand Load													
				Phase C: 2.67 kVA								4.85 kVA				Load x 1.25													
Total Connected Load:				6.46 kVA								5.83 A				AMP													

Figure 123: Existing Panelboard Schedule HL-1B

Panelboard Worksheets

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 Lobby Lighting	4		0.42	KVA	1.00	420	420	
2	A	Spare			3.55	KVA	1.00	3550	3550	
3	B	Spare			3.55	KVA	1.00	3550	3550	
4	B	Zone 19 MS Sidewalk	4		1.215	KVA	1.00	1215	1215	
5	C	Zone 3 Void Lighting	3		0.93	KVA	1.00	930	930	
6	C	Zone 20 MS Canopy Lighting			1.3	KVA	1.00	1300	1300	
7	A	Zone 4 LS Lobby Lighting	4		0.31	KVA	1.00	310	310	
8	A	Zone 21 Pathway Lighting	5		0.525	KVA	1.00	525	525	
9	B	Zone 5 LS Lobby Lighting	4		0.56	KVA	1.00	560	560	
10	B	Zone 22 Pathway Lighting	5		0.455	KVA	1.00	455	455	
11	C	Zone 6 Void Lighting	3		0.93	KVA	1.00	930	930	
12	C	Spare			3.55	KVA	1.00	3550	3550	
13	A	Zone 7 ML Lobby Lighting	4		0.84	KVA	1.00	840	840	
14	A	Zone 24 Pathway Lighting	5		0.49	KVA	1.00	490	490	
15	B	Zone 8 ML Lobby Lighting	4		0.56	KVA	1.00	560	560	
16	B	Spare			3.55	KVA	1.00	3550	3550	
17	C	Zone 9 Bench Lighting			0.063	KVA	1.00	63	63	
18	C	Zone 26 Pathway Lighting	5		0.49	KVA	1.00	490	490	
19	A	Spare			3.55	KVA	1.00	3550	3550	
20	A	Zone 27 Site Lighting	4		0.05	KVA	1.00	50	50	
21	B	Zone 11 LS Sidewalk	3		1.125	KVA	1.00	1125	1125	
22	B	Zone 28 Site Lighting	4		0.4	KVA	1.00	400	400	
23	C	Zone 12 ML Lobby Lighting	4		0.31	KVA	1.00	310	310	
24	C	Zone 29 Pathway Lighting	5		0.455	KVA	1.00	455	455	
25	A	Zone 13 LS Canopy Lighting			1.3	KVA	1.00	1300	1300	
26	A	Zone 30 Pathway Lighting	5		0.27	KVA	1.00	270	270	
27	B	Spare			3.55	KVA	1.00	3550	3550	
28	B	Zone 31 Pathway Lighting	5		0.525	KVA	1.00	525	525	
29	C	Zone 15 Site Lighting	4		2.1	KVA	1.00	2100	2100	
30	C	Zone 32 Pathway Lighting	5		0.49	KVA	1.00	490	490	
31	A	Zone 16 Site Lighting	4		2.1	KVA	1.00	2100	2100	
32	A	Zone 33 Pathway Lighting	5		0.455	KVA	1.00	455	455	
33	B	Zone 17 Site Lighting	4		1.9	KVA	1.00	1900	1900	
34	B	Zone 34 Pathway Lighting	5		0.49	KVA	1.00	490	490	
35	C	Zone 35 ML Lobby Lighting	4		0.46	KVA	1.00	460	460	
36	C	Zone 36 LS Lobby Lighting	4		0.42	KVA	1.00	420	420	
37	A	Spare			3.55	KVA	1.00	3550	3550	
38	A	Spare			3.55	KVA	1.00	3550	3550	
39	B	Spare			3.55	KVA	1.00	3550	3550	
40	B	Spare			3.55	KVA	1.00	3550	3550	
41	C	Spare			3.55	KVA	1.00	3550	3550	
42	C	Spare			3.55	KVA	1.00	3550	3550	
PANEL TOTAL								64.5	64.5	Amps= 77.7
PHASE LOADING										
PHASE TOTAL			A					21.0	21.0	32% 75.7
PHASE TOTAL			B					25.0	25.0	39% 90.2
PHASE TOTAL			C					18.6	18.6	29% 67.1
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		0.0	0.0				
3	fluorescent lighting	3.0	3.0		3.0	3.0	1.00			
4	HID lighting	11.6	11.6		11.6	11.6	1.00			
5	incandescent lighting	4.6	4.6		4.6	4.6	1.00			
6	HVAC fans	0.0	0.0		0.0	0.0				
7	heating	0.0	0.0		0.0	0.0				
8	kitchen equipment	0.0	0.0		0.0	0.0				
9	unassigned	45.3	45.3		45.3	45.3	1.00			
Total Demand Loads					64.5	64.5				
Spare Capacity		0%			0.0	0.0				
Total Design Loads					64.5	64.5	1.00	Amps=	77.7	
Default Power Factor =		1.00								
Default Demand Factor =		100 %								

Figure 124: Panelboard Worksheet LCP-1

PANELBOARD SIZING WORKSHEET											
Panel Tag----->				HLE-1B	Panel Location:			Elec. W-P127			
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	Perimeter Corridor Lighting	3		1.6	KVA	1.00	1600	1600		
2	A	Elec. Tel. Lab Lighting	3		1.02	KVA	1.00	1020	1020		
3	B	Exit Lights			0.04	KVA	1.00	40	40		
4	B	Spare			3.55	KVA	1.00	3550	3550		
5	C	Corridor Lighting	3		1.31	KVA	1.00	1310	1310		
6	C	Spare			3.55	KVA	1.00	3550	3550		
7	A	Stair-W2,W3 Lighting (B.Mezz)	3		0.5	KVA	1.00	500	500		
8	A	Spare			3.55	KVA	1.00	3550	3550		
9	B	Spare			3.55	KVA	1.00	3550	3550		
10	B	Site Lighting XPO-1	4		0.711	KVA	1.00	711	711		
11	C	Spare			3.55	KVA	1.00	3550	3550		
12	C	EL-5 (Emergency)			0	KVA	1.00	0	0		
13	A	Spare			3.55	KVA	1.00	3550	3550		
14	A	Exterior Canopy Lighting	4		0.63	KVA	1.00	630	630		
15	B	Spare			3.55	KVA	1.00	3550	3550		
16	B	Spare			3.55	KVA	1.00	3550	3550		
17	C	Spare			3.55	KVA	1.00	3550	3550		
18	C	Spare			3.55	KVA	1.00	3550	3550		
19	A	Spare			3.55	KVA	1.00	3550	3550		
20	A	Spare			3.55	KVA	1.00	3550	3550		
21	B	Spare			3.55	KVA	1.00	3550	3550		
22	B	Spare			3.55	KVA	1.00	3550	3550		
23	C	Spare			3.55	KVA	1.00	3550	3550		
24	C	Spare			3.55	KVA	1.00	3550	3550		
25	A	Spare			3.55	KVA	1.00	3550	3550		
26	A	Spare			3.55	KVA	1.00	3550	3550		
27	B	Spare			3.55	KVA	1.00	3550	3550		
28	B	Spare			3.55	KVA	1.00	3550	3550		
29	C	Spare			3.55	KVA	1.00	3550	3550		
30	C	Spare			3.55	KVA	1.00	3550	3550		
31	A	Spare			3.55	KVA	1.00	3550	3550		
32	A	Spare			3.55	KVA	1.00	3550	3550		
33	B	Spare			3.55	KVA	1.00	3550	3550		
34	B	Spare			3.55	KVA	1.00	3550	3550		
35	C	Spare			3.55	KVA	1.00	3550	3550		
36	C	Spare			3.55	KVA	1.00	3550	3550		
37	A	Spare			3.55	KVA	1.00	3550	3550		
38	A	Spare			3.55	KVA	1.00	3550	3550		
39	B	Spare			3.55	KVA	1.00	3550	3550		
40	B	Spare			3.55	KVA	1.00	3550	3550		
41	C	Spare			3.55	KVA	1.00	3550	3550		
42	C	Spare			3.55	KVA	1.00	3550	3550		
PANEL TOTAL								126.5	126.5	Amps= 152.2	
PHASE LOADING											
PHASE TOTAL			A					kW	kVA	%	Amps
PHASE TOTAL			B					39.3	39.3	31%	141.7
PHASE TOTAL			C					43.4	43.4	34%	156.5
PHASE TOTAL								43.9	43.9	35%	158.5
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		0.0	0.0			
3		fluorescent lighting		4.4	4.4		4.4	4.4	1.00		
4		HID lighting		1.3	1.3		1.3	1.3	1.00		
5		incandescent lighting		0.0	0.0		0.0	0.0			
6		HVAC fans		0.0	0.0		0.0	0.0			
7		heating		0.0	0.0		0.0	0.0			
8		kitchen equipment		0.0	0.0		0.0	0.0			
9		unassigned		120.7	120.7	0.60	72.4	72.4	1.00		
Total Demand Loads							78.2	78.2			
Spare Capacity					0%		0.0	0.0			
Total Design Loads							78.2	78.2	1.00	Amps= 94.1	
Default Power Factor =				1.00							
Default Demand Factor =				100 %							

Figure 125: Panelboard Worksheet HLE-1B

Revised Panelboard Schedules

PANELBOARD SCHEDULE													
VOLTAGE: 480Y/277V,3PH,4W			PANEL TAG: LCP-1						MIN. C/B AIC: 14K				
SIZE/TYPE BUS: 225A			PANEL LOCATION: N-P052						OPTIONS:				
SIZE/TYPE MAIN: 80A/3P C/B			PANEL MOUNTING: SURFACE										
DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS. NO.	A	B	C	POS. NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION	
Zone 1 Lobby Lighting		420	20A/1P	1	*			2	20A/1P	3550		Spare	
Spare		3550	20A/1P	3		*		4	20A/1P	1215		Zone 19 MS Sidewalk	
Zone 3 Void Lighting		930	20A/1P	5			*	6	20A/1P	1300		Zone 20 MS Canopy Lighting	
Zone 4 LS Lobby Lighting		310	20A/1P	7	*			8	20A/1P	525		Zone 21 Pathway Lighting	
Zone 5 LS Lobby Lighting		560	20A/1P	9		*		10	20A/1P	455		Zone 22 Pathway Lighting	
Zone 6 Void Lighting		930	20A/1P	11			*	12	20A/1P	3550		Spare	
Zone 7 ML Lobby Lighting		840	20A/1P	13	*			14	20A/1P	490		Zone 24 Pathway Lighting	
Zone 8 ML Lobby Lighting		560	20A/1P	15		*		16	20A/1P	3550		Spare	
Zone 9 Bench Lighting		63	20A/1P	17			*	18	20A/1P	490		Zone 26 Pathway Lighting	
Spare		3550	20A/1P	19	*			20	20A/1P	50		Zone 27 Site Lighting	
Zone 11 LS Sidewalk		1125	20A/1P	21		*		22	20A/1P	400		Zone 28 Site Lighting	
Zone 12 ML Lobby Lighting		310	20A/1P	23			*	24	20A/1P	455		Zone 29 Pathway Lighting	
Zone 13 LS Canopy Lighting		1300	20A/1P	25	*			26	20A/1P	270		Zone 30 Pathway Lighting	
Spare		3550	20A/1P	27		*		28	20A/1P	525		Zone 31 Pathway Lighting	
Zone 15 Site Lighting		2100	20A/1P	29			*	30	20A/1P	490		Zone 32 Pathway Lighting	
Zone 16 Site Lighting		2100	20A/1P	31	*			32	20A/1P	455		Zone 33 Pathway Lighting	
Zone 17 Site Lighting		1900	20A/1P	33		*		34	20A/1P	490		Zone 34 Pathway Lighting	
Zone 35 ML Lobby Lightng		460	20A/1P	35			*	36	20A/1P	420		Zone 36 LS Lobby Lighting	
Spare		3550	20A/1P	37	*			38	20A/1P	3550		Spare	
Spare		3550	20A/1P	39		*		40	20A/1P	3550		Spare	
Spare		3550	20A/1P	41			*	42	20A/1P	3550		Spare	
CONNECTED LOAD (KW) - A Ph.		20.96								TOTAL DESIGN LOAD (KW)		64.54	
CONNECTED LOAD (KW) - B Ph.		24.98								POWER FACTOR		1.00	
CONNECTED LOAD (KW) - C Ph.		18.60								TOTAL DESIGN LOAD (AMPS)		78	

Figure 126: Panelboard Schedule LCP-1

PANELBOARD SCHEDULE												
VOLTAGE: 480Y/277V,3PH,4W			PANEL TAG: HLE-1B						MIN. C/B AIC: 14K			
SIZE/TYPE BUS: 100A			PANEL LOCATION: Elec. W-P127						OPTIONS: PROVIDE FEED THROUGH LUGS			
SIZE/TYPE MAIN: 100A/3P C/B			PANEL MOUNTING: SURFACE						FOR PANELBOARD 1L1B			
DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS. NO.	A	B	C	POS. NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION
Perimeter Corridor Lighting		1600	20A/1P	1	*			2	20A/1P	1020		Elec, Tel, Lab Lighting
Exit Lights		40	20A/1P	3		*		4	20A/1P	3550		Spare
Corridor Lighting		1310	20A/1P	5			*	6	20A/1P	3550		Spare
Stair-W2,W3 Lighting (B.Mezz)		500	20A/1P	7	*			8	20A/1P	3550		Spare
Spare		3550	20A/1P	9		*		10	20A/1P	711		Site Lighting XPO-1
Spare		3550	20A/1P	11			*	12	20A/1P	0		EL-5 (Emergency)
Spare		3550	20A/1P	13	*			14	20A/1P	630		Exterior Canopy Lighting
Spare		3550	20A/1P	15		*		16	20A/1P	3550		Spare
Spare		3550	20A/1P	17			*	18	20A/1P	3550		Spare
Spare		3550	20A/1P	19	*			20	20A/1P	3550		Spare
Spare		3550	20A/1P	21		*		22	20A/1P	3550		Spare
Spare		3550	20A/1P	23			*	24	20A/1P	3550		Spare
Spare		3550	20A/1P	25	*			26	20A/1P	3550		Spare
Spare		3550	20A/1P	27		*		28	20A/1P	3550		Spare
Spare		3550	20A/1P	29			*	30	20A/1P	3550		Spare
Spare		3550	20A/1P	31	*			32	20A/1P	3550		Spare
Spare		3550	20A/1P	33		*		34	20A/1P	3550		Spare
Spare		3550	20A/1P	35			*	36	20A/1P	3550		Spare
Spare		3550	20A/1P	37	*			38	20A/1P	3550		Spare
Spare		3550	20A/1P	39		*		40	20A/1P	3550		Spare
Spare		3550	20A/1P	41			*	42	20A/1P	3550		Spare
CONNECTED LOAD (KW) - A Ph.		39.25							TOTAL DESIGN LOAD (KW)		78.22	
CONNECTED LOAD (KW) - B Ph.		43.35							POWER FACTOR		1.00	
CONNECTED LOAD (KW) - C Ph.		43.91							TOTAL DESIGN LOAD (AM		94	

Figure 127: Panelboard Schedule HL-1B

Feeder Sizing

Panel LCP-1 Feeder Sizing	
Voltage	LCP-1
Design Load kVA	64.5
Power Factor	1
Design Load Amps	77.7
Circuit Break Size	80 A
Number of Sets	1
Phase Conductors	(3) #3
Neutral Conductor	(1) #3
Ground Conductor	(1) #8
Conduit	1-1/4"
Run Length	10'
Voltage Drop	0.4V
Percent Voltage drop	0.1%

Table 74: Feeder Sizing for Panelboard LCP-1

Panel HLE-3D Feeder Sizing	
Voltage	277
Design Load kVA	78.2
Power Factor	1
Design Load Amps	94.1
Circuit Break Size	100 A
Number of Sets	1
Phase Conductors	(3) #1
Neutral Conductor	(1) #1
Ground Conductor	(1) #8
Conduit	1-1/2"
Run Length	45'
Voltage Drop	1.3V
Percent Voltage drop	0.5%

Table 75: Feeder Sizing for Panelboard HLE-3D

SHORT CIRCUIT CALCULATION

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				

Table 76: Short Circuit Analysis Calculation Table

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 in Figure 128 below.

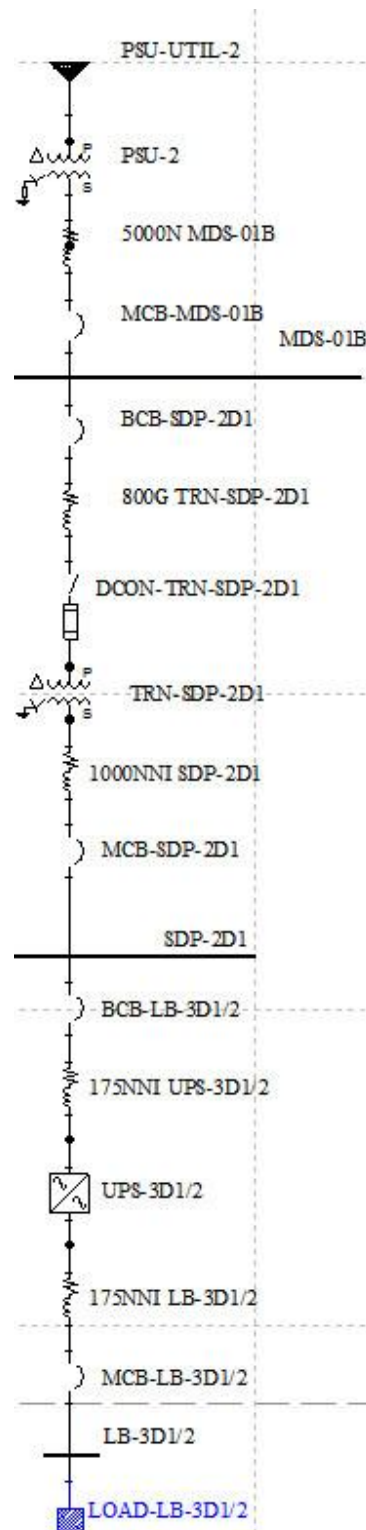


Figure 128: Short Circuit Analysis Path

DEVICE COORDINATION STUDY

■ 450A Trip MDS ■ 175A Trip SDP ■ 20A Trip BRANCH

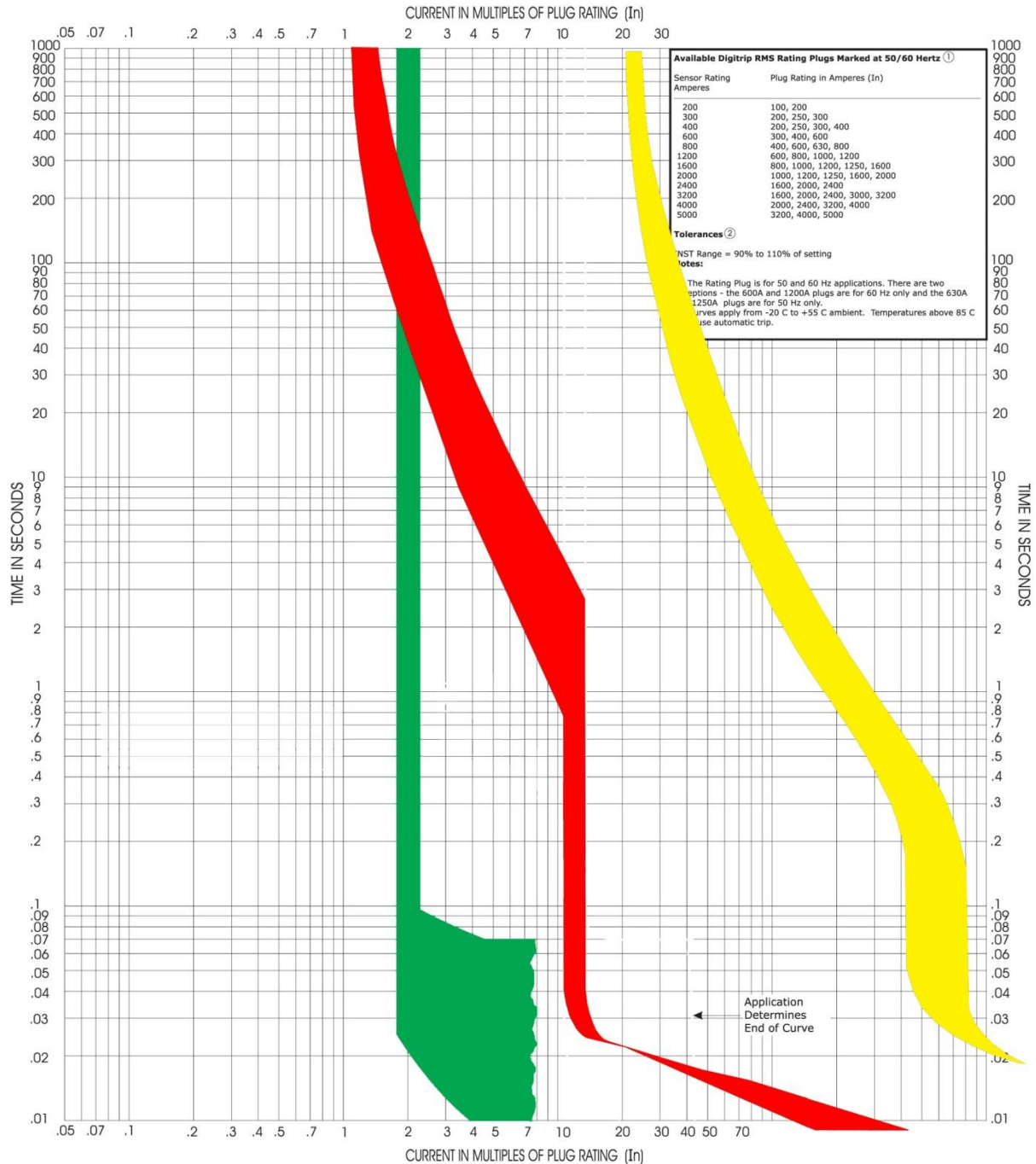


Figure 129: Device Coordination

The devices are coordinated, but there may be an issue regarding a slight over current for a long duration of time.

ELECTRICAL DEPTH TOPIC 1: SKM ANALYSIS

This electrical depth topic was performed cooperatively between the lighting/electrical 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 77 below:

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
		MDS-01B	W-P003	E2.0B-P	480/277V	5,000A	100 kAIC
	0M	MDS-02A	N-P051	E2.0MD-LP	480/277V	2,000A	100 kAIC
		MDS-02B	N-P051	E2.0MD-LP	480/277V	2,000A	100 kAIC
		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
		EDPS-1E2	N-P052	E2.0MD-LP	480/277V	800A	65 kAIC
	Level 2	SDP-2B	W-P249	E2.2B-P	480/277V	1,000A	65 kAIC
		SDP-2D	N-P258	E2.2BD-P	480/277V	1,000A	65 kAIC
		SDP-2D1	N-P238	E2.2E-P	480/277V	1,000A	65 kAIC
	Lvl 3	EDPS-3B	W-P338	E2.3B-P	208/120V	800A	65 kAIC
		EDPS-3D	N-P347	E2.3D-P	208/120V	800A	65 kAIC
	Penthouse	EDPS-M41	N-M401	E2.4C-P	480/277V	800A	65 kAIC
		EDPS-M42	N-M401	E2.4C-P	480/277V	800A	65 kAIC
		MDP-M41	N-M401	E2.4C-P	480/277V	1,000A	65 kAIC
		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.
		HMS-3B	W-P338	E2.3B-P	480/277V	100A	14 kAIC Min.
		LB-3B1/2	W-Q304	E4.3B	208/120V	225A	10 kAIC Min.
		LB-3B3/4	W-321	E4.3B	208/120V	225A	10 kAIC Min.
		LB-3B5/6	W-337	E4.3B	208/120V	225A	10 kAIC Min.
		LB-3B7	W-Q304	E4.3B	208/120V	225A/MLO	10 kAIC Min.
		LBS-3B1/2	W-Q304	E4.3B	208/120V	225A	10 kAIC Min.
		LBS-3B3/4	W-321	E4.3B	208/120V	225A	10 kAIC Min.
		LR-3B	W-P338	E2.3B-P	208/120V	150A	10 kAIC Min.
		LR-3B5/6	W-337	E4.3B	208/120V	225A	10 kAIC Min.
	3C	LS-3B	W-P338	E2.3B-P	208/120V	100A	10 kAIC Min.
		LB-3C1/2	W-Q302	E2.3C-P	208/120V	150A	10 kAIC Min.
	Level 3D	LR-3C1/2	N-Q307	E2.3C-P	208/120V	225A	10 kAIC Min.
		HL-3D	N-P347	E2.3D-P	480/277V	200A	14 kAIC Min.
		HM-3D	N-P347	E2.3D-P	480/277V	100A	14 kAIC Min.
		HMS-3D	N-P347	E2.3D-P	480/277V	100A	14 kAIC Min.
		LB-3D1/2	N-361	E4.3D	208/120V	175A	10 kAIC Min.
		LB-3D5/6	N-361	E4.3D	208/120V	175A	10 kAIC Min.
		LB-3D7/8	N-361	E4.3D	208/120V	175A	10 kAIC Min.
		LBS-3D1/2	N-Q304	E4.3D	208/120V	225A	10 kAIC Min.
		LBS-3D5/6	N-361	E4.3D	208/120V	225A	10 kAIC Min.
		LR-3D1/2	N-P346	E2.3D-P	208/120V	225A	10 kAIC Min.
		LR-3D3/4	N-P346	E2.3D-P	208/120V	225A	10 kAIC Min.
		LS-3D	N-P347	E2.3D-P	208/120V	100A	10 kAIC Min.
Distribution Equipment	Lvl	Name	Location	Enl. Plan	Rating	Poles/Ph/Voltage	Series Rating
	Mezzanine	ATS-HS1	N-P052	E2.0MD-LP	800 A	4P, 480V	65 kAIC
		ATS-HS2	N-P052	E2.0MD-LP	800 A	4P, 480V	65 kAIC
		ATS-HS3	N-P052	E2.0MD-LP	800 A	4P, 480V	65 kAIC
		ATS-HS4	N-P052	E2.0MD-LP	800 A	4P, 480V	65 kAIC
	Lvl 2	TRN-SDP-2B	W-P249	E2.2B-P	300 kVA	480Δ - 208Y/120V	N/A
		TRN-SDP-2D	N-P258	E2.2D-P	300 kVA	480Δ - 208Y/120V	N/A
		TRN-SDP-2D1	N-P238	E2.2E-P	300 kVA	480Δ - 208Y/120V	N/A
	Level 3	TRE-EDPS-3B	W-P338	E2.3B-P	225 kVA	480Δ - 208Y/120V	N/A
		TRE-EDPS-3D	N-P347	E2.3D-P	225 kVA	480Δ - 208Y/120V	N/A
		UPS-3D-1/2	N-361	E4.3D	50 kVA	N/A	Unknown
		UPS-3D-5/6	N-361	E4.3D	50 kVA	N/A	Unknown

	Lvl	Name	Location	Motor Size	Sizing Remarks	Not Used
Mech. Equipment	Penthouse	ACF-1	N-M401	100 hp	200 A MCP, 175 A FS	-----
		ACF-2	N-M401	100 hp	200 A MCP, 175 A FS	-----
		ACF-3	N-M401	100 hp	200 A MCP, 175 A FS	-----
		ACF-4	N-M401	100 hp	200 A MCP, 175 A FS	-----
		ACF-5	N-M401	100 hp	200 A MCP, 175 A FS	-----
		ACF-6	N-M401	60 hp	110 A MCP, 100 A FS	-----
		ACF-7	N-M401	60 hp	110 A MCP, 100 A FS	-----
		ACF-8	N-M401	60 hp	110 A MCP, 100 A FS	-----

Table 77: SKM Equipment Schedule

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 130 below shows the library and component editor overlaid on the one-line diagram for a bus that is used as main switchgear.

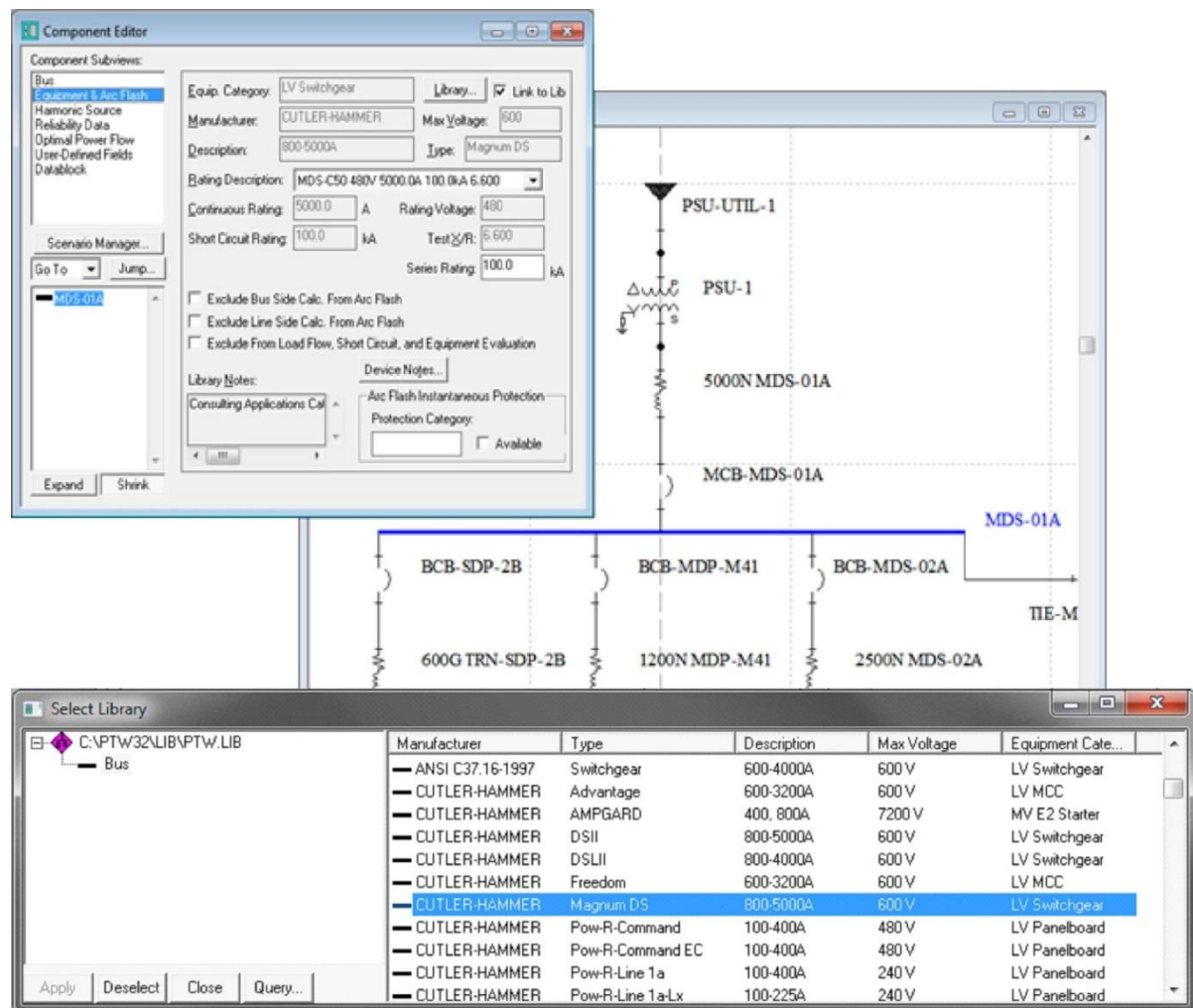


Figure 130: MDS-01A Equipment Inputs

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 131 below:

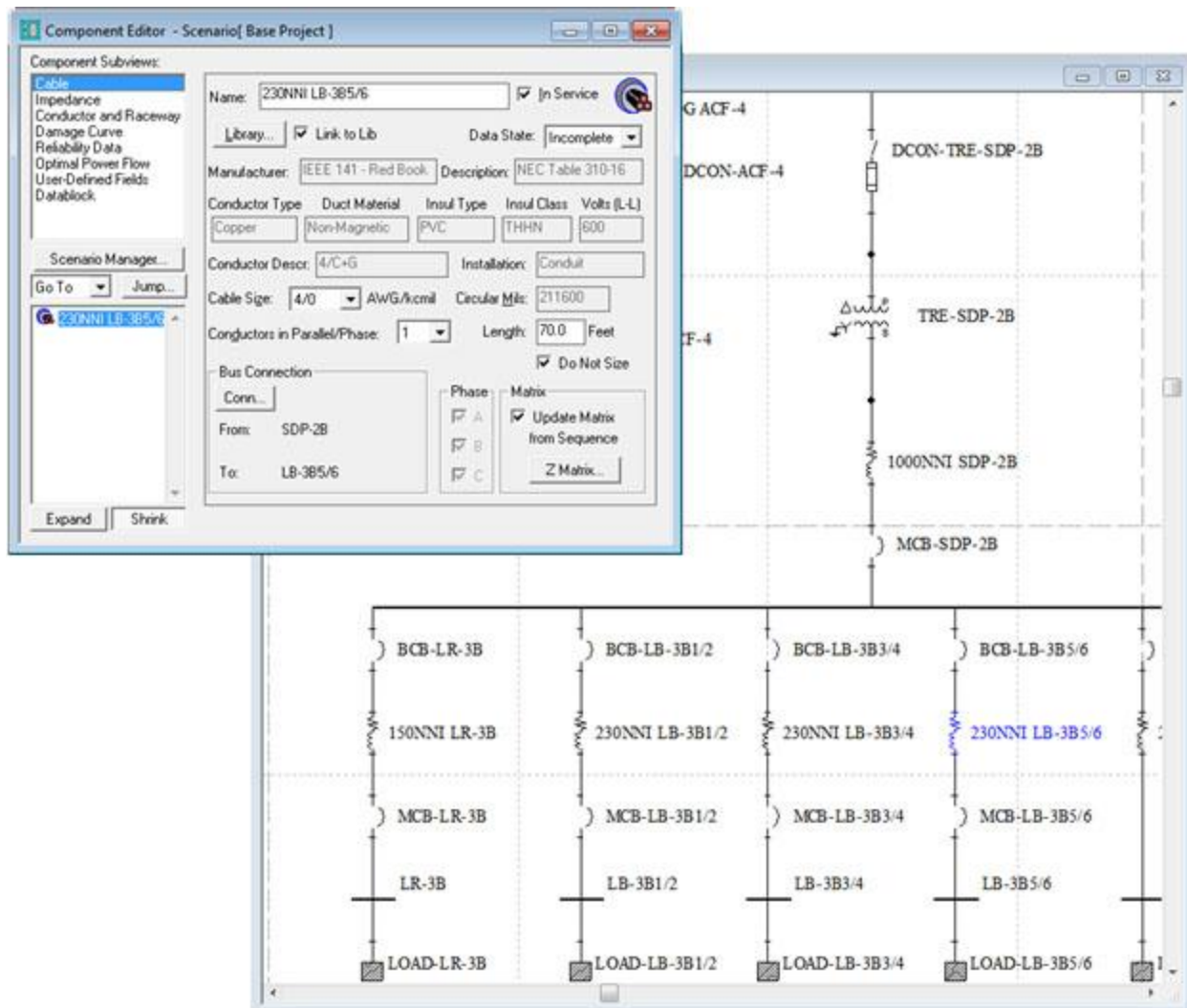


Figure 131: Wire Sizing in SKM

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 132 below:

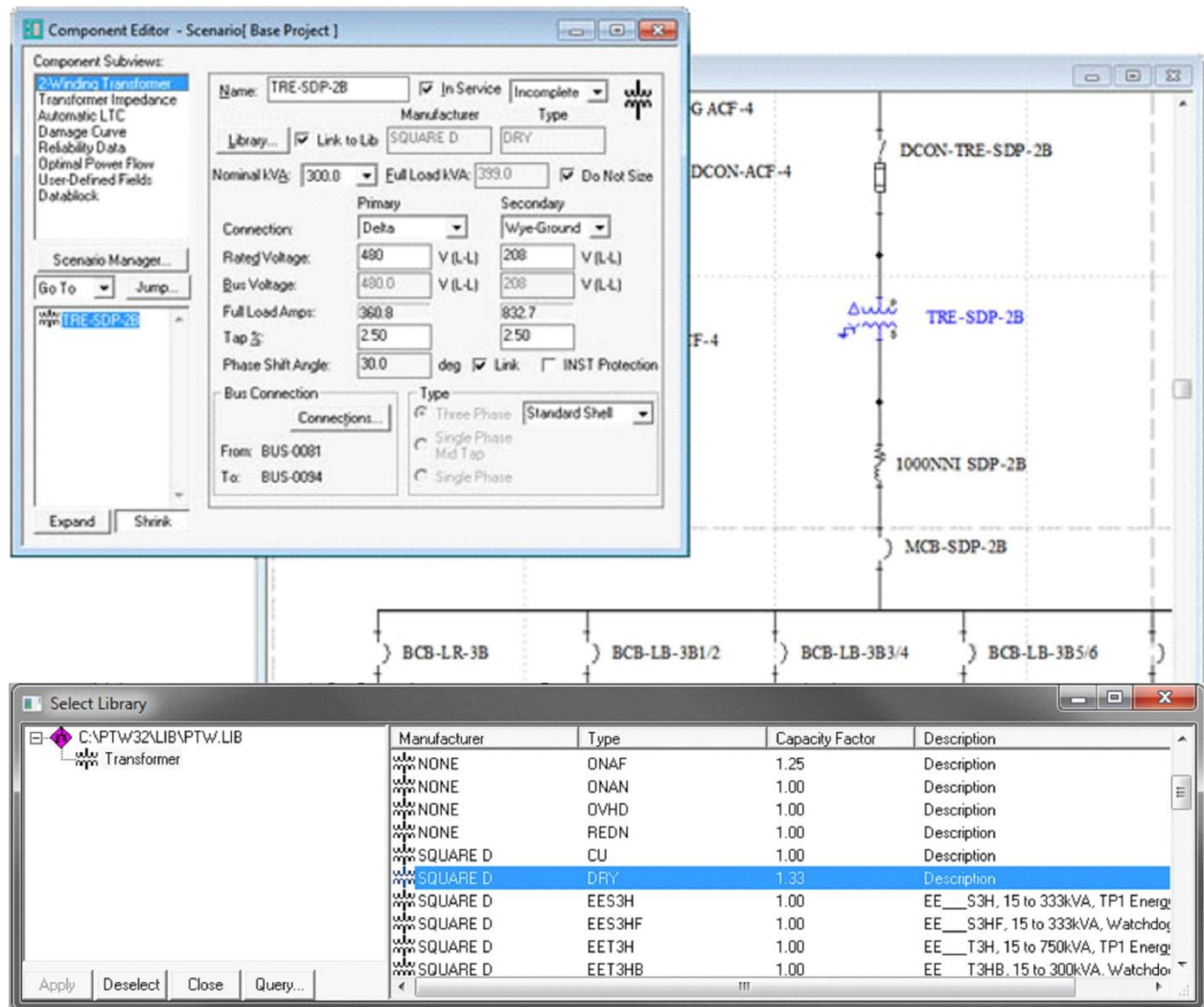


Figure 132: Transformer Inputs in SKM

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. Figures 133-134 below illustrate the inclusion of an induction motor load and non-motor panelboard load for the third floor of the Millennium Science Complex.

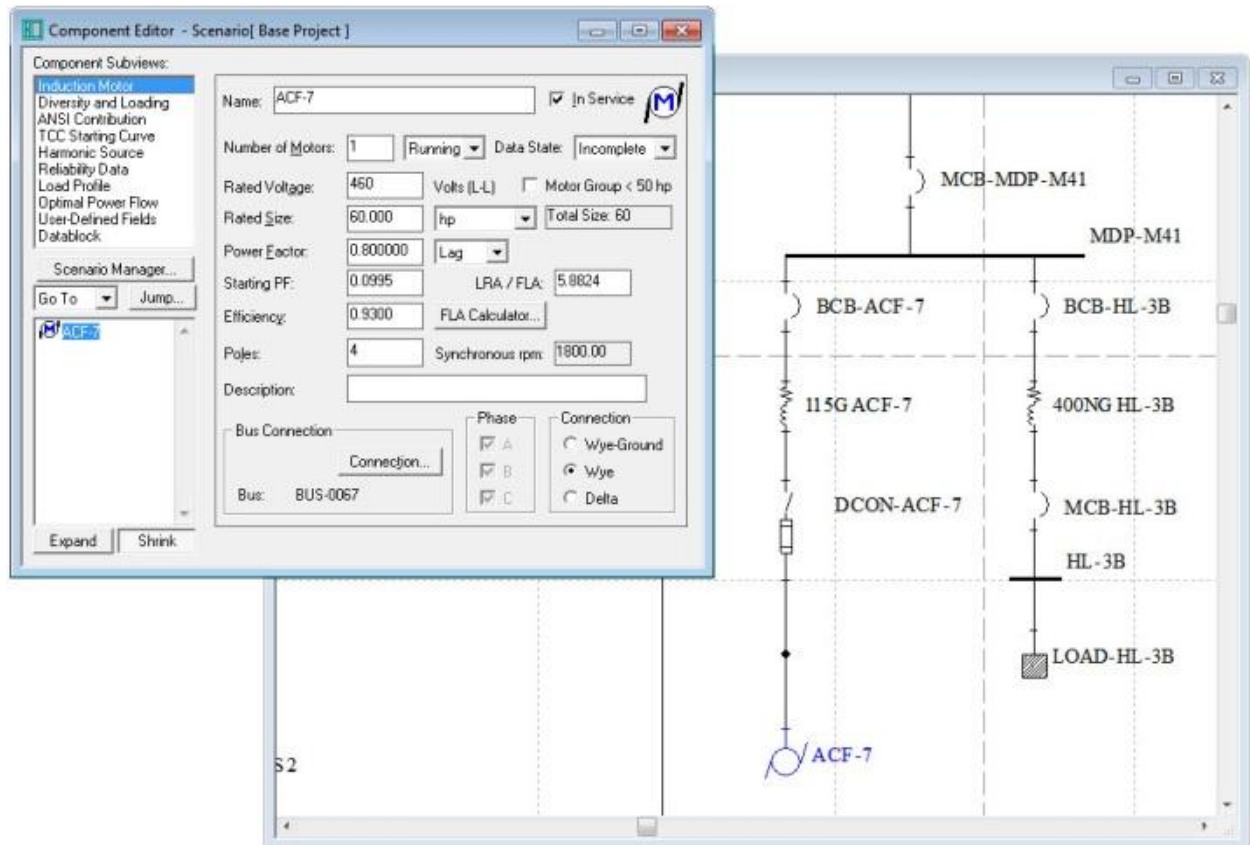


Figure 133: Induction Motor Inputs in SKM

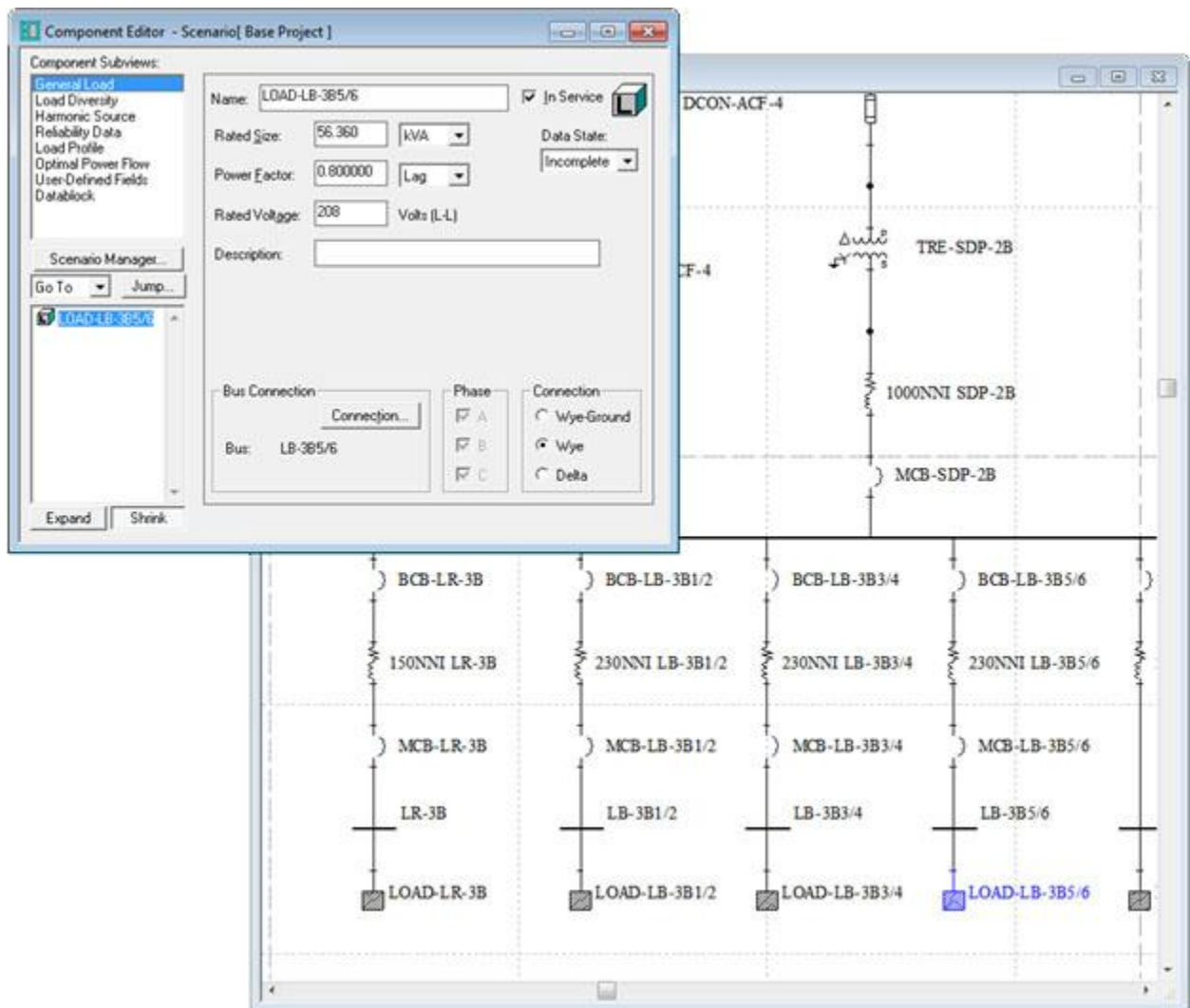


Figure 134: Non-Motor Load Inputs in SKM

Thomas Villacampa

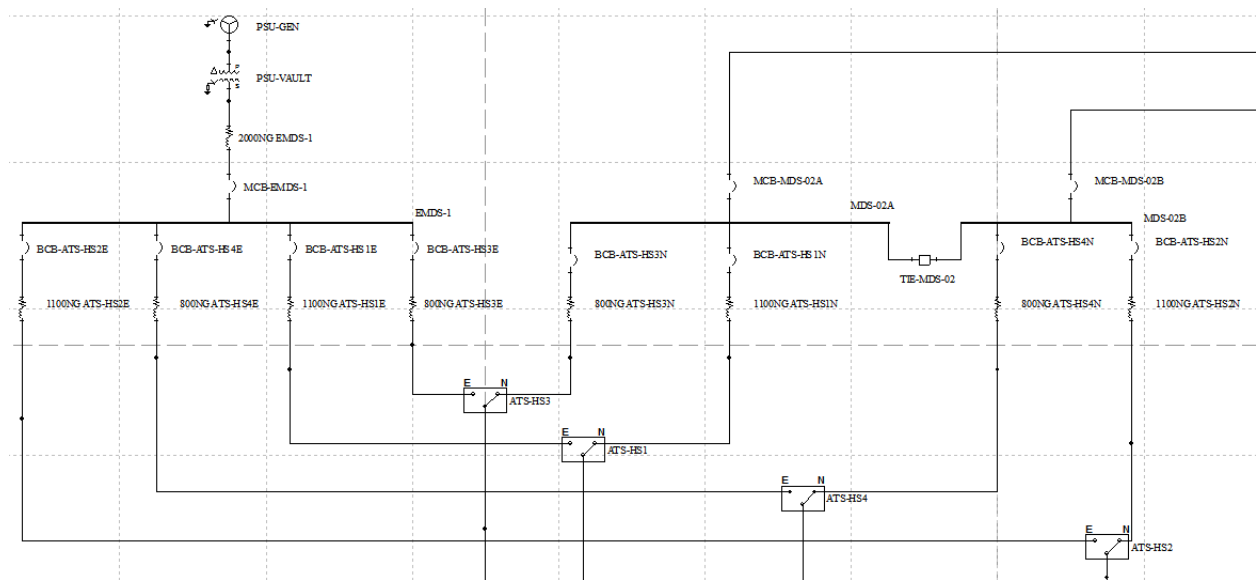


Figure 137: EMDS-1, MDS-02A, and ATSS One-Line Diagram

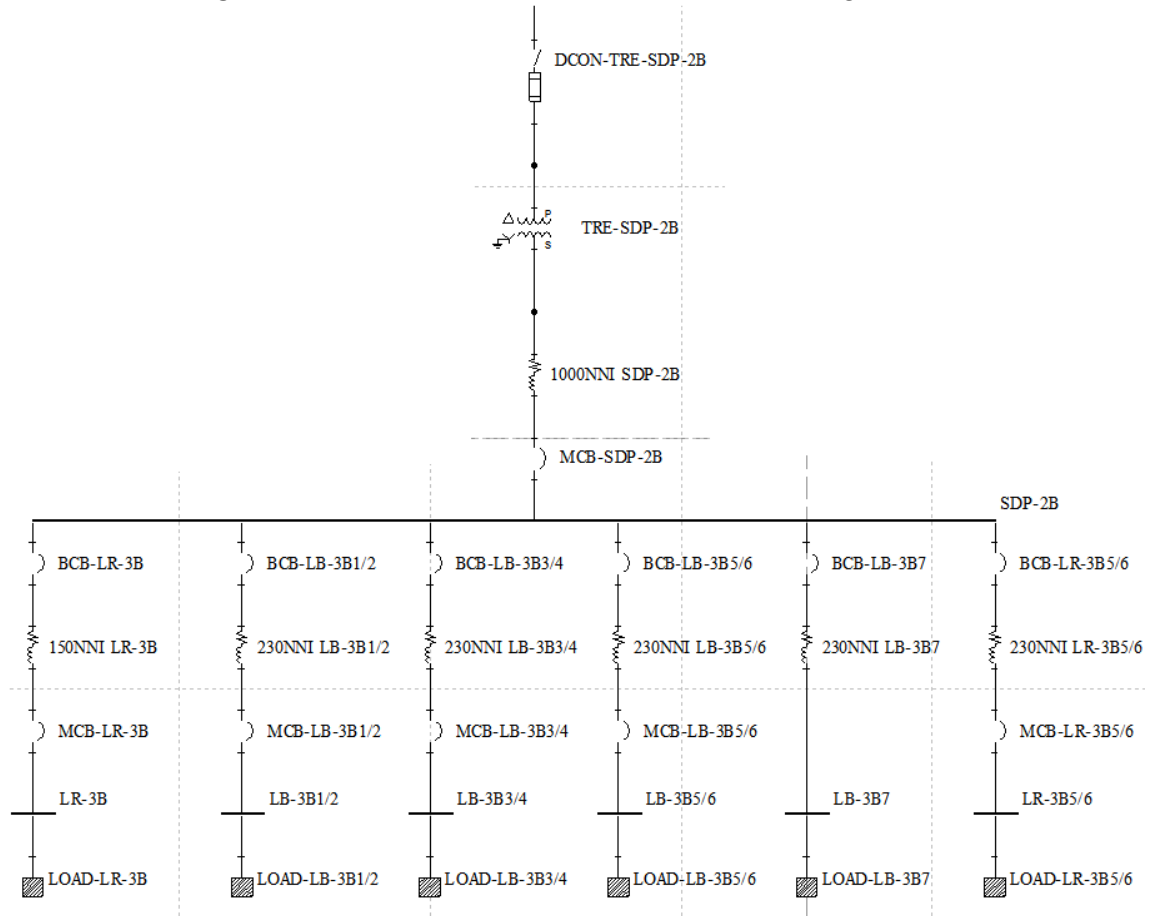


Figure 138: SDP-2B and Loads One-Line Diagram

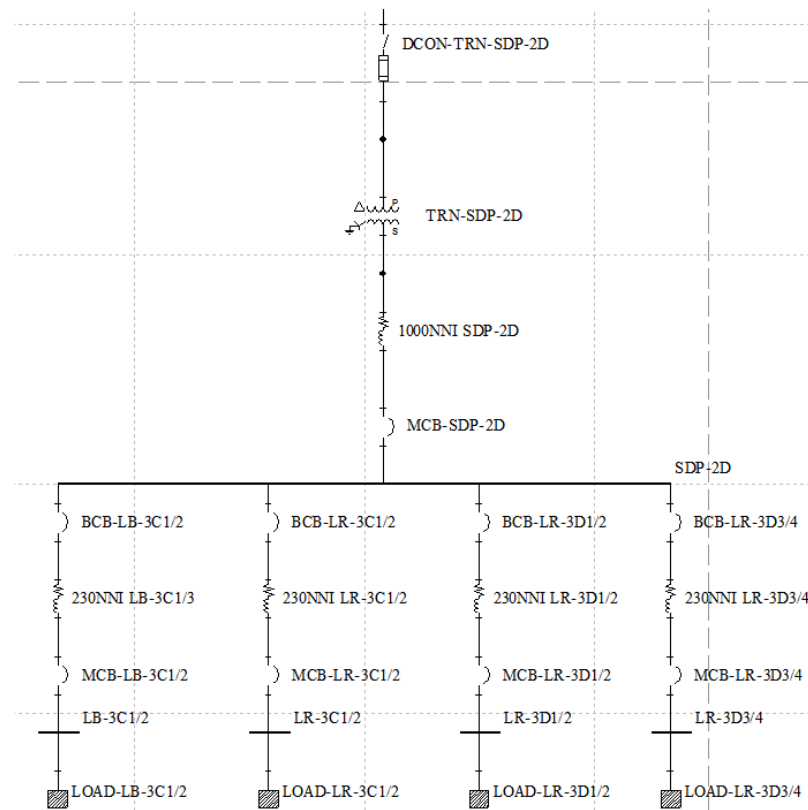


Figure 139: SDP-2D and Loads One-Line Diagram

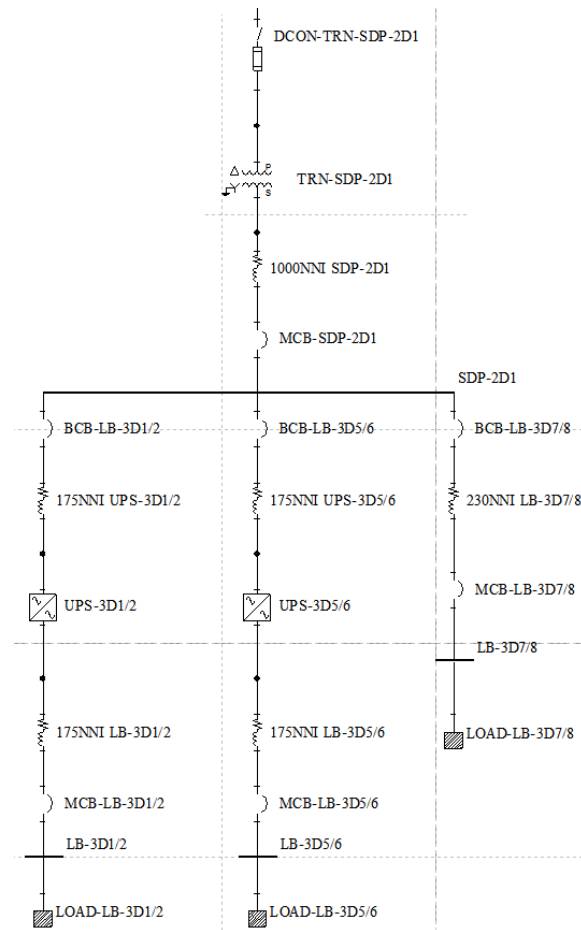


Figure 140: SDP-2D1 and Loads One-Line Diagram

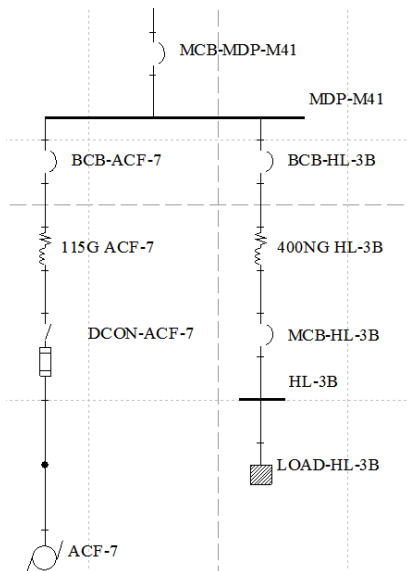


Figure 141: MDP-M41 and Loads One-Line Diagram

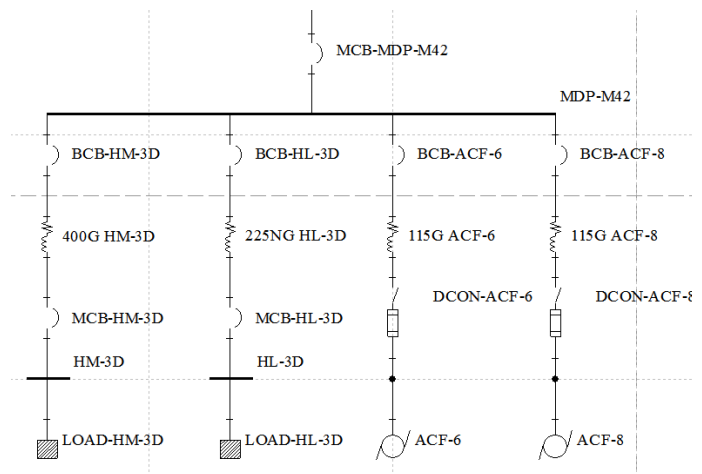


Figure 142: MDP-M42 and Loads One-Line Diagram

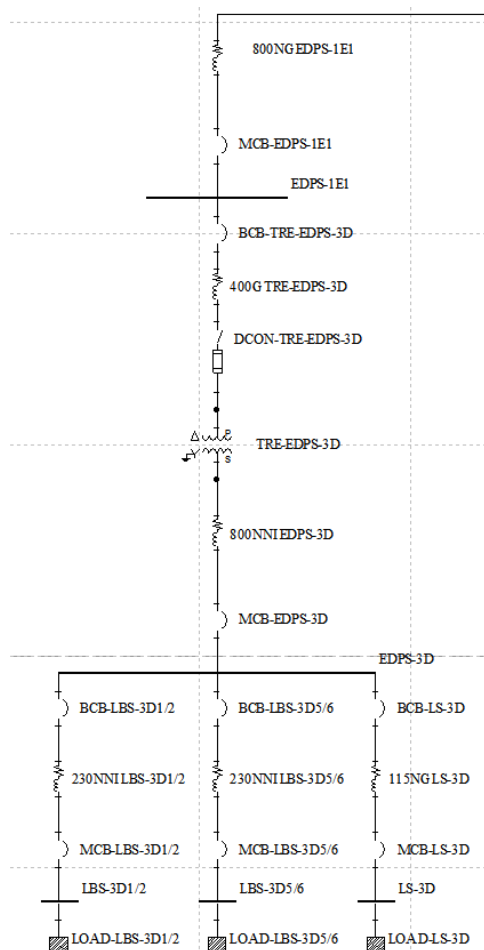


Figure 143: EDPS-1E1 and Loads One-Line Diagram

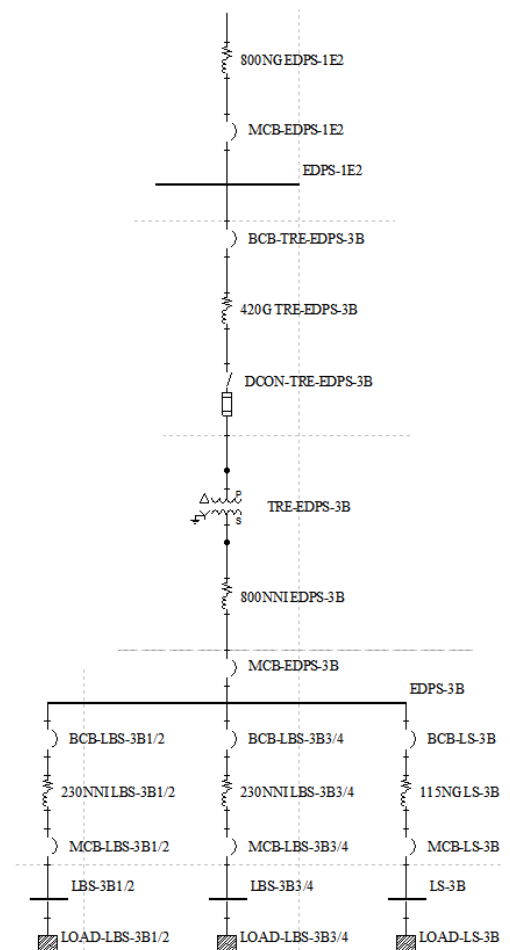


Figure 144: EDPS-3B and Loads One-Line Diagram

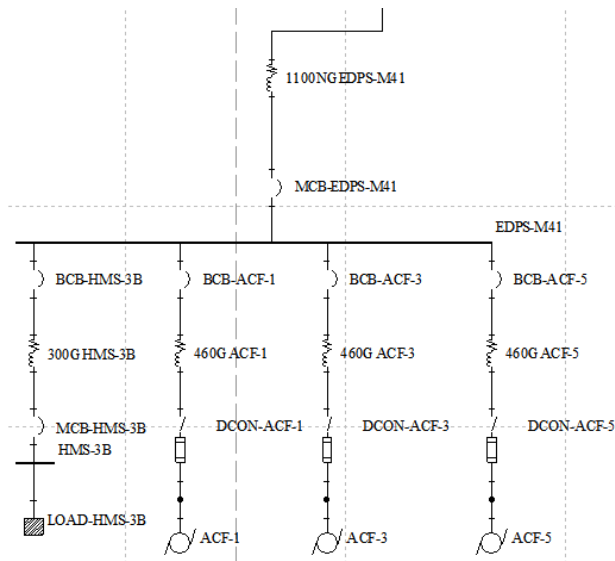


Figure 145: EDPS-M41 and Loads One-Line Diagram

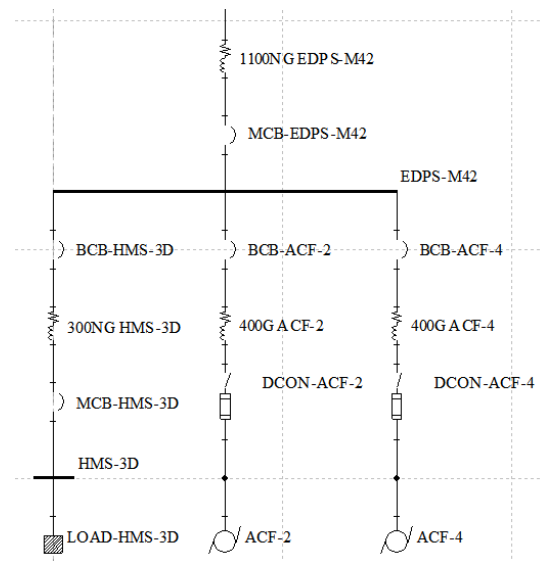


Figure 146: EDPS-M41 and Loads One-Line Diagram

Once the one-line diagram is finalized in the model 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 from utility transformer PSU-1 and 34,372A from utility transformer PSU-2 to the system. The impedance values of the transformers are summarized in Table 78 below.

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

Table 78: Transformer Impedance Summary

Based on the impedances of the transformer tables above, the analyses can be performed and summarized in reports compiled by SKM Power Tools. These reports appear as text documents – file extension .rpt or .rp2 – but can be printed to PDF if the user has that type of converter installed on his or her machine. For simplicity and to conserve space, the SKM report will not be included in this document, but a summary has been composed in table format. Bus short circuit results from the SKM analysis can be seen in Table 79 below.

Fault Analysis Summary					
Bus Name	Voltage	Available Fault Current			
		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

Table 79: SKM Short Circuit Report Summary

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 79 above 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 panelboards (H-prefix) are currently rated for 14,000 AIC. The two HMS panelboards 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.

ELECTRICAL DEPTH TOPIC 2: UPS VS. POWER CONDITIONER

The Millennium Science Complex currently uses nineteen (19) Eaton Powerware 9390 50kVA, 208/120V UPS modules without battery cabinets. Each UPS serves 2 adjacent panelboards. This depth will compare the current system with that of using a 1000kVA Cutler-Hammer Sag Ride Through (SRT) Power Conditioner. The use of a central power conditioning device will also result in the addition of a new distribution panel. The new distribution panel will be the same type as the other typical panels (1200A, 120/208V, 3phase, 4 wire, 65KAIC, with a 200% rated neutral, and isolated ground), and fed from switchboard “MDS-01B.” In order to meet space requirements the Power Conditioning Device and additional panel would need to be located in a new room requiring an architectural change. For the purpose of this depth topic the location for the new devices would be the Electrical Closet N-P129A on the first floor. The cost comparison can be found in Tables 80-84.

Equipment	#	Cost/per	Total
Eaton 9390-50 208V IN & Out UPS w/out Battery	19	\$ 35,000.00	\$665,000.00

Table 80: Existing Equipment Cost

Panel	Run Length	Phase Conductor	#	Material Cost (lf)	Labor Cost (lf)	Neutral	#	Material Cost (lf)	Labor Cost (lf)	Isolated Ground	#	Material Cost (lf)	Labor Cost (lf)	Conduit Size (in)	Material Cost (lf)	Labor Cost	Total Cost
LB-0C1	150	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 5,901.00
LB-0C3	190	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 7,474.60
LB-0C5	170	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 6,687.80
LB-0C7	190	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 7,474.60
LB-0C9	215	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 8,458.10
LB-0C11	330	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 12,982.20
LB-0C13	230	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 9,048.20
LB-0C17	120	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 4,720.80
LB-1D1	170	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 6,687.80
LB-1E5	360	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 14,162.40
LBS-1E3	210	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 8,261.40
LB-2D1	140	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 5,507.60
LB-2D3	140	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 5,507.60
LB-2D5	60	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 2,360.40
LB-2D6	60	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 2,360.40
LB-2D9	160	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 6,294.40
LBR-0C11	260	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 10,228.40
LB-3D1	70	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 2,753.80
LB-3D5	70	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 2,753.80
																	\$129,625.30

Table 81: Existing Feeder Material and Labor Cost

Equipment	#	Cost/per	Total
Eaton Sag Ride Through SRT21000208AB	1	\$250,000.00	\$250,000.00
Pow-R-Line 4 Panelboard (1200A, 120/208V, 65KAIC)	1	\$ 5,000.00	\$ 5,000.00

Table 82: New Equipment Cost

Panel	Run Length	Phase Conductor	#	Material Cost (lf)	Labor Cost (lf)	Neutral	#	Material Cost (lf)	Labor Cost (lf)	Isolated Ground	#	Material Cost (lf)	Labor Cost (lf)	Conduit Size (in)	Material Cost (lf)	Labor Cost	Total Cost
LB-OC1	540	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 21,243.60
LB-OC3	510	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 20,063.40
LB-OC5	420	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 16,522.80
LB-OC7	450	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 17,703.00
LB-OC9	470	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 18,489.80
LB-OC11	360	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 14,162.40
LB-OC13	430	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 16,916.20
LB-OC17	580	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 22,817.20
LB-1D1	160	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 6,294.40
LB-1E5	120	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 4,720.80
LBS-1E3	90	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 3,540.60
LB-2D1	200	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 7,868.00
LB-2D3	210	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 8,261.40
LB-2D5	280	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 11,015.20
LB-2D6	290	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 11,408.60
LB-2D9	190	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 7,474.60
LBR-OC11	380	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 14,949.20
LB-3D1	260	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 10,228.40
LB-3D5	270	#2/0	3	\$ 2.71	\$ 1.39	#2/0	2	\$ 2.71	\$ 1.39	#6	2	\$ 0.55	\$ 0.62	2	\$ 7.55	\$ 8.95	\$ 10,621.80
NEW DP	710	#600	6	\$ 15.00	\$ 3.10	#600	2	\$ 15.00	\$ 3.10	#1/0	2	\$ 3.65	\$ 1.22	3.5	\$ 21.50	\$ 18.30	\$166,239.40
																	\$ 410,540.80

Table 83: New Feeder Cost

Estimated Voltage Drop Calculator

Input

Load Voltage: 208V 3Ø
 Conductor Size: 2/0
 Conductor Type: Cu ☒ Al ☐
 Number of Sets: 1
 Distance (one way): 470 Feet
 Load (A): 9.25 A

Output

Unity Power Factor: 85% PF

Voltage Drop (V): 0.8 V
 Voltage Drop (%): 0.4 %
 Voltage at Load: 207.2 V

Minimum Conductor Size for 3% VD: 8
 Minimum Conductor Size for 5% VD: 10

Figure 147: LB-OC9 Voltage Drop

Estimated Voltage Drop Calculator

Input

Load Voltage: 208V 3Ø
 Conductor Size: 2/0
 Conductor Type: Cu ☒ Al ☐
 Number of Sets: 1
 Distance (one way): 270 Feet
 Load (A): 44.275 A

Output

Unity Power Factor: 85% PF

Voltage Drop (V): 2.1 V
 Voltage Drop (%): 1.0 %
 Voltage at Load: 205.9 V

Minimum Conductor Size for 3% VD: 3
 Minimum Conductor Size for 5% VD: 4

Figure 148: LB-3D5 Voltage Drop Check

Overall Price Comparison	
System	Total Price
Existing Eaton Powerware UPSs	\$794,625.30
New Eaton SRT Central Power Conditioning	\$665,540.80

Table 84: Overall Cost Comparison

This study resulted in a cost savings of \$129,084.50, but through further analysis it was determined the original design using individual UPS would be more beneficial. Older drawing sets call for UPSs without the note saying the without battery racks. This shows that the removal of batteries may have been an upfront cost issue. If that were the case then the newly redesigned system with an Eaton SRT Central Power Conditioner would be most cost efficient than the installed system. However the installed system provides future backup availability. Some of the laboratories served by the individual UPSs still aren't assigned. If the lab equipment were to require backup power then the addition of batteries in the UPS would be cheaper than purchasing a new \$35,000 UPS with the additional cost of the battery rack. For future growth purposes and minimal savings it was decided that the existing system should remain.

IPD / BIM Lessons Learned

BIMception formed as a group to execute thesis as an integrated team. The designs selected for analysis were areas of the Millennium Complex that had the best opportunities to include and benefit from multidisciplinary evaluation. Integrated design was supported by building information modeling. BIM served as the tool that quickly and effectively allowed BIMception to communicate and produce our design concepts. The final product that we have delivered in this product was greatly enhanced and molded by our team focus. BIMception's motto is "improving design through innovation and coordination" and both the IPD process and BIM tools were integral to helping us achieve our goals.

INTEGRATED PROJECT DELIVERY EVALUATION

BIMception established regularly scheduled meetings every week. While these meetings were documented in the meeting minutes, the informal "meetings" that happened every day were much more valuable. The team performed best when members took initiative to stay in constant communication. This open line of communication allowed the team to stay on top of production and design developments.

The team's performance was hurt early in the semester before normal work habits were changed. Working in silos, prevented the team from communicating important changes in design. Oftentimes these changes would be relayed at the end of a process, forcing analyses to be run multiple times with crucial data having to be changed and re-input. Integrated design in this case caused much more work for all members, and any BIM process still required manual inputs of information.

A more vocal team atmosphere solved many of the issues created by the lack of communication. Rather than running an entire individual analysis and relaying to the team the final results, the communication and explanation of each analysis was conveyed to the team with the intentions of gaining feedback before an error was made. This effectively reduced the number of analyses that had to be rerun.

Some issues were unable to be avoided, and may simply be caused by the use of integrated design. Relying on other team members for information inherently affects one's individual design process. If one delivery item to another team member becomes a day late, it has the effect of snowballing throughout the whole team causing each integrated process schedule to be off track. As described above, early communication solves this issue more often than not, but unexpected developments are almost guaranteed to affect any design process.

By the end of the semester, team members were able to prepare and anticipate information exchanges. The team was able to work more fluidly as we communicated our needs more timely and effectively. If the team was to restart the spring semester, BIMception would reach the same conclusions, but in a small fraction of the time. Unfortunately there is no better way to understand an interdisciplinary process than to be a part of a committed integrated team like BIMception.

Even though integrated project delivery required additional time and analysis, it created a more complete building product. The inclusion of each discipline revealed topics that may have been overlooked in silo design. In this manner, each member was able to use their expertise to achieve BIMception's design goals. Understanding the contributions of each team member, allowed the building to realize benefits from discipline compromises. Integrated project delivery balanced individual focuses, leading to a whole building solution that reflects the contributions of each discipline.

BIM EX PLAN

The Penn State BIM Execution Plan laid out the foundation for how *BIMception* organized our interdisciplinary research. Each analysis was preplanned and orchestrated throughout the team. While this plan was developed without a full understanding of how each piece of research would actually proceed, it produced a template and a plan to help the team achieve its goals. Throughout the semester the team learned how to execute the plan and how each member's contributions affected the final design. The BIM EX Plan effectively guided *BIMception* towards its final goals, through processes the team had never experienced.

BUILDING INFORMATION MODELING EVALUATION

Building Information Modeling is the collective set of tools that enabled *BIMception* to create and engineer our alternative designs. Modeling each discipline's designs allowed the coordination and sharing of important design criteria and information. Each model that was created served a specific purpose towards developing this final report and achieving team goals.

BIMception effectively utilized the following BIM Uses as prescribed by the BIM EX Plan: Building System Analysis, Cost Estimation, 4D Modeling, Engineering Analysis, Design Reviews, 3D Coordination, and Energy Analysis.

The existing Revit models, provided by Raphael Vinoly Architects, Flack and Kurtz, and Whiting Turner, enabled *BIMception* to establish baseline conditions for each analysis. As redesigns were developed, models were created to reflect these evolving ideas. Design information was input into the models and the learning process began as *BIMception* experimented with new processes.

Model expectations and building methods evolved as the team tried to move further into design. The structural models had to be rebuilt multiple times to facilitate the next step in producing final documentation. For the 4D modeling, the structural slabs had to be broken up, reflecting the construction pours. For the final presentation, new worksets had to be created, enabling the model to be broken up for visualizations.

In order to energy model, there was a great effort to share project design information through our models. Revit models were created with spaces that had crucial information fields for energy analysis. With the input of our mechanical and electrical engineers' design standards, the model successfully exported embedded building information. When opened for analysis in Trane TRACE, the model retained such important information as room names, floor areas, occupancy, lighting power densities, and equipment load densities. This information would be the basis of our load calculations, energy analysis, and system analysis. The model was unable however to transfer accurate information about the roof areas and exterior walls, which were later manually updated. These errors stem from the creation methodology and complexity of the architecture model, requiring a significant time investment to ensure their correctness. Despite the transfers short comings, it effectively reduced the total amount of time require to produce the energy model that became the basis for all energy analyses.

There were some limitations with the BIM concept for the lighting and electrical redesigns. The lighting calculations from Revit were evaluated in the Lighting/Electrical collaborative Technical Report 1 and some inconsistencies were discovered. The illuminance values didn't match up with those from lighting calculation programs, such as AGi32. For this reason all lighting calculations were done in using a

program whose information could not be linked back into the group models. Due to electrical requirements, worksheets and established panelboard templates, from the electrical consultant electrical changes were not relayed back into the group models. These factors created a disconnect in the lighting and electrical work with the established BIM hierarchy. While there were limitations, the BIM models did provide valuable information for creating lighting models utilized for graphics and calculations. The updated façade architecture model provided building geometry to be utilized in calculations and rendering programs.

Building Information Modeling and Management enhanced the validity of BIMception's designs providing the necessary tools to communicate and engineer our new concepts. While we struggled with new workflows and design processes, information modeling allowed the integrated team to work across disciplines. The modeled design content was easily shared and utilized to coordinate designs and produce analyses or visuals. Building information modeling facilitated the successes and building improvements created by integrated project delivery for the Millennium Science Complex.

Final THESIS Conclusion

BIMception was dedicated to improving design through innovation and coordination. The redesigns of the Millennium Science Complex were highlighted by more energy efficient designs, coordinated system integration, life cycle cost improvements, and a higher valued final building product. The integrated design approach of IPD, allowed each member to incorporate their expertise early in the design phase, while BIM became the tool allowing the team to quickly validate and communicate new design concepts.

Each of the three main areas of focus realized improvements from integrated design:

1. Analysis of the building envelope reduced energy consumption and improved daylight delivery system
2. Investigation into the ceiling plenum space reduced structural profile depth allowing for reductions in energy consumption and improvements in systems coordination
3. Evaluation of the cantilever plaza improved the efficiency of the truss system, creating an architectural statement enhanced by the lighting redesign

One of the primary construction goals was to find a way to accelerate the schedule. This was done by taking advantage of the new sequencing opportunities provided by the redesigned concrete structure. Integration of the cantilever and concrete wing construction allowed for a significant reduction in project schedule. While cost increased, value was added to the Millennium Science Complex through system redesigns.

By redesigning a concrete floor system for the wings a more flexible and coordinated ceiling plenum allowed the redesign of a more efficient mechanical duct system. Structural modifications to the building façade system reduced the amount of structural weight necessary to enclose the building. An addition to the cantilever truss system added efficiency, saving on steel tonnage and cost. This change integrated with the cantilever plaza created an appealing architectural progression of angles that effectively unified structure, architecture, and lighting design.

The lighting redesign of the Millennium Science Complex student areas, private office, and cantilever utilizes energy efficient luminaires. The lighting design reinforces the architectural theme and BIMception's goals of a cost effective, energy efficient system. The illuminance values, Table 85, meet all IESNA recommendations. The higher values for the cantilever plaza are due to the desire to create illuminance ratios between points of interest.

<i>Space</i>	<i>IESNA Recommendation (fc)</i>	<i>Design Illuminance (fc)</i>	<i>LPD (w/ft²)</i>
<i>Student Area</i>	30 fc	34 fc	0.78 W/ft ²
<i>Corridor</i>	5 fc	21.7 fc	0.40 W/ft ²
<i>Office</i>	30 fc	31 fc	0.84 W/ft ²
<i>Cantilever Plaza Pathway</i>	1 fc	2.3 fc	0.44 w/ft ²
<i>Cantilever Plaza Sidewalk</i>	5 fc	12.4 fc	0.44 w/ft ²
<i>Sky Glow</i>	-	5 fc	0.44 w/ft ²

*LPD Values For Cantilever Plaza Based On The Whole Space

Table 85: *Millennium Science Complex Lighting Redesign Summary*

The energy analysis of all alternative design options, including triple pane glazing, a 60% window to wall ration, lighting space redesigns, and duct size redesign, produces a 14% savings compared to the existing design. The life cycle value of the design can be improved by about a half million dollars and a simple payback of about two years proves feasible.

Yearly Energy Savings by Alternative

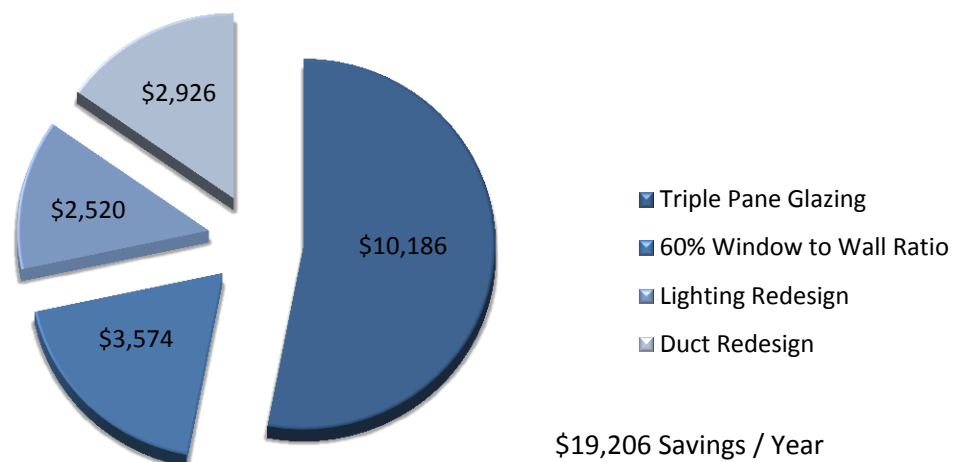


Figure 149: *Yearly Energy Savings Cost Analysis*

	<i>Existing Design</i>	<i>All Alternative Designs</i>	<i>Savings</i>
--	------------------------	--------------------------------	----------------

<i>Total Yearly Operating Costs</i>	\$154,262	\$135,056	\$19,206
<i>Installation Costs</i>	\$1,688,026	\$1,730,213	\$-42,187
<i>30 yr Life Cycle Cost</i>	\$5,663,480	\$5,210,708	\$452,772

Table 86: *Combined Alternative Life Cycle Cost Analysis*

APPENDIX A: MAE/BAE Requirements

MECHANICAL MAE

In order to fulfill the requirements established for the MAE program, the exterior façade was investigated with material taught in AE 542 – Building Enclosure Design and Science. This class analyzes the effects the enclosure can have on the control of thermal transfer and structural loading. Knowledge learned in this class guided the evaluation and analysis of the existing façade's heat and moisture transfer characteristics, as seen in pages 23-28. A redesigned façade incorporates the concepts of cavity wall design, moisture control, thermal transfer, and phase change materials, as seen in pages 31-34.

In addition, knowledge learned in AE558 – Centralized Heating Production and Distribution Systems enabled much iteration of economic modeling and system lifecycle costing. The evaluation of dynamic investment allowed for a comparison of first installed and energy costs. This understanding helped provide validity to design selections, as seen in page 41.

STRUCTURAL MAE

To adequately represent the knowledge base of an integrated MAE/BAE student in the field of building structures, analyses and redesigns of the gravity system, lateral system, and cantilever redesigns incorporated specific advanced techniques of structural modeling learned in AE597A and advanced seismic considerations learned in AE538.

Multiple iterations of models within SAP2000 used advanced area and frame meshing and used dynamic modal analysis to calculate period of vibrations of typical bays within the existing and redesigned floor systems to calculate vibrational criteria and help compare the effectiveness of all design iterations. The cantilever truss system redesigns involved critical meshing between shell and frame elements and stiffness comparison analysis. A proper understanding of element contribution to overall truss stiffnesses pulled material from the most critical lessons of stiffness definitions from AE597A. These focuses are highlighted in existing and redesign vibration modeling sections within the Plenum Investigation and within the entirety of the structural truss redesigns in the Cantilever Redesign discussion.

In checking the existing lateral system for strength and drift limitations, knowledge about seismic analysis according to ASCE7-05 was pulled from AE538 including more advanced analysis of horizontal and vertical structural irregularities. Modeling lessons from AE597A also helped when creating the ETABS lateral models when defining rigid diaphragms and applying additional area masses lumped at the story levels. These focuses are highlighted in check of the existing lateral system and the lateral system redesign sections within the Plenum Investigation.

APPENDIX B: List of Tables and Figures

Figure 1: View of Millennium Science Complex from corner of Pollack and Bigler Roads courtesy of the Huck Institute at Penn State	8
Figure 2: Mockup of building enclosure, including precast panels courtesy of Ryan Solnosky	9
Figure 3: Model of typical steel framing layout	10
Figure 4: Layout of existing lateral system elements on first floor	11
Figure 5: Gravity load simulation in cantilever truss along Frame B. Red and blue denote tension and compression respectively.	12
Figure 6: Bing Map of Millennium Science Complex Site	15
Figure 7: Map of Material Delivery Route	16
Figure 8: Whiting-Turner Staffing Plan	19
Figure 9: Exploded View of Existing Façade Panel Composition	23
Figure 10: 3D Render and Section of Existing Façade Composition	24
Figure 11: HAM Condensation Analysis of Existing Wall – Winter Condition – No Vapor Barrier	25
Figure 12: HAM Condensation Analysis of Existing Wall – Winter Condition – Vapor Barrier	26
Figure 13: Evaluation of Condensation Potential of Existing Wall – Winter Condition – No Vapor Barrier	27
Figure 14: Conduction Time Series Factor of Existing Wall	28
Figure 15: Structural Load Cases: Left- Flexure Due to Wind, Right- Flexure Due to Dead Loads	30
Figure 16: Exploded View of Alternate PCM Façade Panel Composition	31
Figure 17: 3D Render and Section of Alternate PCM Façade Panel Design	32
Figure 18: Condensation Analysis of Redesigned Wall – Winter Conditions	33
Figure 19: Conduction Time Series Factor – Redesigned Wall	34
Figure 20: Structural Load Case: Bending Due to Self-Weight During Precast Fabrication.	35
Figure 21: Millennium Science Complex Third Floor Daylight Autonomy 322.8 lux	45
Figure 22: West Façade Existing Useful Illuminance	50
Figure 23: West Façade 60% WWR Useful Illuminance	50
Figure 24: Lighting/Electrical Window to Wall Ratio Analysis Graph	51
Figure 25: Mechanical Window to Wall Ratio Analysis Graph	52
Figure 26: Construction Management Window to Wall Analysis	55
Figure 27: Integrated Window to Wall Analysis Graph	56
Figure 28: Existing Building Rendering	57
Figure 29: Building Rendering With 60% Final Selection WWR	57
Figure 30: Equinox Direct Sunlight Penetration Comparison for West Façade	61
Figure 31: Typical Vasari Visualization of Solar Loading with Shades Included	62
Figure 32: MechoShade Material Properties	64
Figure 33: Student Area/Corridor Floor Plan	65
Figure 34: Student Area/Corridor Materials	66
Figure 35: Student Area Furniture Plan	67
Figure 36: Partition elevation	67
Figure 37: Student Area Perspective Rendering	70
Figure 38: Student Area Perspective Rendering	70
Figure 39: Student Area Pseudo Color	71
Figure 40: Student Area Contour Lines	71

Figure 41: Private Office Floor Plan	73
Figure 42: Private Office Material Plan.....	74
Figure 43: Private Office Perspective Rendering	77
Figure 44: Private Office Perspective Rendering	77
Figure 46: Private Office Perspective	78
Figure 45: Private Office Perspective Rendering	78
Figure 47: South Façade Daylight Autonomy.....	81
Figure 48: South Façade Continuous Daylight Autonomy	81
Figure 49: South Façade Critical Point Selection.....	82
Figure 50: South Façade Signal vs. Dimming Plot.....	82
Figure 51: Schedule of Lighting Power Density Monthly Setbacks –Student Areas	83
Figure 52: Plan View: Typical Exterior Bay Layout of Waffle Slab With 3ft Module	89
Figure 53: 3D View: Typical Interior Bay Waffle Slab Construction	89
Figure 54: Reference Velocity Equation from AISC Design Guide 11.....	90
Figure 55: SAP 3D View: Composite Beam and Slab Modeled in SAP2000	91
Figure 56: SAP 3D View: Composite Beam and Slab Modeled in SAP2000	91
Figure 57: Plan View: SAP2000 Existing Structure Vibration Model.....	92
Figure 58: 3D View: Existing Conditions SAP Model, Undeformed Shape.....	93
Figure 59: Plan View: Waffle Slab Vibration SAP Model Rib and Beam Frame Element Layout.....	95
Figure 60: 3D View: Waffle Slab Vibration SAP Model	96
Figure 61: Plan View: Redesigned Pan-Joist System layout	97
Figure 62: 3D View: Redesigned Pan-Joist System Typical Bay.....	98
Figure 63: Plan View: Redesigned Pan-Joist System Layout in SAP2000.	99
Figure 64: 3D View: Redesigned Pan-Joist in SAP2000.	99
Figure 65: Plan View: Existing Lateral Resisting Elements on First Floor.....	101
Figure 66: Plan View: New Proposed Lateral Resisting Elements on First Floor	102
Figure 67: 3D View: Existing ETABS Lateral Model	103
Figure 68: Render of Laboratory Supply Ductwork in Third Floor Materials Science Lab	107
Figure 69: Laboratory Supply System on Penthouse Level. Manifolds are shown in Red, while the Supply Mains are Green and the Air Handlers are Teal.....	108
Figure 70: Laboratory Supply on Third Floor Material Science Wing.....	109
Figure 71: Swamee-Jain Equation Used to Approximate Friction Factor.....	110
Figure 72: Exponential Relationship of Duct Size and Static Pressure	111
Figure 73: Comparison of Installed and Operational Costs.....	114
Figure 74: Visual of Concrete Pour.....	117
Figure 75: Navisworks Model of Third Floor Duct Systems.....	119
Figure 76: Render of Laboratory Supply Ductwork in Third Floor Materials Science Lab	121
Figure 77: Render of Structural Concrete Wing Alternative.....	122
Figure 78: Existing Coordination of Laboratory Supply and Structure	125
Figure 79: Coordination of Laboratory Supply and Alternate Structure	126
Figure 80: Coordination of Alternate Laboratory Supply and Alternate Structure	126
Figure 81: Existing Coordination of Laboratory Supply and Structure	127
Figure 82: Coordination of Laboratory Supply and Alternate Structure	128
Figure 83: Coordination of Alternate Laboratory Supply and Alternate Structure	128

<i>Figure 84: Existing Coordination of Office Ductwork and Structure</i>	<i>129</i>
<i>Figure 85: Coordination of Alternate Office Ductwork and Alternate Structure.....</i>	<i>130</i>
<i>Figure 86: Collision of Alternate Office Ductwork and Existing Structure.....</i>	<i>130</i>
<i>Figure 87: 3D Section of Coordinated Alternate Office Ductwork and Alternate Structure.....</i>	<i>131</i>
<i>Figure 88: Existing Coordination of Drainage Piping and Structure.....</i>	<i>132</i>
<i>Figure 89: Existing Coordination of Drainage Piping and Structure.....</i>	<i>133</i>
<i>Figure 90: Coordination of Drainage Piping and Alternate Structure.....</i>	<i>133</i>
<i>Figure 91: Existing Coordination of Drainage Piping and Structure.....</i>	<i>134</i>
<i>Figure 92: Coordination of Drainage Piping and Alternate Structure.....</i>	<i>134</i>
<i>Figure 93: Existing Exterior Truss on Frame- B.....</i>	<i>138</i>
<i>Figure 94: Existing Interior Truss on Frame-E</i>	<i>139</i>
<i>Figure 95: Exterior Truss with Efficient Compression Load Paths Highlighted in Blue.....</i>	<i>140</i>
<i>Figure 96: SAP2000 Model of Existing Truss Configurations</i>	<i>141</i>
<i>Figure 97: SAP Model of Entire Cantilever Support System With Supported Gravity Systems.....</i>	<i>142</i>
<i>Figure 98: Redesign-1a: Exterior Truss on Frame-B With Tension Members.....</i>	<i>143</i>
<i>Figure 99: Redesign-1b: Interior Truss on Frame-E With Tension Members.....</i>	<i>144</i>
<i>Figure 100: Redesign-1a+: Additional Shear Wall Within Truss Configuration.....</i>	<i>145</i>
<i>Figure 101: Redesign-2a: Exterior Truss on Frame-B With Added Brace</i>	<i>147</i>
<i>Figure 102: Redesign-2b: Interior Truss on Frame-E With Added Brace</i>	<i>148</i>
<i>Figure 103: Cantilever Plaza BIMception’s Structural Changes</i>	<i>149</i>
<i>Figure 104: Cantilever Plaza BIMception’s Architectural Changes</i>	<i>151</i>
<i>Figure 105: Cantilever Plaza BIMception’s Architectural Changes</i>	<i>151</i>
<i>Figure 106: Cantilever Plaza Site Plan</i>	<i>152</i>
<i>Figure 107: Cantilever Plaza Section.....</i>	<i>152</i>
<i>Figure 108: Cantilever Plaza Perspective Rendering.....</i>	<i>156</i>
<i>Figure 109: Cantilever Plaza Perspective Rendering.....</i>	<i>157</i>
<i>Figure 110: Cantilever Plaza Perspective Rendering.....</i>	<i>157</i>
<i>Figure 111: Cantilever Plaza Pseudo Color.....</i>	<i>158</i>
<i>Figure 112: Cantilever Plaza Pseudo Color.....</i>	<i>158</i>
<i>Figure 113: Existing Panelboard Schedule HL-3D</i>	<i>163</i>
<i>Figure 114: Existing Panelboard Schedule HLE-3D</i>	<i>164</i>
<i>Figure 115: Panelboard Worksheet HL-3D.....</i>	<i>165</i>
<i>Figure 116: Panelboard Worksheet HLE-3D.....</i>	<i>166</i>
<i>Figure 117: Panelboard Schedule HL-3D.....</i>	<i>167</i>
<i>Figure 118: Panelboard Schedule HLE-3D.....</i>	<i>167</i>
<i>Figure 119: Existing Student Area Wiring Diagram</i>	<i>168</i>
<i>Figure 120: Student Area Wiring Diagram.....</i>	<i>168</i>
<i>Figure 121: Private Office Wiring Diagram.....</i>	<i>171</i>
<i>Figure 122: Existing Panelboard Schedule LCP-1</i>	<i>173</i>
<i>Figure 123: Existing Panelboard Schedule HL-1B.....</i>	<i>174</i>
<i>Figure 124: Panelboard Worksheet LCP-1</i>	<i>175</i>
<i>Figure 125: Panelboard Worksheet HLE-1B.....</i>	<i>176</i>
<i>Figure 126: Panelboard Schedule LCP-1.....</i>	<i>177</i>
<i>Figure 127: Panelboard Schedule HL-1B</i>	<i>177</i>

<i>Figure 128: Short Circuit Analysis Path</i>	<i>180</i>
<i>Figure 129: Device Coordination.....</i>	<i>181</i>
<i>Figure 130: MDS-01A Equipment Inputs.....</i>	<i>184</i>
<i>Figure 131: Wire Sizing in SKM</i>	<i>185</i>
<i>Figure 132: Transformer Inputs in SKM</i>	<i>186</i>
<i>Figure 133: Induction Motor Inputs in SKM</i>	<i>187</i>
<i>Figure 134: Non-Motor Load Inputs in SKM.....</i>	<i>188</i>
<i>Figure 135: Millennium Science Complex Third Floor Service Equipment One-Line Diagram.....</i>	<i>189</i>
<i>Figure 136: MDS-01A and MDS-01B One-Line Diagram</i>	<i>189</i>
<i>Figure 137: EMDS-1, MDS-02A, and ATSS One-Line Diagram.....</i>	<i>190</i>
<i>Figure 138: SDP-2B and Loads One-Line Diagram</i>	<i>190</i>
<i>Figure 139: SDP-2D and Loads One-Line Diagram.....</i>	<i>191</i>
<i>Figure 140: SDP-2D1 and Loads One-Line Diagram.....</i>	<i>192</i>
<i>Figure 141: MDP-M41 and Loads One-Line Diagram</i>	<i>193</i>
<i>Figure 142: MDP-M42 and Loads One-Line Diagram</i>	<i>193</i>
<i>Figure 143: EDPS-1E1 and Loads One-Line Diagram</i>	<i>193</i>
<i>Figure 144: EDPS-3B and Loads One-Line Diagram</i>	<i>193</i>
<i>Figure 145: EDPS-M41 and Loads One-Line Diagram.....</i>	<i>194</i>
<i>Figure 146: EDPS-M41 and Loads One-Line Diagram.....</i>	<i>194</i>
<i>Figure 147: LB-0C9 Voltage Drop</i>	<i>197</i>
<i>Figure 148: LB-3D5 Voltage Drop Check.....</i>	<i>197</i>
<i>Figure 149: Yearly Energy Savings Cost Analysis</i>	<i>203</i>
<i>Figure 150: Temperature Analysis of Redesigned Wall Assembly</i>	<i>365</i>
<i>Table 1: Schedule Summary of Key Tasks</i>	<i>17</i>
<i>Table 2: Total Cost of Building</i>	<i>18</i>
<i>Table 3: Construction Cost of Building.....</i>	<i>18</i>
<i>Table 4: Building System Costs</i>	<i>18</i>
<i>Table 5: ASHRAE Weather Data for University Park, PA.....</i>	<i>23</i>
<i>Table 6: OPP Interior Design Conditions</i>	<i>23</i>
<i>Table 7: Hand Calculation Condensation Analysis of Existing Wall – Winter Condition – No Vapor Barrier</i>	<i>27</i>
<i>Table 8: Thickness Analysis Due to In Place Wind Loads For Existing Façade Panel.....</i>	<i>30</i>
<i>Table 9: Thickness Analysis Due to In Place Dead Loads For Existing Façade Panel.....</i>	<i>30</i>
<i>Table 10: Comparison of Thermal Properties</i>	<i>32</i>
<i>Table 11: Thickness Analysis Due to Self-Weight Flexure During Precast Fabrication.....</i>	<i>35</i>
<i>Table 12: Comparison of Thermal Properties</i>	<i>37</i>
<i>Table 13: Total Energy Consumption of Design Options.....</i>	<i>38</i>
<i>Table 14: Yearly Operating Cost Breakdown</i>	<i>39</i>
<i>Table 15: Construction Costs of Existing Panels on Third Floor with 2 & 3-Pane Glass</i>	<i>40</i>
<i>Table 16: 30 Year Life Cycle Cost Assessment.....</i>	<i>41</i>
<i>Table 17: Wall Composition Life Cycle Cost Analysis Summary</i>	<i>42</i>
<i>Table 18: Third Floor Daysim Settings</i>	<i>44</i>
<i>Table 19: Student Area Daysim Settings.....</i>	<i>45</i>
<i>Table 20: Room Cavity Glass to Wall Ratio Energy Analysis.....</i>	<i>46</i>

<i>Table 21: Original Erection Dates for the Precast Panels.</i>	47
<i>Table 22: New Erection Dates for the Precast Panels.</i>	48
<i>Table 23: Existing Façade Useful Illuminance Values by Orientation</i>	49
<i>Table 24: Useful Illuminance for tested Window to Wall Ratios</i>	49
<i>Table 25: Mechanical Window to Wall Ratio Analysis</i>	52
<i>Table 26: Window to Wall Ratio Based on Minimum Thicknesses of Façade Panel</i>	53
<i>Table 27: Construction Costs of Redesigned Panel on Third Floor at 70% and 60% ratio</i>	55
<i>Table 28: Window to Wall Ratio Life Cycle Cost Analysis Summary</i>	56
<i>Table 29: Interior Shelf Analysis Study Times</i>	59
<i>Table 30: No Shelf Problematic Times</i>	59
<i>Table 31: Interior Shelf Problematic Times</i>	61
<i>Table 32: Analysis of Shade Mounting Height</i>	63
<i>Table 33: Analysis of Shade Mounting Height</i>	63
<i>Table 34: Student Area/Corridor Material Properties</i>	66
<i>Table 35: Student Area Luminaire Schedule</i>	69
<i>Table 36: Student Area/Corridor Light Loss Factors</i>	69
<i>Table 37: Student Area Illuminance Values</i>	71
<i>Table 38: Corridor Illuminance Values</i>	71
<i>Table 39: Private Office Material Properties</i>	74
<i>Table 40: Private Office Luminaire Schedule</i>	76
<i>Table 41: Private Office Light Loss Factors</i>	76
<i>Table 42: Private Office Illuminance Values</i>	78
<i>Table 43: Cost of Existing Lighting, Third Floor</i>	79
<i>Table 44: Cost of Redesigned Lighting, Third Floor</i>	79
<i>Table 45: South Façade Dimmed Zone Energy Savings</i>	80
<i>Table 46: Yearly Operating Costs – Lighting Redesign</i>	84
<i>Table 47: Lighting Redesign Life Cycle Cost Analysis</i>	85
<i>Table 48: Facade Redesign Life Cycle Cost Analysis</i>	86
<i>Table 49: Worst Case Floor Loading</i>	88
<i>Table 50: Typical Reinforcement for Waffle Slab Design</i>	90
<i>Table 51: Summary of Theoretical vs. SAP2000 Deflections</i>	92
<i>Table 52: Summary of Velocity Calculation For the Existing Composite Beam System</i>	94
<i>Table 53: Summary of Velocity Calculation for Redesigned Concrete Waffle Slab</i>	96
<i>Table 54: Summary of Velocity Calculation for Redesigned Concrete Pan-Joist System</i>	100
<i>Table 55: Summary Table of Existing Cost of Structure</i>	105
<i>Table 56: Summary Table of Redesigned Concrete Structure</i>	106
<i>Table 57: Duct Sizing Effects on Fan Selection</i>	111
<i>Table 58: Energy and Cost Analysis of Changing Duct Size</i>	112
<i>Table 59: Construction Costs of Changing Duct Size</i>	113
<i>Table 60: Life Cycle Cost of Duct Size Alternatives</i>	114
<i>Table 61: Schedule Summary of Redesign</i>	117
<i>Table 62: Duct Redesign Life Cycle Cost Analysis</i>	135
<i>Table 63: Cantilever Plaza Material Properties</i>	153
<i>Table 64: Cantilever Plaza Luminaire Schedule</i>	155

<i>Table 65: Cantilever Plaza Light Loss Factors</i>	<i>155</i>
<i>Table 66: Cantilever Plaza Lighting Control Hours of Operation</i>	<i>156</i>
<i>Table 67: Pathway Illuminance Values.....</i>	<i>159</i>
<i>Table 68: Sidewalk Illuminance Values.....</i>	<i>159</i>
<i>Table 69: Sidewalk Illuminance Values.....</i>	<i>159</i>
<i>Table 70: Panelboards Affected by Lighting Redesign.....</i>	<i>162</i>
<i>Table 71: Feeder Sizing for Panelboard HL-3D.....</i>	<i>169</i>
<i>Table 72: Feeder Sizing for Panelboard HLE-3D.....</i>	<i>169</i>
<i>Table 73: Cantilever Plaza Lighting Control Hours of Operation</i>	<i>172</i>
<i>Table 74: Feeder Sizing for Panelboard LCP-1</i>	<i>178</i>
<i>Table 75: Feeder Sizing for Panelboard HLE-3D.....</i>	<i>178</i>
<i>Table 76: Short Circuit Analysis Calculation Table</i>	<i>179</i>
<i>Table 77: SKM Equipment Schedule.....</i>	<i>183</i>
<i>Table 78: Transformer Impedance Summary.....</i>	<i>194</i>
<i>Table 79: SKM Short Circuit Report Summary</i>	<i>195</i>
<i>Table 80: Existing Equipment Cost.....</i>	<i>196</i>
<i>Table 81: Existing Feeder Material and Labor Cost</i>	<i>196</i>
<i>Table 82: New Equipment Cost.....</i>	<i>196</i>
<i>Table 83: New Feeder Cost</i>	<i>197</i>
<i>Table 84: Overall Cost Comparison.....</i>	<i>197</i>
<i>Table 85: Millennium Science Complex Lighting Redesign Summary</i>	<i>203</i>
<i>Table 86: Combined Alternative Life Cycle Cost Analysis.....</i>	<i>204</i>

APPENDIX C: Citations

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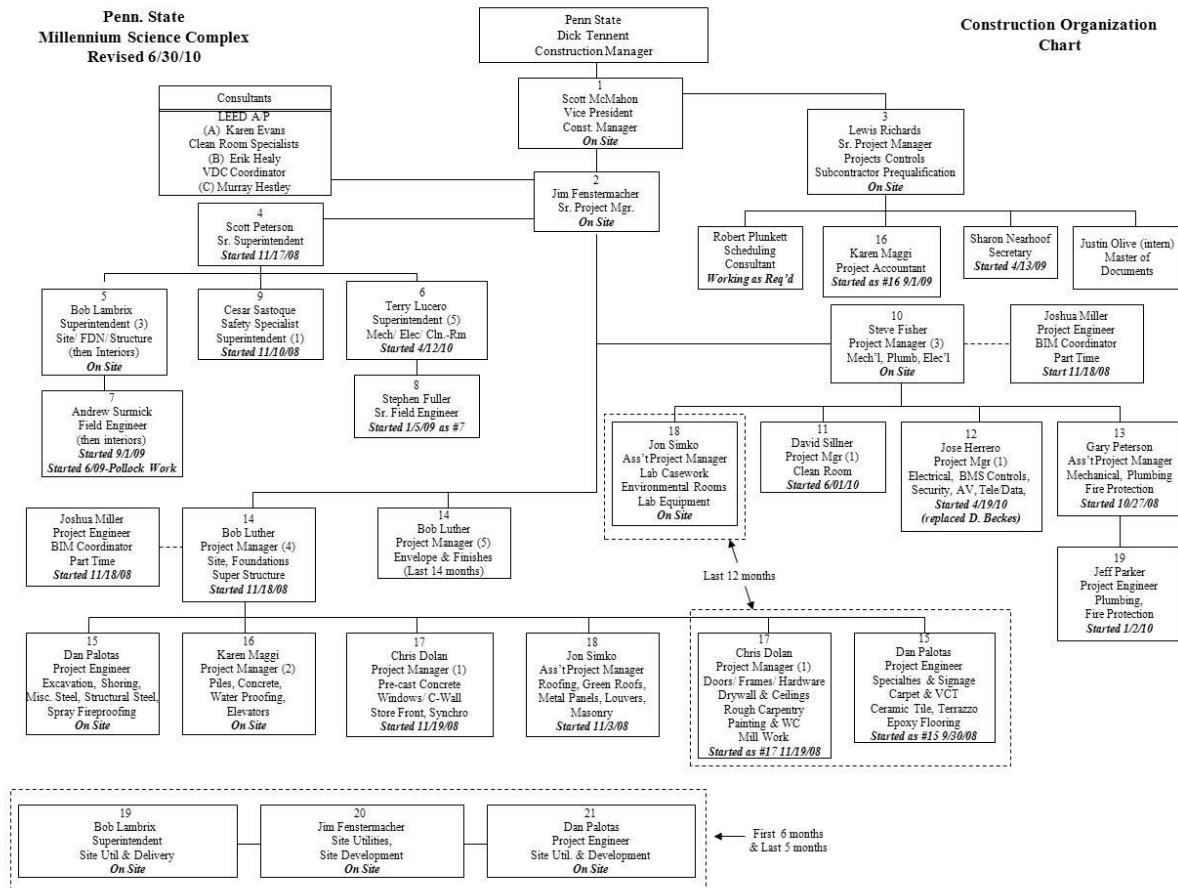
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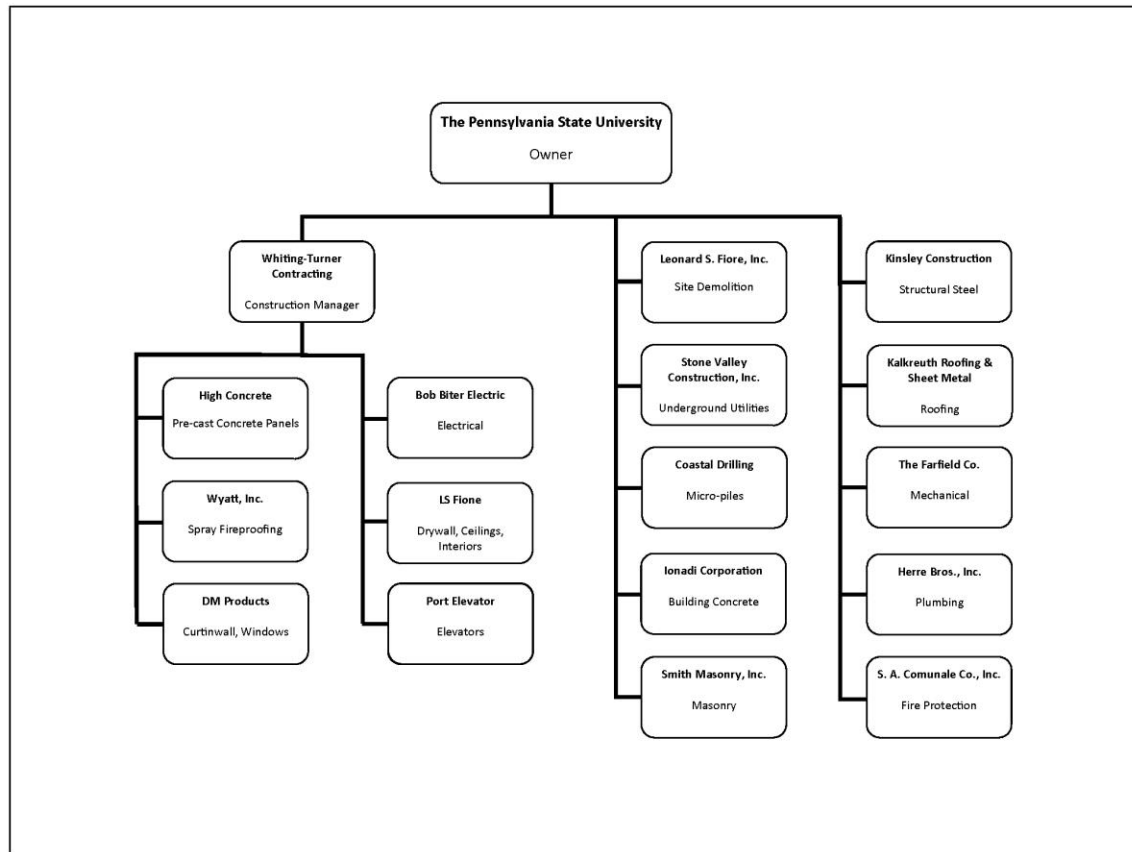
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APPENDIX D: Construction Management

Project Staff

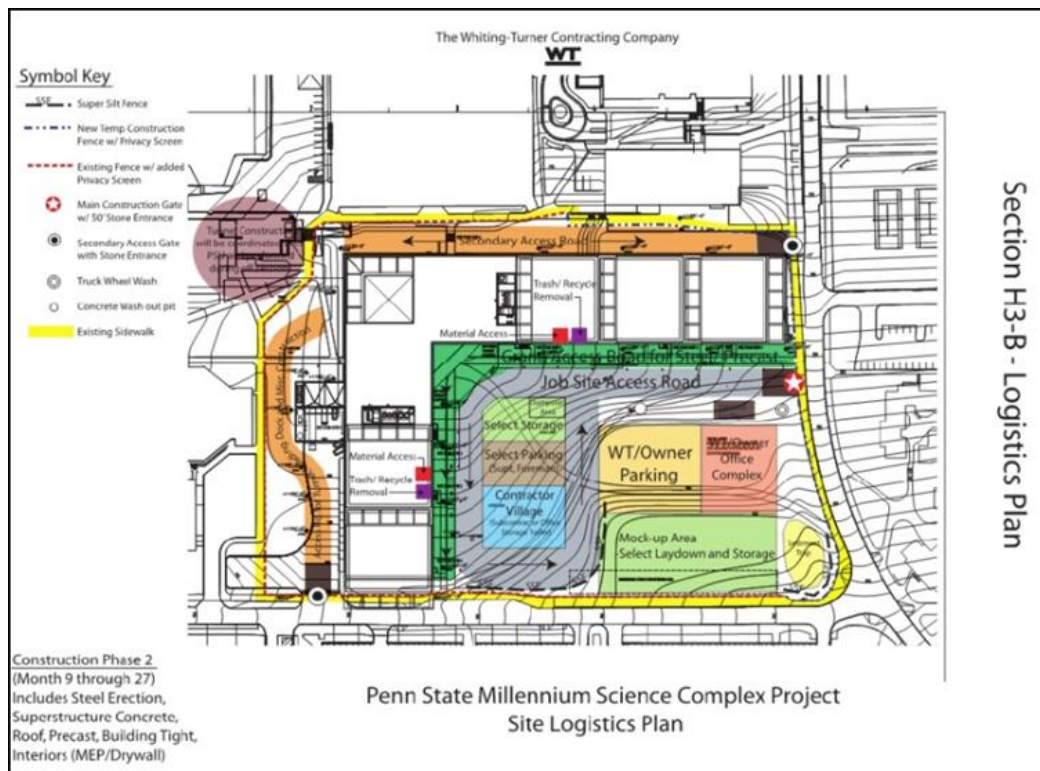


Project Delivery Method

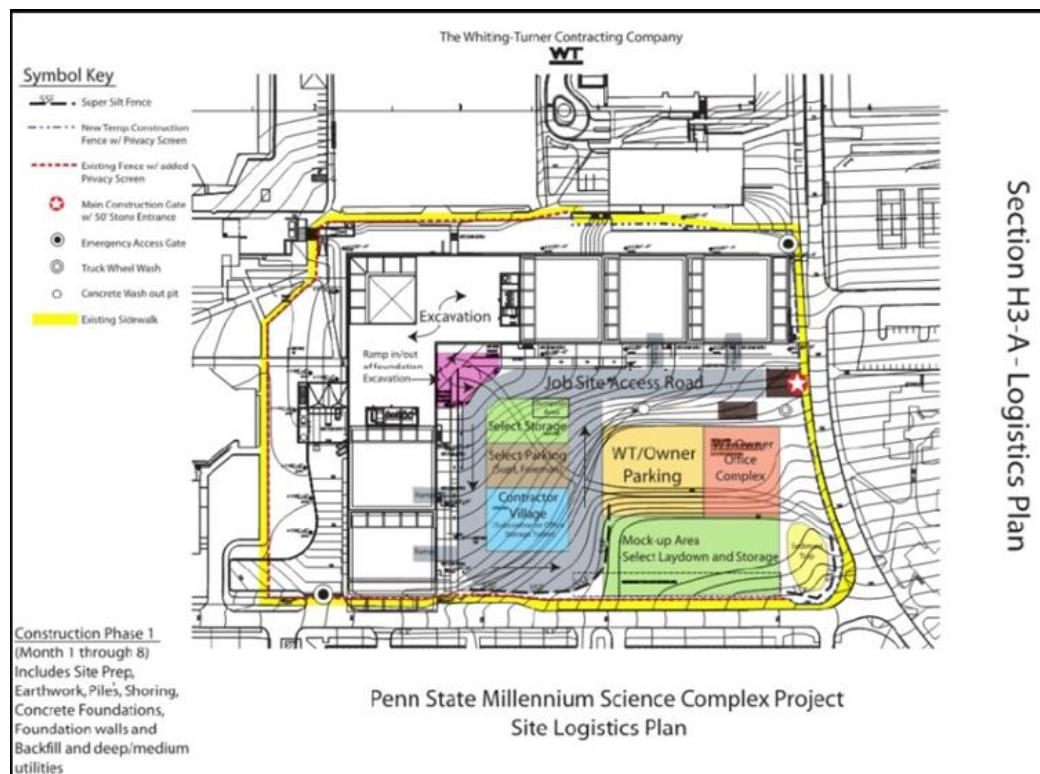


Project Delivery Method Organizational Model

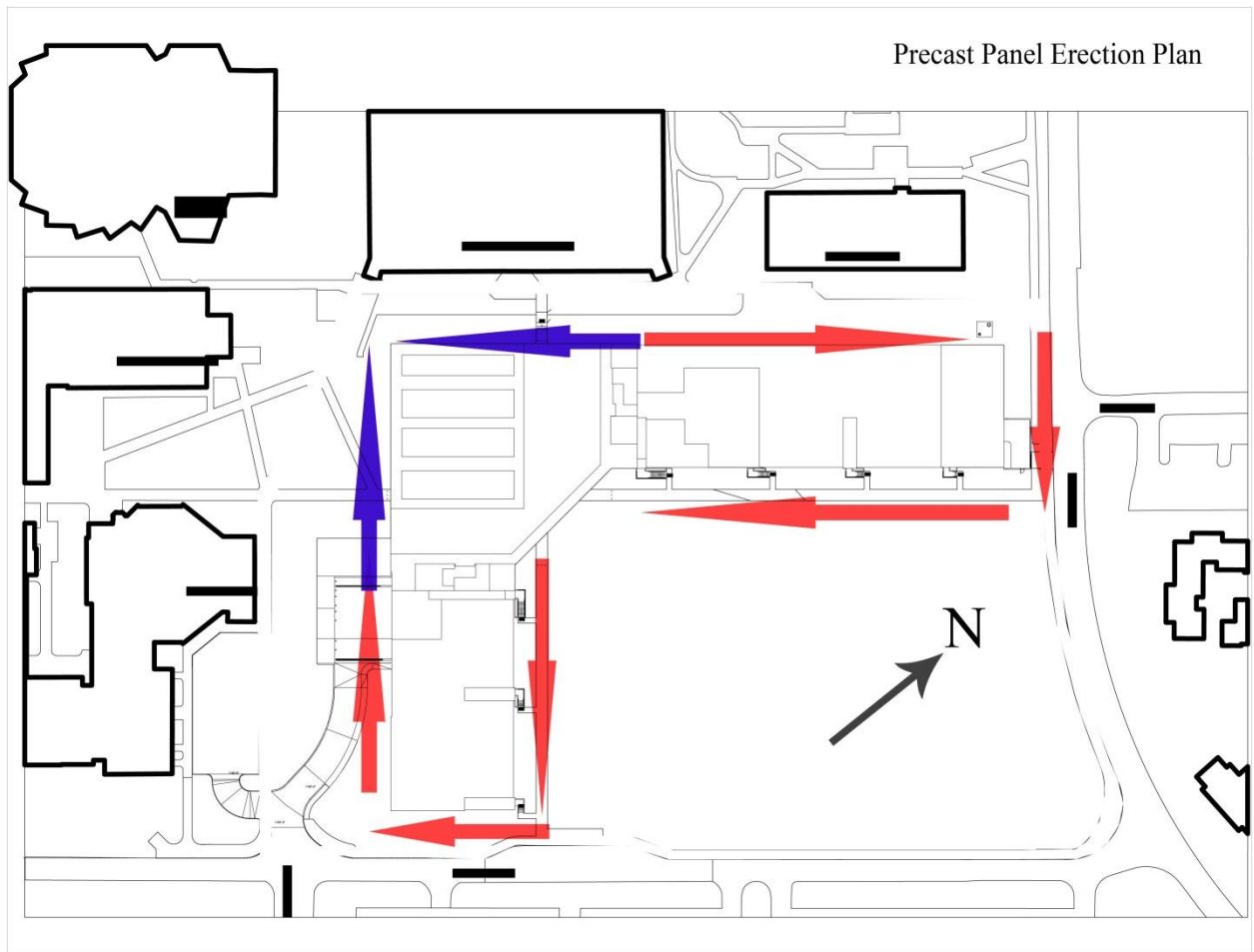
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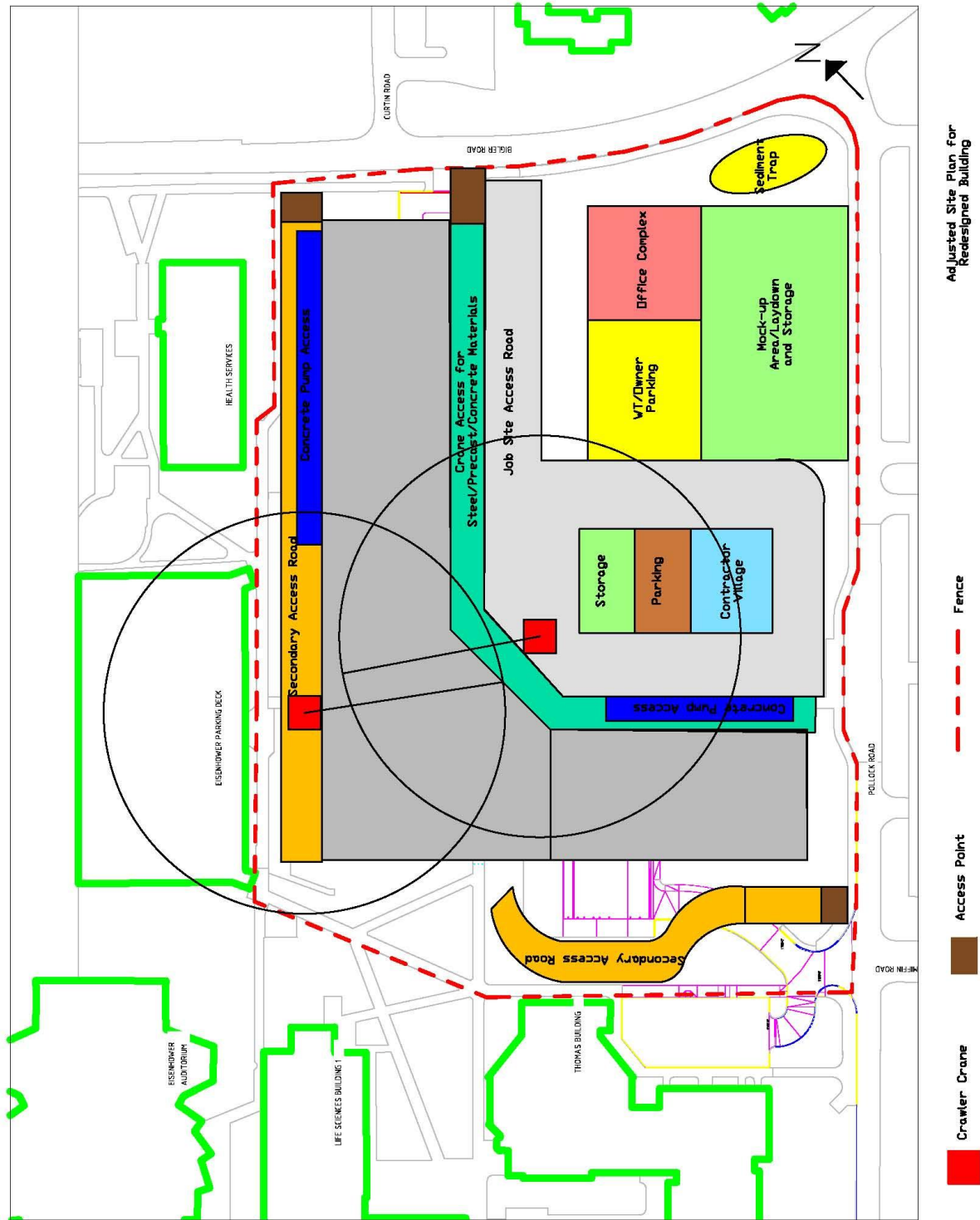


Whiting-Turner Phase 1 Site Plan

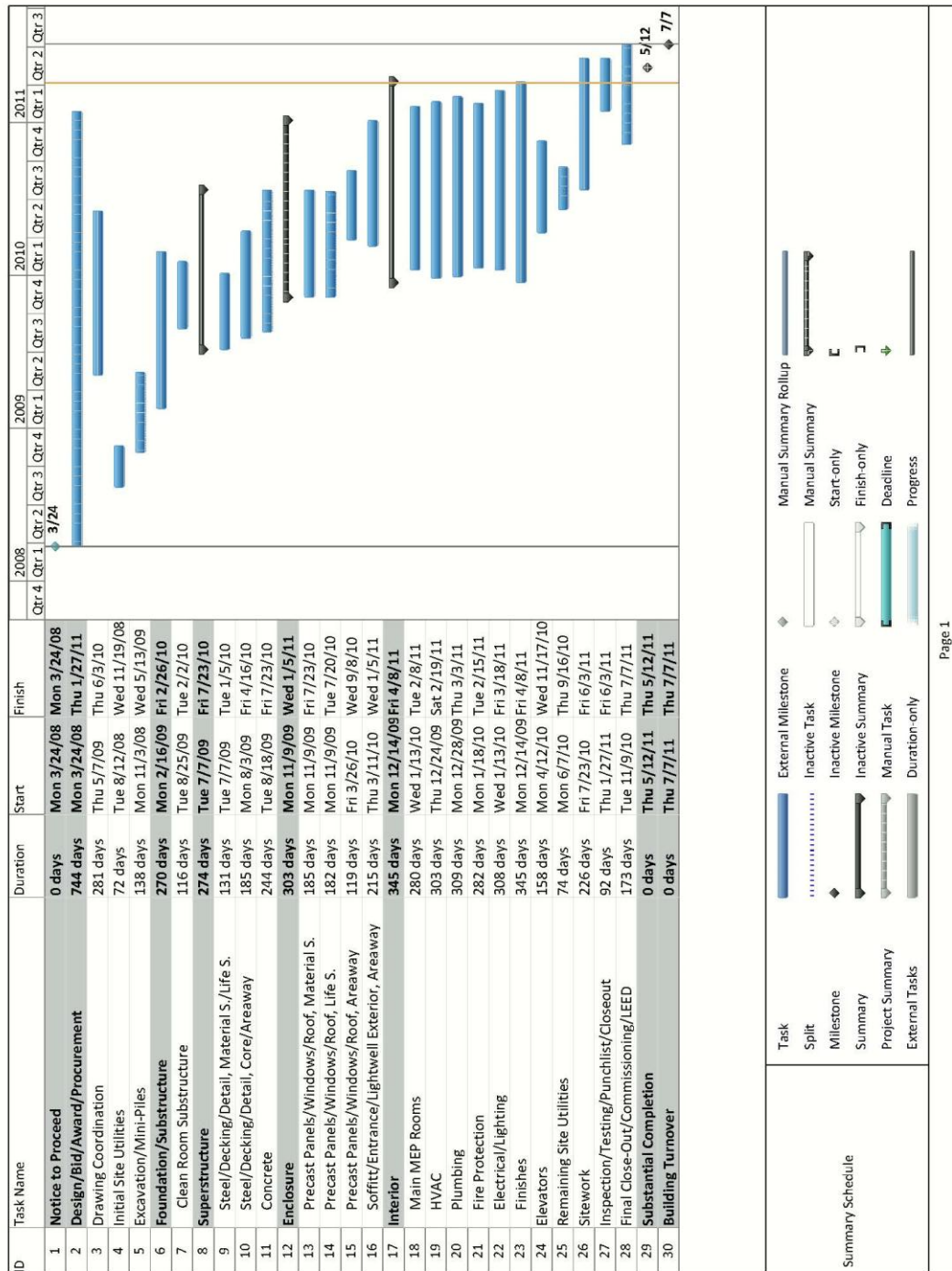


Whiting-Turner Phase 2 Site Plan

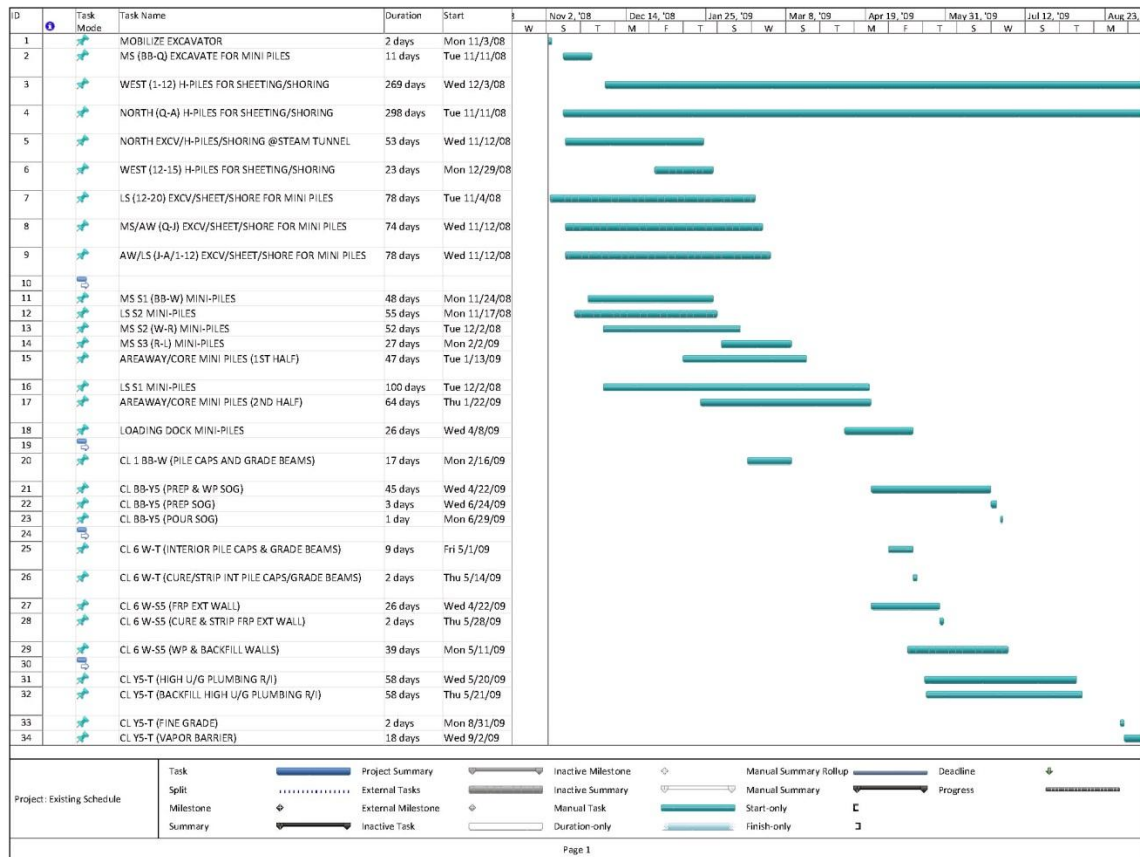


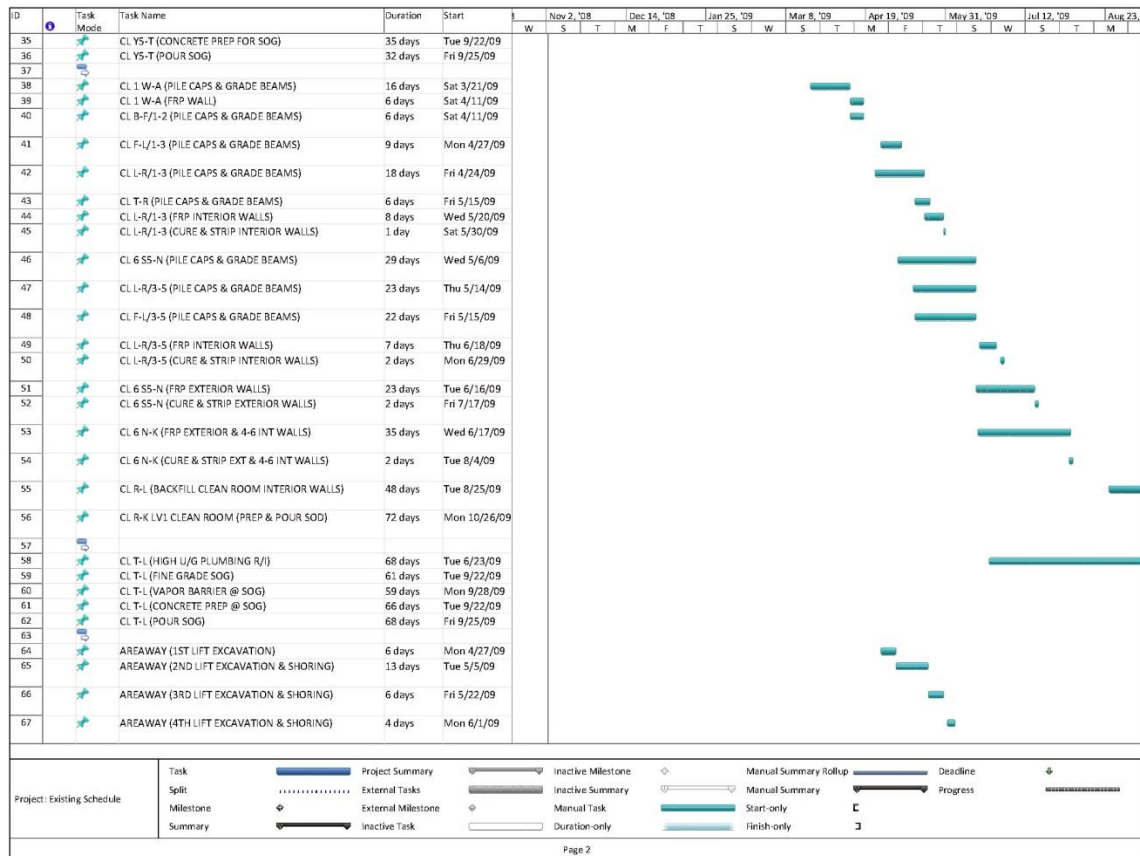


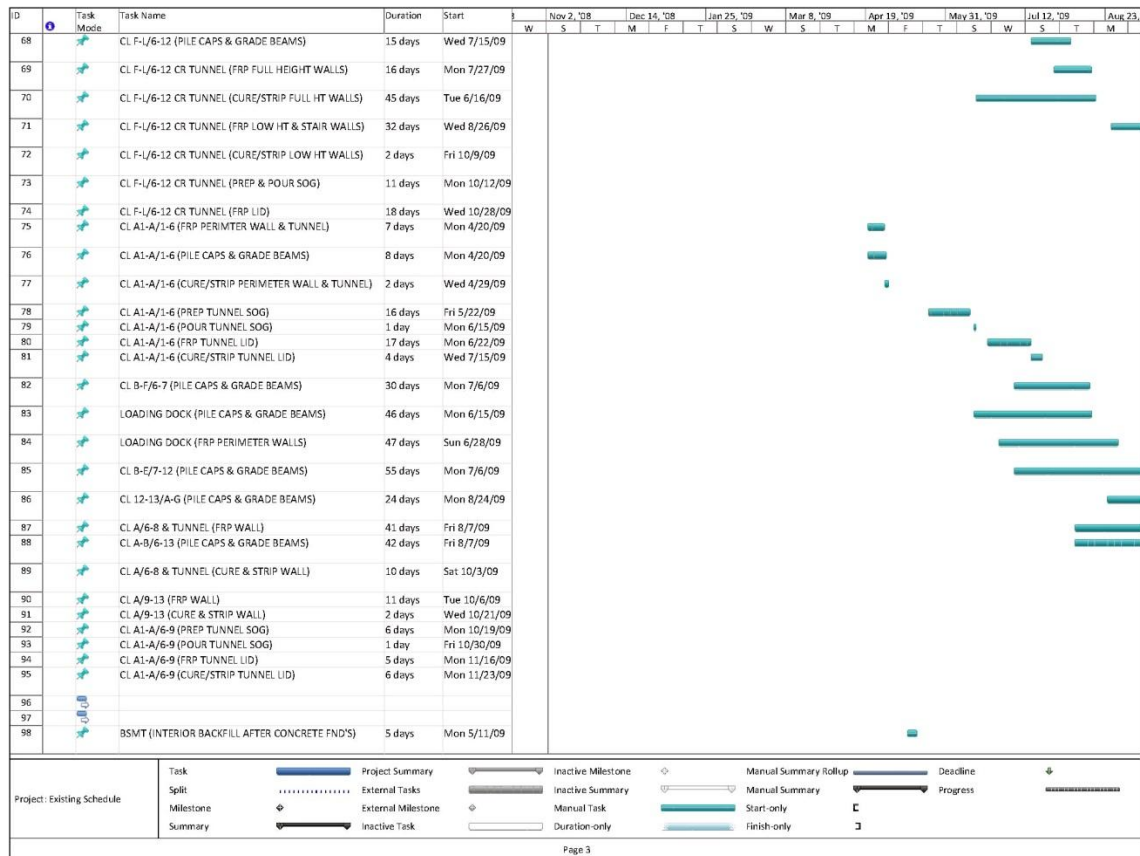
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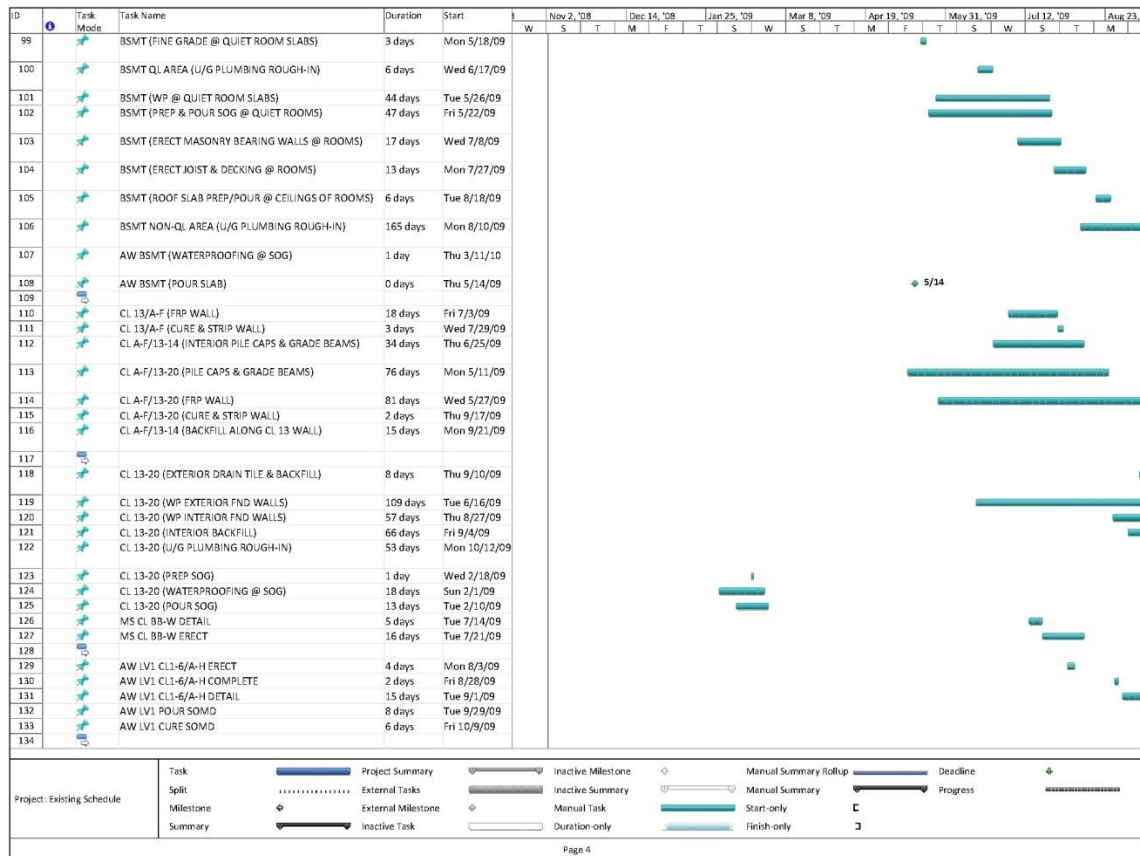


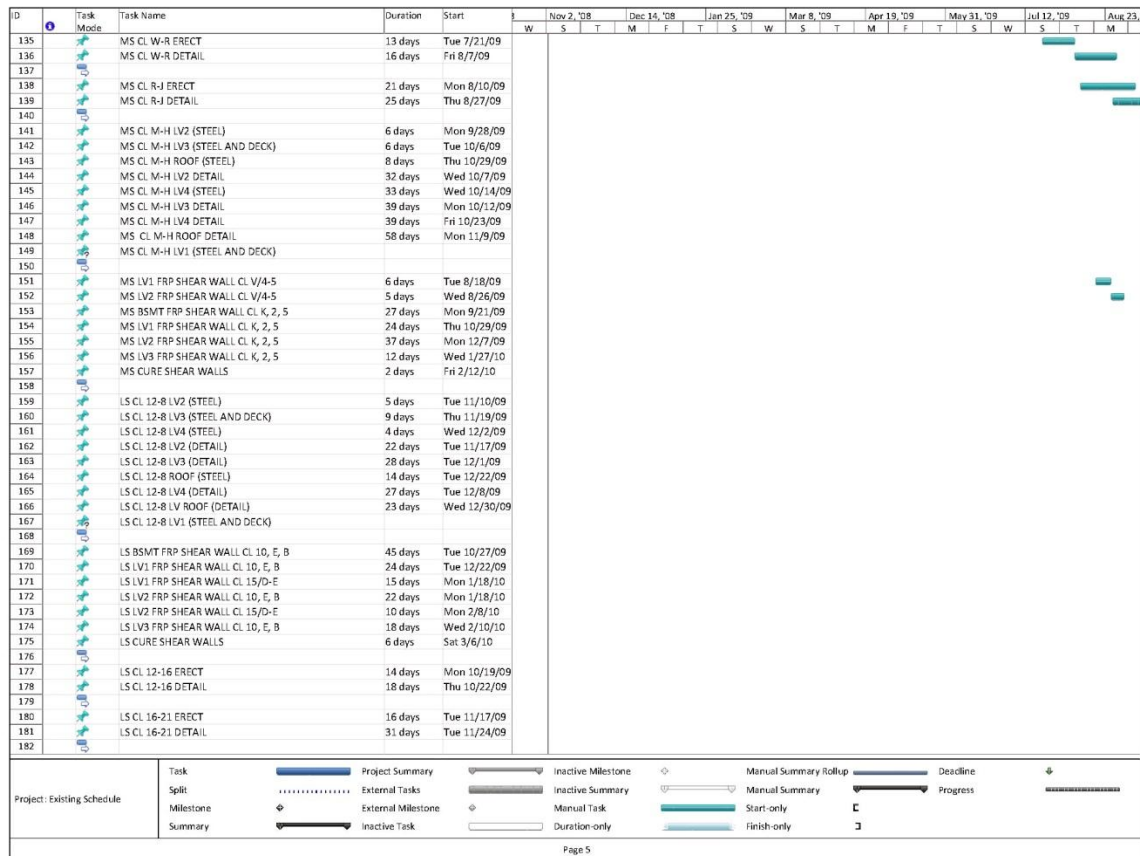
Project Summary Schedule



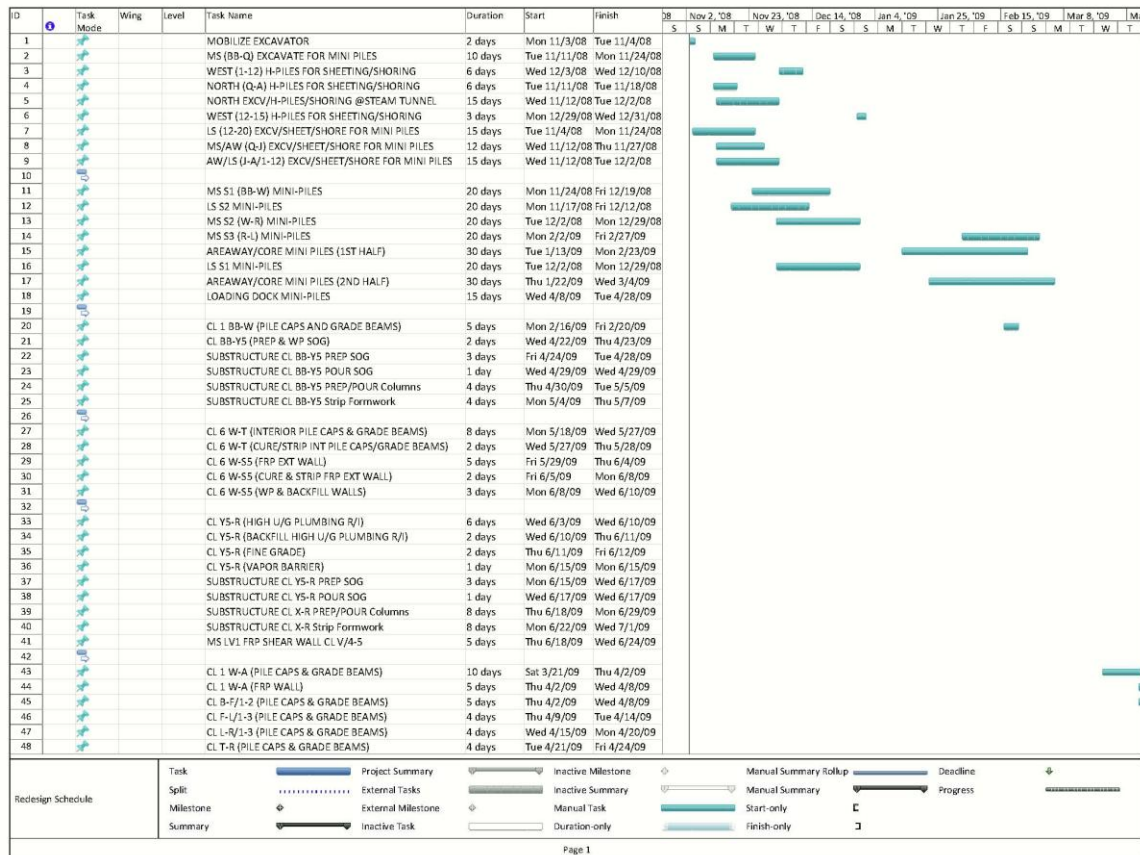








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ID	Task Mode	Wing	Level	Task Name	Duration	Start	Finish	28	Nov 2, '08	Nov 23, '08	Dec 14, '08	Jan 4, '09	Jan 25, '09	Feb 15, '09	Mar 8, '09	Mar
49				CL L-R/1-3 (FRP INTERIOR WALLS)	5 days	Wed 4/22/09	Tue 4/28/09		S	S	M	T	W	T	F	S
50				CL L-R/1-3 (CURE & STRIP INTERIOR WALLS)	1 day	Wed 4/29/09	Wed 4/29/09									
51				CL 6 SS-N (PILE CAPS & GRADE BEAMS)	4 days	Thu 4/30/09	Tue 5/5/09									
52				CL L-R/3-5 (PILE CAPS & GRADE BEAMS)	4 days	Wed 5/6/09	Mon 5/11/09									
53				CL F-L/3-5 (PILE CAPS & GRADE BEAMS)	4 days	Tue 5/12/09	Fri 5/15/09									
54				CL L-R/3-5 (FRP INTERIOR WALLS)	5 days	Mon 5/18/09	Fri 5/22/09									
55				CL L-R/3-5 (CURE & STRIP INTERIOR WALLS)	2 days	Mon 5/25/09	Tue 5/26/09									
56				CL 6 SS-N (FRP EXTERIOR WALLS)	7 days	Wed 5/27/09	Thu 6/4/09									
57				CL 6 SS-N (CURE & STRIP EXTERIOR WALLS)	2 days	Fri 6/5/09	Mon 6/8/09									
58				CL 6 N-K (FRP EXTERIOR & 4-6 INT WALLS)	8 days	Thu 5/28/09	Mon 6/8/09									
59				CL 6 N-K (CURE & STRIP EXT & 4-6 INT WALLS)	2 days	Tue 6/9/09	Wed 6/10/09									
60				CL R-L (BACKFILL CLEAN ROOM INTERIOR WALLS)	7 days	Thu 6/11/09	Fri 6/19/09									
61																
62				CL R-L (HIGH U/G PLUMBING R/I)	2 days	Mon 5/25/09	Tue 5/26/09									
63				CL R-L (FINE GRADE SOG)	2 days	Tue 5/26/09	Wed 5/27/09									
64				CL R-L (VAPOR BARRIER @ SOG)	1 day	Thu 5/28/09	Thu 5/28/09									
65				SUBSTRUCTURE CL R-L PREP HIGH SOG	3 days	Thu 6/11/09	Mon 6/15/09									
66				SUBSTRUCTURE CL R-L POUR HIGH SOG	1 day	Tue 6/16/09	Tue 6/16/09									
67																
68				AREAWAY (1ST LIFT EXCAVATION)	5 days	Mon 4/27/09	Fri 5/1/09									
69				AREAWAY (2ND LIFT EXCAVATION & SHORING)	10 days	Mon 5/4/09	Fri 5/15/09									
70				AREAWAY (3RD LIFT EXCAVATION & SHORING)	10 days	Mon 5/18/09	Fri 5/29/09									
71				AREAWAY (4TH LIFT EXCAVATION & SHORING)	10 days	Mon 6/1/09	Fri 6/12/09									
72				CL F-L/6-12 (PILE CAPS & GRADE BEAMS)	12 days	Wed 7/15/09	Thu 7/30/09									
73				CL F-L/6-12 CR TUNNEL (FRP FULL HEIGHT WALLS)	10 days	Mon 7/27/09	Fri 8/7/09									
74				CL F-L/6-12 CR TUNNEL (CURE/STRIP FULL HT WALLS)	2 days	Tue 6/16/09	Wed 6/17/09									
75				CL F-L/6-12 CR TUNNEL (FRP LOW HT & STAIR WALLS)	10 days	Wed 8/26/09	Tue 9/8/09									
76				CL F-L/6-12 CR TUNNEL (CURE/STRIP LOW HT WALLS)	2 days	Fri 10/9/09	Mon 10/12/09									
77				CL F-L/6-12 CR TUNNEL (PREP & POUR SOG)	8 days	Mon 10/12/09	Wed 10/21/09									
78				CL F-L/6-12 CR TUNNEL (FRP LID)	5 days	Wed 10/28/09	Tue 11/3/09									
79				CL A1-A/1-6 (FRP PERIMETER WALL & TUNNEL)	15 days	Mon 4/20/09	Fri 5/8/09									
80				CL A1-A/1-6 (PILE CAPS & GRADE BEAMS)	5 days	Mon 4/20/09	Fri 4/24/09									
81				CL A1-A/1-6 (CURE/STRIP PERIMETER WALL & TUNNEL)	2 days	Wed 4/29/09	Thu 4/30/09									
82				CL A1-A/1-6 (PREP TUNNEL SOG)	4 days	Fri 5/22/09	Wed 5/27/09									
83				CL A1-A/1-6 (POUR TUNNEL SOG)	1 day	Mon 6/15/09	Mon 6/15/09									
84				CL A1-A/1-6 (FRP TUNNEL LID)	5 days	Mon 6/22/09	Fri 6/26/09									
85				CL A1-A/1-6 (CURE/STRIP TUNNEL LID)	4 days	Wed 7/15/09	Mon 7/20/09									
86				CL B-7/6-7 (PILE CAPS & GRADE BEAMS)	7 days	Mon 7/6/09	Tue 7/14/09									
87				LOADING DOCK (PILE CAPS & GRADE BEAMS)	4 days	Mon 6/15/09	Thu 6/18/09									
88				LOADING DOCK (FRP PERIMETER WALLS)	15 days	Sun 6/28/09	Thu 7/16/09									
89				CL B-7/7-12 (PILE CAPS & GRADE BEAMS)	16 days	Mon 7/6/09	Mon 7/27/09									
90				CL 12-13/A-G (PILE CAPS & GRADE BEAMS)	4 days	Mon 8/3/09	Thu 8/6/09									
91				CL A/6-8 & TUNNEL (FRP WALL)	7 days	Fri 8/7/09	Mon 8/17/09									
92				CL A/6-13 (PILE CAPS & GRADE BEAMS)	4 days	Tue 7/28/09	Fri 7/31/09									
93				CL A/6-8 & TUNNEL (CURE & STRIP WALL)	2 days	Sat 10/3/09	Mon 10/5/09									
94				CL A/9-13 (FRP WALL)	7 days	Tue 10/6/09	Wed 10/14/09									
95				CL A/9-13 (CURE & STRIP WALL)	2 days	Wed 10/21/09	Thu 10/22/09									
96				CL A1-A/6-9 (PREP TUNNEL SOG)	4 days	Mon 10/19/09	Thu 10/22/09									

Redesign Schedule

Task

Split

Milestone

Summary

Project Summary

External Tasks

External Milestone

Inactive Task

Inactive Milestone

Inactive Summary

Manual Task

Duration-only

Manual Summary Rollup

Manual Summary

Start-only

Finish-only

Deadline

Progress

Page 2

ID	Task Mode	Wing	Level	Task Name	Duration	Start	Finish	28	Nov 2, '09	Nov 23, '09	Dec 14, '09	Jan 6, '10	Jan 25, '10	Feb 15, '10	Mar 8, '10	Me
97				CL A1-A/6-9 (POUR TUNNEL SOG)	1 day	Fri 10/30/09	Fri 10/30/09		S	S	M	T	W	T	F	S
98				CL A1-A/6-9 (FRP TUNNEL LID)	5 days	Mon 11/9/09	Fri 11/13/09									
99				CL A1-A/6-9 (CURE/STRIP TUNNEL LID)	4 days	Mon 11/23/09	Thu 11/26/09									
100																
101				BSMT (INTERIOR BACKFILL AFTER CONCRETE FND'S)	5 days	Mon 5/11/09	Fri 5/15/09									
102				BSMT (FINE GRADE @ QUIET ROOM SLABS)	3 days	Mon 5/18/09	Wed 5/20/09									
103				BSMT QL AREA (U/G PLUMBING ROUGH-IN)	3 days	Thu 5/21/09	Mon 5/25/09									
104				BSMT (WP @ QUIET ROOM SLABS)	3 days	Tue 5/26/09	Thu 5/28/09									
105				BSMT (PREP & POUR SOG @ QUIET ROOMS)	10 days	Mon 5/18/09	Fri 5/29/09									
106				BSMT (ERECT MASONRY BEARING WALLS @ ROOMS)	15 days	Fri 5/15/09	Thu 6/4/09									
107				BSMT (ERECT JOIST & DECKING @ ROOMS)	4 days	Fri 6/5/09	Wed 6/10/09									
108				BSMT (ROOF SLAB PREP/POUR @ CEILINGS OF ROOMS)	2 days	Thu 6/11/09	Fri 6/12/09									
109				BSMT NON-QL AREA (U/G PLUMBING ROUGH-IN)	7 days	Fri 6/5/09	Mon 6/15/09									
110				AW BSMT (WATERPROOFING @ SOG)	10 days	Thu 3/11/10	Wed 3/24/10									
111				AW BSMT (POUR SLAB)	8 days	Thu 3/18/10	Mon 3/29/10									
112																
113				SUBSTRUCTURE CL R-K LV1 (PREP & POUR SOG)	5 days	Mon 7/6/09	Fri 7/10/09									
114				SUBSTRUCTURE CL R-N LV1 PREP SOG	3 days	Mon 7/6/09	Wed 7/8/09									
115				SUBSTRUCTURE CL R-N LV1 POUR SOG	1 day	Thu 7/9/09	Thu 7/9/09									
116				CL R-N LV1 PREP/POUR COLUMNS	12 days	Fri 7/10/09	Mon 7/27/09									
117				CL R-N LV1 Strip Formwork	12 days	Mon 7/13/09	Tue 7/28/09									
118																
119				CL 13/A-F (FRP WALL)	7 days	Fri 7/3/09	Mon 7/13/09									
120				CL 13/A-F (CURE & STRIP WALL)	2 days	Tue 7/14/09	Wed 7/15/09									
121				CL A-F/13-20 (INTERIOR PILE CAPS & GRADE BEAMS)	4 days	Wed 6/24/09	Mon 6/29/09									
122				CL A-F/13-20 (PILE CAPS & GRADE BEAMS)	16 days	Mon 5/11/09	Mon 6/1/09									
123				CL A-F/13-20 (FRP WALL)	15 days	Wed 5/27/09	Tue 6/16/09									
124				CL A-F/13-20 (CURE & STRIP WALL)	2 days	Thu 9/17/09	Fri 9/18/09									
125				CL A-F/13-14 (BACKFILL ALONG CL 13 WALL)	4 days	Mon 9/21/09	Thu 9/24/09									
126																
127				CL 13-20 (EXTERIOR DRAIN TILE & BACKFILL)	5 days	Thu 9/10/09	Wed 9/16/09									
128				CL 13-20 (WP EXTERIOR FND WALLS)	5 days	Tue 6/16/09	Mon 6/22/09									
129				CL 13-20 (WP INTERIOR FND WALLS)	4 days	Tue 6/23/09	Fri 6/26/09									
130				CL 13-20 (INTERIOR BACKFILL)	4 days	Mon 6/29/09	Thu 7/2/09									
131				CL 13-20 (U/G PLUMBING ROUGH-IN)	8 days	Fri 7/3/09	Tue 7/14/09									
132				CL 13-20 (WATERPROOFING @ SOG)	5 days	Wed 7/15/09	Tue 7/21/09									
133				SUBSTRUCTURE CL 13-20 PREP SOG	4 days	Fri 7/17/09	Wed 7/22/09									
134				SUBSTRUCTURE CL 13-20 POUR SOG	4 days	Tue 7/21/09	Fri 7/24/09									
135				CL 13-20 LV1 PREP/POUR COLUMNS	9 days	Mon 7/27/09	Thu 8/6/09									
136				CL 13-20 LV1 Strip Formwork	9 days	Wed 7/29/09	Mon 8/10/09									
137				LS LV1 FRP SHEAR WALL CL 15/D-E	5 days	Thu 7/30/09	Wed 8/5/09									
138																
139		MS	2	Floor System CL BB-Y Prep	5 days	Wed 7/29/09	Tue 8/4/09									
140		MS	2	Floor System Pour CL BB-Y	1 day	Wed 8/5/09	Wed 8/5/09									
141		MS	2	Floor System Strip Formwork CL BB-Y	1 day	Thu 8/6/09	Thu 8/6/09									
142		MS	2	Floor System CL Y-V Prep	5 days	Fri 8/7/09	Thu 8/13/09									
143		MS	2	Floor System Pour CL Y-V	1 day	Fri 8/14/09	Fri 8/14/09									
144		MS	2	Floor System Strip Formwork CL Y-V	1 day	Mon 8/17/09	Mon 8/17/09									

Task

Split

Milestone

Summary

Project Summary

External Tasks

External Milestone

Inactive Task

Inactive Milestone

Inactive Summary

Manual Task

Duration-only

Manual Summary Rollup

Manual Summary

Start-only

Finish-only

Deadline

Progress

Page 3

ID	Task Mode	Wing	Level	Task Name	Duration	Start	Finish	Nov 2, '08	Nov 23, '08	Dec 14, '08	Jan 6, '09	Jan 25, '09	Feb 15, '09	Mar 8, '09	Me
145		MS	2	CL W-V Prep Columns	4 days	Tue 8/18/09	Fri 8/21/09								
146		MS	2	CL W-V Pour Columns	3 days	Thu 8/20/09	Mon 8/24/09								
147		MS	2	CL W-V Strip Column Formwork	3 days	Mon 8/24/09	Wed 8/26/09								
148		MS	2	FRP Shear Wall CL V/4-5	5 days	Tue 8/18/09	Mon 8/24/09								
149		MS	2	Floor System CL V-S Prep	5 days	Wed 8/26/09	Tue 9/1/09								
150		MS	2	Floor System Pour CL V-S	1 day	Wed 9/2/09	Wed 9/2/09								
151		MS	2	Floor System Strip Formwork CL V-S	1 day	Thu 9/3/09	Thu 9/3/09								
152		MS	2	CL U-S Prep Columns	4 days	Fri 9/4/09	Wed 9/9/09								
153		MS	2	CL U-S Pour Columns	4 days	Tue 9/8/09	Fri 9/11/09								
154		MS	2	CL U-S Strip Column Formwork	4 days	Thu 9/10/09	Tue 9/15/09								
155		MS	2	Floor System CL S-P Prep	5 days	Tue 9/15/09	Mon 9/21/09								
156		MS	2	Floor System Pour CL S-P	1 day	Tue 9/22/09	Tue 9/22/09								
157		MS	2	Floor System Strip Formwork CL S-P	1 day	Wed 9/23/09	Wed 9/23/09								
158		MS	2	CL R-P Prep Columns	4 days	Thu 9/24/09	Tue 9/29/09								
159		MS	2	CL R-P Pour Columns	4 days	Mon 9/28/09	Thu 10/1/09								
160		MS	2	CL R-P Strip Column Formwork	4 days	Wed 9/30/09	Mon 10/5/09								
161		MS	2	Floor System CL P-N Prep	3 days	Mon 10/5/09	Wed 10/7/09								
162		MS	2	Floor System Pour CL P-N	1 day	Thu 10/8/09	Thu 10/8/09								
163		MS	2	Floor System Strip Formwork CL P-N	1 day	Fri 10/9/09	Fri 10/9/09								
164		MS	2	CL N Prep Columns	2 days	Mon 10/12/09	Tue 10/13/09								
165		MS	2	CL N Pour Columns	2 days	Wed 10/14/09	Thu 10/15/09								
166		MS	2	CL N Strip Column Formwork	2 days	Fri 10/16/09	Mon 10/19/09								
167															
168		MS	3	Floor System CL W-T Prep	5 days	Mon 10/19/09	Fri 10/23/09								
169		MS	3	Floor System Pour CL W-T	1 day	Mon 10/26/09	Mon 10/26/09								
170		MS	3	Floor System Strip Formwork CL W-T	1 day	Tue 10/27/09	Tue 10/27/09								
171		MS	3	Floor System CL T-Q Prep	5 days	Wed 10/28/09	Tue 11/3/09								
172		MS	3	Floor System Pour CL T-Q	1 day	Wed 11/4/09	Wed 11/4/09								
173		MS	3	Floor System Strip Formwork CL T-Q	1 day	Thu 11/5/09	Thu 11/5/09								
174		MS	3	CL R-Q Prep Columns	3 days	Fri 11/6/09	Tue 11/10/09								
175		MS	3	CL R-Q Pour Columns	3 days	Tue 11/10/09	Thu 11/12/09								
176		MS	3	CL R-Q Strip Column Formwork	3 days	Thu 11/12/09	Mon 11/16/09								
177		MS	3	Floor System CL Q-N Prep	3 days	Mon 11/16/09	Wed 11/18/09								
178		MS	3	Floor System Pour CL Q-N	1 day	Thu 11/19/09	Thu 11/19/09								
179		MS	3	Floor System Strip Formwork CL Q-N	1 day	Fri 11/20/09	Fri 11/20/09								
180		MS	3	CL P-N Prep Columns	3 days	Mon 11/23/09	Wed 11/25/09								
181		MS	3	CL P-N Pour Columns	3 days	Wed 11/25/09	Fri 11/27/09								
182		MS	3	CL P-N Strip Column Formwork	3 days	Fri 11/27/09	Tue 12/1/09								
183															
184		MS	MECH	Floor System CL R-N Prep	7 days	Tue 12/1/09	Wed 12/9/09								
185		MS	MECH	Floor System Pour CL R-N	1 day	Thu 12/10/09	Thu 12/10/09								
186		MS	MECH	Floor System Strip Formwork CL R-N	1 day	Fri 12/11/09	Fri 12/11/09								
187															
188		LS	2	Floor System CL 20-17 Prep	5 days	Tue 8/11/09	Mon 8/17/09								
189		LS	2	Floor System Pour CL 20-17	1 day	Tue 8/18/09	Tue 8/18/09								
190		LS	2	Floor System Strip Formwork CL 20-17	1 day	Wed 8/19/09	Wed 8/19/09								
191		LS	2	Floor System CL 17-14 Prep	5 days	Thu 8/20/09	Wed 8/26/09								
192		LS	2	Floor System Pour CL 17-14	1 day	Thu 8/27/09	Thu 8/27/09								

Redesign Schedule

Task

Split

Milestone

Summary

Project Summary

External Tasks

External Milestone

Inactive Task

Inactive Milestone

Inactive Summary

Manual Task

Duration-only

Manual Summary Rollup

Manual Summary

Start-only

Finish-only

Deadline

Progress

Page 4

ID	Task Mode	Wing	Level	Task Name	Duration	Start	Finish	28	Nov 2, '08	Nov 23, '08	Dec 14, '08	Jan 6, '09	Jan 25, '09	Feb 15, '09	Mar 8, '09	Me
193		LS	2	Floor System Strip Formwork CL 17-14	1 day	Fri 8/28/09	Fri 8/28/09		S	S	M	T	W	T	F	S
194		LS	2	CL 16-14 Prep Columns	5 days	Mon 8/31/09	Fri 9/4/09									
195		LS	2	CL 16-14 Pour Columns	4 days	Wed 9/2/09	Mon 9/7/09									
196		LS	2	CL 16-14 Strip Column Formwork	4 days	Fri 9/4/09	Wed 9/9/09									
197		LS	2	FRP SHEAR WALL CL 15/D-E	5 days	Mon 8/31/09	Fri 9/4/09									
198		LS	2	Floor System CL 14-13 Prep	3 days	Wed 9/9/09	Fri 9/11/09									
199		LS	2	Floor System Pour CL 14-13	1 day	Mon 9/14/09	Mon 9/14/09									
200		LS	2	Floor System Strip Formwork CL 14-13	1 day	Tue 9/15/09	Tue 9/15/09									
201		LS	2	CL 13 Prep Columns	2 days	Wed 9/16/09	Thu 9/17/09									
202		LS	2	CL 13 Pour Columns	2 days	Fri 9/18/09	Mon 9/21/09									
203		LS	2	CL 13 Strip Column Formwork	2 days	Tue 9/22/09	Wed 9/23/09									
204																
205		LS	3	Floor System CL 21-18 Prep	5 days	Wed 9/23/09	Tue 9/29/09									
206		LS	3	Floor System Pour CL 21-18	1 day	Wed 9/30/09	Wed 9/30/09									
207		LS	3	Floor System Strip Formwork CL 21-18	1 day	Thu 10/1/09	Thu 10/1/09									
208		LS	3	Floor System CL 18-15 Prep	5 days	Fri 10/2/09	Thu 10/8/09									
209		LS	3	Floor System Pour CL 18-15	1 day	Fri 10/9/09	Fri 10/9/09									
210		LS	3	Floor System Strip Formwork CL 18-15	1 day	Mon 10/12/09	Mon 10/12/09									
211		LS	3	CL 16-15 Prep Columns	3 days	Tue 10/13/09	Thu 10/15/09									
212		LS	3	CL 16-15 Pour Columns	3 days	Thu 10/15/09	Mon 10/19/09									
213		LS	3	CL 16-15 Strip Column Formwork	3 days	Mon 10/19/09	Wed 10/21/09									
214		LS	3	Floor System CL 15-13 Prep	3 days	Wed 10/21/09	Fri 10/23/09									
215		LS	3	Floor System Pour CL 15-13	1 day	Mon 10/26/09	Mon 10/26/09									
216		LS	3	Floor System Strip Formwork CL 15-13	1 day	Tue 10/27/09	Tue 10/27/09									
217		LS	3	CL 14-13 Prep Columns	3 days	Wed 10/28/09	Fri 10/30/09									
218		LS	3	CL 14-13 Pour Columns	3 days	Fri 10/30/09	Tue 11/3/09									
219		LS	3	CL 14-13 Strip Column Formwork	3 days	Tue 11/3/09	Thu 11/5/09									
220																
221		LS	MECH	Floor System CL 16-13 Prep	4 days	Thu 11/5/09	Tue 11/10/09									
222		LS	MECH	Floor System Pour CL 16-13	1 day	Wed 11/11/09	Wed 11/11/09									
223		LS	MECH	Floor System Strip Formwork CL 16-13	1 day	Thu 11/12/09	Thu 11/12/09									
224																
225																
226				MS CL M-H LV1 (STEEL AND DECK)	8 days	Mon 8/10/09	Wed 8/19/09									
227				MS CL M-H LV2 (STEEL)	6 days	Thu 8/20/09	Thu 8/27/09									
228				MS CL M-H LV3 (STEEL AND DECK)	6 days	Fri 8/28/09	Fri 9/4/09									
229				MS CL M-H LV4 (STEEL)	6 days	Mon 9/7/09	Mon 9/14/09									
230				MS CL M-H ROOF (STEEL)	6 days	Tue 9/15/09	Tue 9/22/09									
231				MS CL M-H LV1 DETAIL	15 days	Thu 8/20/09	Wed 9/9/09									
232				MS CL M-H LV2 DETAIL	15 days	Fri 8/28/09	Thu 9/17/09									
233				MS CL M-H LV3 DETAIL	15 days	Mon 9/7/09	Fri 9/25/09									
234				MS CL M-H LV4 DETAIL	15 days	Tue 9/15/09	Mon 10/5/09									
235				MS CL M-H ROOF DETAIL	15 days	Wed 9/23/09	Tue 10/13/09									
236																
237				MS BSMT FRP SHEAR WALL CL K, 2, 5	10 days	Fri 9/4/09	Thu 9/17/09									
238				MS LV1 FRP SHEAR WALL CL K, 2, 5	10 days	Fri 9/18/09	Thu 10/1/09									
239				MS LV2 FRP SHEAR WALL CL K, 2, 5	10 days	Fri 10/2/09	Thu 10/15/09									
240				MS LV3 FRP SHEAR WALL CL K, 2, 5	10 days	Fri 10/16/09	Thu 10/29/09									

Redesign Schedule

Task

Split

Milestone

Summary

Project Summary

External Tasks

External Milestone

Inactive Task

Inactive Milestone

Inactive Summary

Manual Task

Duration-only

Manual Summary Rollup

Manual Summary

Start-only

Finish-only

Deadline

Progress

Page 5

ID	Task Mode	Wing	Level	Task Name	Duration	Start	Finish	Nov 2, '09	Nov 23, '09	Dec 14, '09	Jan 6, '10	Jan 25, '10	Feb 15, '10	Mar 8, '10	Mar 22, '10
241				MS CURE SHEAR WALLS	7 days	Fri 10/30/09	Mon 11/9/09	S	S	M	T	W	T	F	S
242															
243				LS CL 12-8 LV1 (STEEL AND DECK)	8 days	Wed 9/23/09	Fri 10/2/09								
244				LS CL 12-8 LV2 (STEEL)	5 days	Mon 10/5/09	Fri 10/9/09								
245				LS CL 12-8 LV3 (STEEL AND DECK)	5 days	Mon 10/12/09	Fri 10/16/09								
246				LS CL 12-8 LV4 (STEEL)	5 days	Mon 10/19/09	Fri 10/23/09								
247				LS CL 12-8 ROOF (STEEL)	5 days	Mon 10/26/09	Fri 10/30/09								
248				LS CL 12-8 LV1 (DETAIL)	15 days	Mon 10/5/09	Fri 10/23/09								
249				LS CL 12-8 LV2 (DETAIL)	15 days	Mon 10/12/09	Fri 10/30/09								
250				LS CL 12-8 LV3 (DETAIL)	15 days	Mon 10/19/09	Fri 11/6/09								
251				LS CL 12-8 LV4 (DETAIL)	15 days	Mon 10/26/09	Fri 11/13/09								
252				LS CL 12-8 LV ROOF (DETAIL)	15 days	Mon 11/2/09	Fri 11/20/09								
253															
254				LS BSMT FRP SHEAR WALL CL 10, E, B	10 days	Tue 10/20/09	Mon 11/2/09								
255				LS LV1 FRP SHEAR WALL CL 10, E, B	10 days	Tue 11/3/09	Mon 11/16/09								
256				LS LV2 FRP SHEAR WALL CL 10, E, B	10 days	Tue 11/17/09	Mon 11/30/09								
257				LS LV3 FRP SHEAR WALL CL 10, E, B	10 days	Tue 12/1/09	Mon 12/14/09								
258				LS CURE SHEAR WALLS	7 days	Tue 12/15/09	Wed 12/23/09								
259															
260				AW LV1 CL1-6/A-H ERECT	3 days	Mon 8/3/09	Wed 8/5/09								
261				AW LV1 CL1-6/A-H COMPLETE	2 days	Thu 8/6/09	Fri 8/7/09								
262				AW LV1 CL1-6/A-H DETAIL	5 days	Mon 8/10/09	Fri 8/14/09								
263				AW LV1 POUR SOMD	4 days	Mon 8/17/09	Thu 8/20/09								
264				AW LV1 CURE SOMD	7 days	Fri 8/21/09	Mon 8/31/09								
265															
266				AREAWAY MS H-E ERECT	20 days	Mon 11/23/09	Fri 12/18/09								
267				AREAWAY LS 8-5 ERECT	10 days	Mon 12/7/09	Fri 12/18/09								
268				AREAWAY MS H-E DETAIL	20 days	Tue 11/24/09	Mon 12/21/09								
269				AREAWAY LS 8-5 DETAIL	10 days	Tue 12/8/09	Mon 12/21/09								
270				AREAWAY E-A/5-1 ERECT	15 days	Tue 12/15/09	Mon 1/4/10								
271				AREAWAY E-A/5-1 DETAIL	20 days	Fri 12/18/09	Thu 1/14/10								
272															
273															
274				MS NORTH ELEVATION PC PANELS	10 days	Mon 12/21/09	Fri 1/1/10								
275				MS EAST ELEVATION PC PANELS	5 days	Mon 1/4/10	Fri 1/8/10								
276				MS SOUTH ELEVATION PC PANELS	13 days	Mon 1/11/10	Wed 1/27/10								
277				LS WEST ELEVATION PC PANELS	7 days	Thu 1/28/10	Fri 2/5/10								
278				LS SOUTH ELEVATION PC PANELS	5 days	Mon 2/8/10	Fri 2/12/10								
279				LS EAST ELEVATION PC PANELS	11 days	Mon 2/15/10	Mon 3/1/10								
280				AREAWAY LS WEST ELEVATION PC PANELS	7 days	Tue 3/2/10	Wed 3/10/10								
281				AREAWAY MS NORTH ELEVATION PC PANELS	9 days	Mon 3/8/10	Thu 3/18/10								

Redesign Schedule

Task

Split

Milestone

Summary

Project Summary

External Tasks

External Milestone

Inactive Task

Inactive Milestone

Inactive Summary

Manual Task

Duration-only

Manual Summary Rollup

Manual Summary

Start-only

Finish-only

Deadline

Progress

Page 6

Project Estimates

Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 22'	Concrete, Brick, Reinforcing	215.875	SF	60	12952.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	Existing	22	LF	150	3300
Insulation	3" Rigid	175.24	SF	6.25	1095.25
Window Assembly/Glass	2-pane glazing assembly	176	SF	55	9680
				Total Cost	28777.75
Existing Big Panel					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 31'	Concrete, Brick, Reinforcing	304.186	SF	60	18251.16
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	Existing	22	LF	150	3300
Insulation	3" Rigid	370.215	SF	6.25	2313.84375
Window Assembly/Glass	2-pane glazing assembly	248	SF	55	13640
				Total Cost	39255.00375
Existing Small Panel					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 14'	Concrete, Brick, Reinforcing	137.375	SF	60	8242.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	24"	22	LF	150	3300
Insulation	3" Rigid	174.958	SF	6.25	1093.4875
Window Assembly/Glass	2-pane glazing assembly	112	SF	55	6160
				Total Cost	20545.9875

Existing Façade Components with 2-Pane Glazing Estimate

Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 22'	Concrete, Brick, Reinforcing	215.875	SF	60	12952.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	Existing	22	LF	150	3300
Insulation	3" Rigid	175.24	SF	6.25	1095.25
Window Assembly/Glass	3-pane glazing assembly	176	SF	65	11440
				Total Cost	30537.75
Existing Big Panel					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 31'	Concrete, Brick, Reinforcing	304.186	SF	60	18251.16
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	Existing	22	LF	150	3300
Insulation	3" Rigid	370.215	SF	6.25	2313.84375
Window Assembly/Glass	3-pane glazing assembly	248	SF	65	16120
				Total Cost	41735.00375
Existing Small Panel					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 14'	Concrete, Brick, Reinforcing	137.375	SF	60	8242.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	24"	22	LF	150	3300
Insulation	3" Rigid	174.958	SF	6.25	1093.4875
Window Assembly/Glass	3-pane glazing assembly	112	SF	65	7280
				Total Cost	21665.9875

Existing Façade Components with 3-Pane Glazing Estimate

Redesign, 70%					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 22'	Concrete, Brick, Reinforcing	215.875	SF	60	12952.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	16"	22	LF	100	2200
Insulation	3" Rigid	175.24	SF	6.25	1095.25
Window Assembly/Glass	3-pane glazing assembly	176	SF	65	11440
				Total Cost	29437.75
Existing Big Panel, 70%					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 31'	Concrete, Brick, Reinforcing	304.186	SF	60	18251.16
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	16"	22	LF	100	2200
Insulation	3" Rigid	370.215	SF	6.25	2313.84375
Window Assembly/Glass	3-pane glazing assembly	248	SF	65	16120
				Total Cost	40635.00375
Existing Small Panel, 70%					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 14'	Concrete, Brick, Reinforcing	137.375	SF	60	8242.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	16"	22	LF	100	2200
Insulation	3" Rigid	174.958	SF	6.25	1093.4875
Window Assembly/Glass	3-pane glazing assembly	112	SF	65	7280
				Total Cost	20565.9875

Redesigned Façade Components at 70% WW Ratio Estimate

Redesign, 60%					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 22'	Concrete, Brick, Reinforcing	240.075	SF	60	14404.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	16"	22	LF	100	2200
Insulation	3" Rigid	198.056	SF	6.25	1237.85
Window Assembly/Glass	3-pane glazing assembly	154	SF	65	10010
				Total Cost	29602.35
Redesigned Big Panel, 60%					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 31'	Concrete, Brick, Reinforcing	338.288	SF	60	20297.28
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	16"	22	LF	100	2200
Insulation	3" Rigid	402.354	SF	6.25	2514.7125
Window Assembly/Glass	3-pane glazing assembly	217	SF	65	14105
				Total Cost	40866.9925
Redesigned Small Panel, 60%					
Component	Types	Quantity	Unit	Cost per Unit	Cost
Precast Panel, 14'	Concrete, Brick, Reinforcing	152.775	SF	60	9166.5
Structural Steel Connections	Lateral Connection	4	EA	250	1000
	Bearing Connection	2	EA	250	500
	Seismic Connection	1	EA	250	250
Light Shelf	16"	22	LF	100	2200
Insulation	3" Rigid	188.681	SF	6.25	1179.25625
Window Assembly/Glass	3-pane glazing assembly	98	SF	65	6370
				Total Cost	20665.75625

Redesigned Façade Components at 60% WW Ratio Estimate

Material (Items Only)

Description	Quantity 1		Quantity 2		Material Cost		Labor Cost		Total Cost
					Unit Cost	Total Cost	Unit Cost	Total Cost	
Materials									\$1,722,146.17
Floor Generic - 6 1/4" - slab	55,281.235	sq. ft.	1,066.382	cubic yd	150.25	160,223.87	21.15	22,553.98	182,777.85
Floor Generic - 7 1/2" - slab	53,518.375	sq. ft.	1,238.851	cubic yd	111.25	137,822.20	21.15	26,201.70	164,023.91
W-Wide Flange1\W12X19	1,089.000	ft	10.346	ft	1,328.80	13,747.10	263.20	2,722.94	16,470.04
W-Wide Flange1\W14X132	50.000	ft	3.300	ft	1,328.80	4,385.04	263.20	868.56	5,253.60
W-Wide Flange1\W14X43	550.000	ft	11.825	ft	1,328.80	15,713.06	263.20	3,112.34	18,825.40
W-Wide Flange1\W18X35	21.500	ft	0.376	ft	1,328.80	499.96	263.20	99.03	598.99
W-Wide Flange1\W18X40	1,320.000	ft	26.400	ft	1,328.80	35,080.32	263.20	6,948.48	42,028.80
W-Wide Flange1\W18X76	682.000	ft	25.916	ft	1,328.80	34,437.18	263.20	6,821.09	41,258.27
W-Wide Flange1\W21X44	5,412.000	ft	119.064	ft	1,328.80	158,212.24	263.20	31,337.64	189,549.88
W-Wide Flange1\W21X50	176.000	ft	4.400	ft	1,328.80	5,846.72	263.20	1,158.08	7,004.80
W-Wide Flange1\W21X68	1,210.000	ft	41.140	ft	1,328.80	54,666.83	263.20	10,828.05	65,494.88
W-Wide Flange1\W24X176	264.000	ft	23.232	ft	1,328.80	30,870.68	263.20	6,114.66	36,985.34
W-Wide Flange1\W24X55	3,366.000	ft	92.565	ft	1,328.80	123,000.37	263.20	24,363.11	147,363.48
W-Wide Flange1\W24X76	836.000	ft	31.768	ft	1,328.80	42,213.32	263.20	8,361.34	50,574.66
W-Wide Flange1\W24X84	1,540.000	ft	64.680	ft	1,328.80	85,946.78	263.20	17,023.78	102,970.56
W-Wide Flange1\W27X84	528.000	ft	22.176	ft	1,328.80	29,467.47	263.20	5,836.72	35,304.19
W-Wide Flange1\W40X149	264.000	ft	19.668	ft	1,328.80	26,134.84	263.20	5,176.62	31,311.46
W-Wide Flange1\W40X167	88.000	ft	7.348	ft	1,328.80	9,764.02	263.20	1,933.99	11,698.02
W-Wide Flange1\W44X230	176.000	ft	20.240	ft	1,328.80	26,894.91	263.20	5,327.17	32,222.08
W-Wide Flange-Column1\W14X176	980.000	ft	86.240	ft	1,328.80	114,595.71	263.20	22,698.37	137,294.08
W-Wide Flange-Column1\W14X193	75.000	ft	7.238	ft	1,328.80	9,617.19	263.20	1,904.91	11,522.10
W-Wide Flange-Column1\W14X211	335.458	ft	35.391	ft	1,328.80	47,027.37	263.20	9,314.87	56,342.24
W-Wide Flange-Column1\W14X233	362.833	ft	42.270	ft	1,328.80	56,168.49	263.20	11,125.49	67,293.97
W-Wide Flange-Column1\W14X257	40.625	ft	5.220	ft	1,328.80	6,936.75	263.20	1,373.99	8,310.74
W-Wide Flange-Column1\W14X311	43.792	ft	6.810	ft	1,328.80	9,048.60	263.20	1,792.29	10,840.89
W-Wide Flange-Column1\W14X61	637.042	ft	19.430	ft	1,328.80	25,818.29	263.20	5,113.92	30,932.21
W-Wide Flange-Column1\W14X68	398.604	ft	13.553	ft	1,328.80	18,008.61	263.20	3,567.03	21,575.64

Existing Structural Estimate

Material (Items Only)

Description	Quantity 1		Quantity 2		Material Cost		Labor Cost		Total Cost
					Unit Cost	Total Cost	Unit Cost	Total Cost	
W-Wide Flange-Column1\W 14X74	406.167	1	15.028	1	1,328.80	19,969.43	263.20	3,955.41	23,924.84
W-Wide Flange-Column1\W 14X82	210.125	1	8.615	1	1,328.80	11,447.78	263.20	2,267.50	13,715.28
W-Wide Flange-Column1\W 14X90	1,953.938	1	87.927	1	1,328.80	116,837.65	263.20	23,142.44	139,980.08
W-Wide Flange-Column1\W 14X99	237.271	1	11.745	1	1,328.80	15,606.63	263.20	3,091.26	18,697.89
Total Cost								\$1,722,146.17	

Existing Steel and Slab Estimate

Metal Decking		2009 RS Means Concrete	
Type	Mat. Cost	SF	Total
3" 18 ga.	3.54	108799.61	408606.3
	Labor Cost		
	0.4		46170.2
Total for Building			454776.5

Existing Metal Deck Estimate

[illegible]

Existing Rebar Estimate

Finishing	2009 RS Means Concrete			
LW Concrete				
03 35 29.30 (0100)	Manual Screed, Bull Float			
Crew C-10	Labor	0.22	per SF	
		One Crew		Two Crews
	Labor	12902.53	Labor	25805.06
NW Concrete				
03 35 29.30 (0100)	Manual Screed, Bull Float			
Crew C-10	Labor	0.22	per SF	
		One Crew		Two Crews
	Labor	12491.08	Labor	24982.16

Existing Finish Estimate

Formwork

2009 RS Means Concrete

LW Concrete, 6-1/4"

03 11 13.35 (7101)	Edge Forms, 7-12" high, elevated slab			
4-use	Floor Slab Formwork			
Crew C-1	Material	0.17	per SFCA	
	Labor	3.46	per SFCA	
	One Crew		Three Crews	10% Waste
	Material	181.8559	Material	545.5678 600.1246075
	Labor	3701.303	Labor	11103.91 11103.90985
	Total	3883.159	Total	11649.48 11704.03446

NW Concrete, 7-1/2"

03 11 13.35 (7101)	Edge Forms, 7-12" high, elevated slab			
4-use	Floor Slab Formwork			
Crew C-1	Material	0.17	per SFCA	
	Labor	3.46	per SFCA	
	One Crew		Three Crews	10% Waste
	Material	190.1221	Material	570.3664 627.4029988
	Labor	3869.544	Labor	11608.63 11608.63303
	Total	4059.666	Total	12179 12236.03602

SFCA

229.1667	per 5x5 pour	Assume 5x5 bays per pour	
458.3333	2 units	110	110
183.3333	per 3x5 pour	3x5 bays per pour	
550	3 units	66	110

SFCA

229.1667	per 5x5 pour	Assume 5x5 bays per pour	
687.5	3 units	110	110
183.3333	per 3x5 pour	3x5 bays per pour	
366.6667	2 units	66	110

Existing Formwork Estimate

Cranes								
Dates for Steel Erection of Material Science Wing, CL BB-N					Duration		Cost	
July 7, 2009 - August 20, 2009					35 days		137500	
Dates for Steel Erection of Life Science Wing, CL 21-13					Duration		Cost	
October 19, 2009 - January 5, 2010					60 days		225000	
							Total	362500
300 ton crane and 275 ton crane								
25,000 per month			Rental					
2500 per day			Operations					
Assume rental cost is paid every four weeks at the beginning of the first week of the cycle.								

Existing Crane Estimate

Welding					
Add additional 15% to total steel cost for welding in wings					

Existing Welding Estimate

Material Science Wing				Life Science Wing			
First Floor		Floor Dimensions		First Floor		Floor Dimensions	
		113	287.5			113	155.5
Slab				Slab			
Thickness	4.5	inch	# of Columns	Thickness	4.5	inch	# of Columns
Area	32487.5	SF	14	Area	17571.5	SF	8
Volume	12182.81	CF		Volume	6589.313	CF	
	451.2153	CY			244.0486	CY	
Girders				Girders			
Thickness	10	inch		Thickness	10	inch	
Length	1725	LF		Length	933	LF	
Width	3	LF		Width	3	LF	
Volume	4312.5	CF		Volume	2332.5	CF	
	159.7222	CY			86.38889	CY	
Beams				Beams			
Thickness	10	inch		Thickness	10	inch	
Length	1582	LF		Length	904	LF	
Width	1.5	LF		Width	1.5	LF	
Volume	1977.5	CF		Volume	1130	CF	
	73.24074	CY			41.85185	CY	
Joists				Joists			
Thickness	10	inch	Joists per bay	Thickness	10	inch	Joists per bay
Length	7980	LF	Bays	Length	4560	LF	Bays
Width	0.5	LF	Total # of Joists	Width	0.5	LF	Total # of Joists
Volume	3325	CF	Length of Joist	Volume	1900	CF	Length of Joist
	123.1481	CY	19		70.37037	CY	19
Second Floor		Floor Dimensions		Second Floor		Floor Dimensions	
		113	177.5			113	177.5
Slab				Slab			
Thickness	4.5	inch	# of Columns	Thickness	4.5	inch	# of Columns
Area	20057.5	SF	9	Area	20057.5	SF	9
Volume	7521.563	CF		Volume	7521.563	CF	
	278.5764	CY			278.5764	CY	
Girders				Girders			
Thickness	10	inch		Thickness	10	inch	
Length	1065	LF		Length	1065	LF	
Width	3	LF		Width	3	LF	
Volume	2662.5	CF		Volume	2662.5	CF	
	98.61111	CY			98.61111	CY	
Beams				Beams			
Thickness	10	inch		Thickness	10	inch	
Length	1017	LF		Length	1017	LF	
Width	1.5	LF		Width	1.5	LF	
Volume	1271.25	CF		Volume	1271.25	CF	
	47.08333	CY			47.08333	CY	
Joists				Joists			
Thickness	10	inch	Joists per bay	Thickness	10	inch	Joists per bay
Length	5130	LF	Bays	Length	5130	LF	Bays
Width	0.5	LF	Total # of Joists	Width	0.5	LF	Total # of Joists
Volume	2137.5	CF	Length of Joist	Volume	2137.5	CF	Length of Joist
	79.16667	CY	19		79.16667	CY	19

Third Floor		Floor Dimensions		Third Floor		Floor Dimensions	
		113	67.5			113	67.5
Slab				Slab			
Thickness	4.5	inch	# of Columns	Thickness	4.5	inch	# of Columns
Area	7627.5	SF	4	Area	7627.5	SF	4
Volume	2860.313	CF		Volume	2860.313	CF	
	105.9375	CY			105.9375	CY	
Girders				Girders			
Thickness	10	inch		Thickness	10	inch	
Length	405	LF		Length	405	LF	
Width	3	LF		Width	3	LF	
Volume	1012.5	CF		Volume	1012.5	CF	
	37.5	CY			37.5	CY	
Beams				Beams			
Thickness	10	inch		Thickness	10	inch	
Length	452	LF		Length	452	LF	
Width	1.5	LF		Width	1.5	LF	
Volume	565	CF		Volume	565	CF	
	20.92593	CY			20.92593	CY	
Joists		Joists per bay		Joists		Joists per bay	
Thickness	10	inch	5	Thickness	10	inch	5
Length	2280	LF	4	Length	2280	LF	4
Width	0.5	LF	Total # of Joists	Width	0.5	LF	Total # of Joists
Volume	950	CF	19	Volume	950	CF	19
	35.18519	CY			35.18519	CY	

Building Total		Concrete Cost
Total	2655.958 CY	295475.3646
With 10% waste factor	2921.554 CY	325022.901

4000 psi, NW concrete w/ winter concrete admixture	
Base	106 per CY
Winter	5.25 per CY
Total	111.25

RSMeans Concrete & Masonry Cost Data 2009	
03 31	Structural Concrete
03 31 05.3	Normal Weight Concrete, Ready Mix p70

Material Science Wing				Life Science Wing			
First Floor		First Floor		First Floor		First Floor	
Floor Dimensions		Floor Dimensions		Floor Dimensions		Floor Dimensions	
113		287.5		113		155.5	
Slab		#3		Slab		#3	
Vert. Rebar/Bay		19 Unit		Vert. Rebar/Bay		19 Unit	
Horiz. Rebar/Bay		14 Unit		Horiz. Rebar/Bay		14 Unit	
Total Length		42607.5 LF		Total Length		22942.5 LF	
Weight, #3		8.01021 Tons		Weight, #3		4.31319 Tons	

Second Floor				Second Floor				Floor Dimensions			
								113 177.5			
Slab				Slab							
Vert. Rebar/Bay	19	Unit		Vert. Rebar/Bay	19	Unit		# of Columns Lines			
Horiz. Rebar/Bay	14	Unit		Horiz. Rebar/Bay	14	Unit		9			
Total Length	26220	LF		Total Length	26220	LF		# of Bays			
Weight, #3	4.92936	Tons		Weight, #3	4.92936	Tons		40			

[illegible]

		Slab			
		Total	With 5% waste factor		
	#3	25.87914	27.173097		
	Cost/Ton				
	1327	34341.6188	36058.69972		
		Beam/Joist			
		Total	With 5% waste factor		
	#3	4.9632	5.21136		
	#6	13.69824	14.383152		
	#7	48.93336	51.380028		
	Costs				
	Cost/Ton	Total	With 5% waste factor		
#3	1327	6586.1664	6915.47472		
#6	1228	16821.4387	17662.51066		
#7	1222	59796.5659	62786.39422		

Redesign Floor System Rebar Estimate, Total

Material Science Wing			Life Science Wing		
First Floor	Floor Dimensions		First Floor	Floor Dimensions	
	113	286		113	154
Interior Girder			Interior Girder		

Redesign Floor System Girder Rebar Estimate, First Floor

Unit Wt.			Cost per Ton	
#3	0.376	lb/ft	1327	
#6	1.502	lb/ft	1228	
#7	2.044	lb/ft	1222	
#9	3.4	lb/ft	1222	
Material Science			Life Science	
# of Columns Lines			# of Columns Lines	
14			8	
# of Bays			# of Bays	
13			7	
# of Column Lines				
6				
Development Length, Top				
1.75				
Development Length, Bottom				
0.5				

Redesign Floor System Girder Rebar Estimate Info, First Floor

Exterior Girder			Exterior Girder		
# of Top Rebar, Full Length	2	Unit	# of Top Rebar, Full Length	2	Unit
Length of Top Rebar, Full Length	287.75	LF	Length of Top Rebar, Full Length	155.75	LF
Total Length, #7	1151	LF	Total Length, #7	623	LF
Weight, #7	1.176322	Tons	Weight, #7	0.636706	Tons
# of Bottom Rebar, Full Length	2	Unit	# of Bottom Rebar, Full Length	2	Unit
Length of Bottom Rebar, Full Length	286.5	LF	Length of Bottom Rebar, Full Length	154.5	LF
Total Length, #7	1146	LF	Total Length, #7	618	LF
Weight, #7	1.171212	Tons	Weight, #7	0.631596	Tons
# of Bottom Rebar, Exterior Span	5	Unit	# of Bottom Rebar, Exterior Span	5	Unit
Length of Bottom Rebar, Full Length	9.3333	LF	Length of Bottom Rebar, Full Length	9.3333	LF
Total Length, #7	93.333	LF	Total Length, #7	93.333	LF
Weight, #7	0.095386326	Tons	Weight, #7	0.095386	Tons
# of Bottom Rebar, Interior Span	5	Unit	# of Bottom Rebar, Interior Span	5	Unit
Length of Bottom Rebar, Full Length	11.8333	LF	Length of Bottom Rebar, Full Length	11.8333	LF
Total Length, #7	1419.996	LF	Total Length, #7	709.998	LF
Weight, #7	1.451235912	Tons	Weight, #7	0.725618	Tons
# of Top Rebar, First Interior Column	6	Unit	# of Top Rebar, First Interior Column	6	Unit
Length of Bottom Rebar, Full Length	13.75	LF	Length of Bottom Rebar, Full Length	13.75	LF
Total Length, #7	165	LF	Total Length, #7	165	LF
Weight, #7	0.16863	Tons	Weight, #7	0.16863	Tons
# of Top Rebar, All Other Interior Col.	4	Unit	# of Top Rebar, All Other Interior Col.	4	Unit
Length of Bottom Rebar, Full Length	10.5	LF	Length of Bottom Rebar, Full Length	10.5	LF
Total Length, #7	1008	LF	Total Length, #7	504	LF
Weight, #7	1.030176	Tons	Weight, #7	0.515088	Tons
# of Ties/Girder	25	Unit	# of Ties/Girder	25	Unit
Length of Tie Configuration	7.667	LF	Length of Tie Configuration	7.667	LF
Total Length, #3	4983.55	LF	Total Length, #3	2683.45	LF
Weight, #3	0.9369074	Tons	Weight, #3	0.504489	Tons

Material Science Wing			Life Science Wing		
Second Floor	Floor Dimensions		Second Floor	Floor Dimensions	
	113	176		113	176
Interior Girder			Interior Girder		
# of Top Rebar, Full Length	4	Unit	# of Top Rebar, Full Length	4	Unit
Length of Top Rebar, Full Length	177.75	LF	Length of Top Rebar, Full Length	177.75	LF
Total Length, #9	2844	LF	Total Length, #9	2844	LF
Weight, #9	4.8348	Tons	Weight, #9	4.8348	Tons
# of Bottom Rebar, Full Length	4	Unit	# of Bottom Rebar, Full Length	4	Unit
Length of Bottom Rebar, Full Length	176.5	LF	Length of Bottom Rebar, Full Length	176.5	LF
Total Length, #9	2824	LF	Total Length, #9	2824	LF
Weight, #9	4.8008	Tons	Weight, #9	4.8008	Tons
# of Bottom Rebar, Exterior Span	6	Unit	# of Bottom Rebar, Exterior Span	6	Unit
Length of Bottom Rebar, Full Length	11.75	LF	Length of Bottom Rebar, Full Length	11.75	LF
Total Length, #9	282	LF	Total Length, #9	282	LF
Weight, #9	0.4794	Tons	Weight, #9	0.4794	Tons
# of Bottom Rebar, Interior Span	5	Unit	# of Bottom Rebar, Interior Span	5	Unit
Length of Bottom Rebar, Full Length	11.8333	LF	Length of Bottom Rebar, Full Length	11.8333	LF
Total Length, #9	1656.662	LF	Total Length, #9	1656.662	LF
Weight, #9	2.8163254	Tons	Weight, #9	2.816325	Tons
# of Top Rebar, First Interior Column	6	Unit	# of Top Rebar, First Interior Column	6	Unit
Length of Bottom Rebar, Full Length	12.5	LF	Length of Bottom Rebar, Full Length	12.5	LF
Total Length, #9	300	LF	Total Length, #9	300	LF
Weight, #9	0.51	Tons	Weight, #9	0.51	Tons
# of Top Rebar, All Other Interior Col.	6	Unit	# of Top Rebar, All Other Interior Col.	6	Unit
Length of Bottom Rebar, Full Length	11.8333	LF	Length of Bottom Rebar, Full Length	11.8333	LF
Total Length, #9	1987.9944	LF	Total Length, #9	1987.994	LF
Weight, #9	3.37959048	Tons	Weight, #9	3.37959	Tons
# of Ties/Girder	25	Unit	# of Ties/Girder	25	Unit
Length of Tie Configuration	9.8333	LF	Length of Tie Configuration	9.8333	LF
Total Length, #3	7866.64	LF	Total Length, #3	7866.64	LF
Weight, #3	1.47892832	Tons	Weight, #3	1.478928	Tons

Redesign Floor System Girder Rebar Estimate, Second Floor

Unit Wt.		Cost per Ton	
#3	0.376 lb/ft	1327	
#6	1.502 lb/ft	1228	
#7	2.044 lb/ft	1222	
#9	3.4 lb/ft	1222	

Material Science	Life Science
# of Columns Lines	# of Columns Lines
9	9
# of Bays	# of Bays
8	8
# of Column Lines	
6	

Development Length, Top
1.75
Development Length, Bottom
0.5

Redesign Floor System Girder Rebar Estimate Info, Second Floor

Exterior Girder			Exterior Girder		
# of Top Rebar, Full Length	2	Unit	# of Top Rebar, Full Length	2	Unit
Length of Top Rebar, Full Length	177.75	LF	Length of Top Rebar, Full Length	177.75	LF
Total Length, #7	711	LF	Total Length, #7	711	LF
Weight, #7	0.726642	Tons	Weight, #7	0.726642	Tons
# of Bottom Rebar, Full Length	2	Unit	# of Bottom Rebar, Full Length	2	Unit
Length of Bottom Rebar, Full Length	176.5	LF	Length of Bottom Rebar, Full Length	176.5	LF
Total Length, #7	706	LF	Total Length, #7	706	LF
Weight, #7	0.721532	Tons	Weight, #7	0.721532	Tons
# of Bottom Rebar, Exterior Span	5	Unit	# of Bottom Rebar, Exterior Span	5	Unit
Length of Bottom Rebar, Full Length	9.3333	LF	Length of Bottom Rebar, Full Length	9.3333	LF
Total Length, #7	93.333	LF	Total Length, #7	93.333	LF
Weight, #7	0.095386326	Tons	Weight, #7	0.095386	Tons
# of Bottom Rebar, Interior Span	5	Unit	# of Bottom Rebar, Interior Span	5	Unit
Length of Bottom Rebar, Full Length	11.8333	LF	Length of Bottom Rebar, Full Length	11.8333	LF
Total Length, #7	828.331	LF	Total Length, #7	828.331	LF
Weight, #7	0.846554282	Tons	Weight, #7	0.846554	Tons
# of Top Rebar, First Interior Column	6	Unit	# of Top Rebar, First Interior Column	6	Unit
Length of Bottom Rebar, Full Length	13.75	LF	Length of Bottom Rebar, Full Length	13.75	LF
Total Length, #7	165	LF	Total Length, #7	165	LF
Weight, #7	0.16863	Tons	Weight, #7	0.16863	Tons
# of Top Rebar, All Other Interior Col.	4	Unit	# of Top Rebar, All Other Interior Col.	4	Unit
Length of Bottom Rebar, Full Length	10.5	LF	Length of Bottom Rebar, Full Length	10.5	LF
Total Length, #7	588	LF	Total Length, #7	588	LF
Weight, #7	0.600936	Tons	Weight, #7	0.600936	Tons
# of Ties/Girder	25	Unit	# of Ties/Girder	25	Unit
Length of Tie Configuration	7.667	LF	Length of Tie Configuration	7.667	LF
Total Length, #3	3066.8	LF	Total Length, #3	3066.8	LF
Weight, #3	0.5765584	Tons	Weight, #3	0.576558	Tons
		Total			With 5% waste factor
#3		4.110973	#3		4.316522112
#6			#6		0
#7		6.319361	#7		6.635329277
#9		33.64183	#9		35.32392335

Material Science Wing			Life Science Wing		
Third Floor	Floor Dimensions		Third Floor	Floor Dimensions	
	113	66		113	66
Interior Girder			Interior Girder		

Redesign Floor System Girder Rebar Estimate, Third Floor

Unit Wt.			Cost per Ton
#3	0.376	lb/ft	1327
#6	1.502	lb/ft	1228
#7	2.044	lb/ft	1222
#9	3.4	lb/ft	1222

Material Science	Life Science
# of Columns Lines	# of Columns Lines
4	4
# of Bays	# of Bays
3	3
# of Column Lines	
6	
Development Length, Top	
1.75	
Development Length, Bottom	
0.5	

Redesign Floor System Girder Rebar Estimate Info, Third Floor

Exterior Girder			Exterior Girder		
# of Top Rebar, Full Length	2	Unit	# of Top Rebar, Full Length	2	Unit
Length of Top Rebar, Full Length	67.75	LF	Length of Top Rebar, Full Length	67.75	LF
Total Length, #7	271	LF	Total Length, #7	271	LF
Weight, #7	0.276962	Tons	Weight, #7	0.276962	Tons
# of Bottom Rebar, Full Length	2	Unit	# of Bottom Rebar, Full Length	2	Unit
Length of Bottom Rebar, Full Length	66.5	LF	Length of Bottom Rebar, Full Length	66.5	LF
Total Length, #7	266	LF	Total Length, #7	266	LF
Weight, #7	0.271852	Tons	Weight, #7	0.271852	Tons
# of Bottom Rebar, Exterior Span	5	Unit	# of Bottom Rebar, Exterior Span	5	Unit
Length of Bottom Rebar, Full Length	9.3333	LF	Length of Bottom Rebar, Full Length	9.3333	LF
Total Length, #7	93.333	LF	Total Length, #7	93.333	LF
Weight, #7	0.095386326	Tons	Weight, #7	0.095386	Tons
# of Bottom Rebar, Interior Span	5	Unit	# of Bottom Rebar, Interior Span	5	Unit
Length of Bottom Rebar, Full Length	11.8333	LF	Length of Bottom Rebar, Full Length	11.8333	LF
Total Length, #7	236.666	LF	Total Length, #7	236.666	LF
Weight, #7	0.241872652	Tons	Weight, #7	0.241873	Tons
# of Top Rebar, First Interior Column	6	Unit	# of Top Rebar, First Interior Column	6	Unit
Length of Bottom Rebar, Full Length	13.75	LF	Length of Bottom Rebar, Full Length	13.75	LF
Total Length, #7	165	LF	Total Length, #7	165	LF
Weight, #7	0.16863	Tons	Weight, #7	0.16863	Tons
# of Top Rebar, All Other Interior Col.	4	Unit	# of Top Rebar, All Other Interior Col.	4	Unit
Length of Bottom Rebar, Full Length	10.5	LF	Length of Bottom Rebar, Full Length	10.5	LF
Total Length, #7	168	LF	Total Length, #7	168	LF
Weight, #7	0.171696	Tons	Weight, #7	0.171696	Tons
# of Ties/Girder	25	Unit	# of Ties/Girder	25	Unit
Length of Tie Configuration	7.667	LF	Length of Tie Configuration	7.667	LF
Total Length, #3	1150.05	LF	Total Length, #3	1150.05	LF
Weight, #3	0.2162094	Tons	Weight, #3	0.216209	Tons
		Total			With 5% waste factor
#3		1.541615	#3		1.618695792
#6			#6		0
#7		2.452798	#7		2.575437854
#9		12.82252	#9		13.46364953

	Material	Life	Height (ft)	Column Dimensions				
First	84	48	20	1.5	1.5			
Second	54	54	18					
Third	24	24	18	Rebar Weight		Cost/Ton		
Total	162	126	56	#3	0.376	1327		
				#9	3.4	1222		
Concrete								
	Columns	Height	Total Height of Column	Volume of Concrete (CY)				
First	132	20	2640	220				
Second	108	18	1944	162				
Third	48	18	864	72		Cost		
				Total	454	50507.5		
				10% Waste	499.4	55558.25		
Rebar								
#9	Rebar/Column	Total Height of Column	Total Length of Rebar	Weight of Rebar (tons)				
First	4	2640	10560	17.952				
Second	4	1944	7776	13.2192				
Third	4	864	3456	5.8752		Cost		
				Total	37.0464	45270.7		
				5% Waste	38.89872	47534.24		
#3	Ties/Column	Total # of Ties	Length of Tie	Total Length of Ties	Weight of Rebar (tons)			
First	14	1848	5.33	9849.84	1.85176992			
Second	13	1404	5.33	7483.32	1.40686416			
Third	13	624	5.33	3325.92	0.62527296		Cost	
				Total	3.88390704	5153.945		
				5% Waste	4.078102392	5411.642		
4000 psi, NW concrete w/ winter concrete admixture								
	Base	106	per CY					
	Winter	5.25	per CY					
	Total	111.25						

Redesign Floor System Column Estimate

			Ht. of Col	SF of C.A.		Column Size			
		First Floor	2640	15840		1.5	1.5		
		Second Floor	1944	11664		Height of Column			
		Third Floor	864	5184		18	20		
		Total		32688					
Columns									
03 11 13.25 (6150)	Column Formwork					Daily Output:	235	SFCA/day	
16x16 Column	Material	0.73	per SFCA			Three Crews	705	SFCA/day	
4-use	Labor	5.15	per SFCA						
Crew C-1	One Crew		Three Crews		10% Waste				
	Material	23862.24	Material	71586.72	78745.392				
	Labor	168343.2	Labor	505029.6	505029.6				
	Total	192205.4	Total	576616.3	583774.992				
Floor System									
03 11 13.35 (3650)	Floor Slab, with one-way joist pans					Daily Output:	500	SF/day	
4-use	Floor Slab Formwork					Three Crews	1500	SF/day	
Crew C-2	Material	3.26	per SF						
	Labor	3.73	per SF						
	One Crew		Three Crews		10% Waste				
	Material	343698.5	Material	1031096	1134205.18				
	Labor	393250.2	Labor	1179751	1179750.51				
	Total	736948.7	Total	2210846	2313955.69				

Redesign Floor System Formwork Estimate

Rebar Placement					
Based on Walker's Guide to Estimating					
	One Crew	1.8	tons/day	Cost	
One Ironworker	32.35	per hour		575.1111	per ton
Four Ironworkers	129.4	per hour		1035.2	per day
Floor System Rebar, Tons					
Slab, Beam, Joist	93.47394				
Girders	115.8634				
Columns	40.93031				
Total Tons of Rebar	250.2676				
Days for Rebar	139.0376				
Total Cost	143931.7				

Redesign Floor System Rebar Placement Estimate

Concrete Placement									
Columns									
03 31 05.70 (0600)	Columns, 18" pumped					Daily Output:		90 CY/day	
Crew C-20	Labor	32.8	per CY						
	One Crew								
	Labor	14891.2							
Beams, Girders, Joists									
03 31 05.70 (0500)	Beams, Elevated, Small Beams, pumped					Daily Output:		60 CY/day	
Crew C-20	Labor	49.15	per CY						
	One Crew								
	Labor	58570.42							
Floor Slab									
03 31 05.70 (1400)	Elevated Slab, less than 6" thick, pumped					Daily Output:		60 CY/day	
Crew C-20	Labor	21.15	per CY						
	One Crew								
	Labor	30969.77							

Redesign Floor System Concrete Placement Estimate

Concrete Finishing					
03 35 29.30 (0100)	Manual Screed, Bull Float				
Crew C-10	Labor	0.22	per SF		
	One Crew		Two Crews		
	Labor	23194.38	Labor	46388.76	
Daily Output:					
		4000 SF/day			
Two Crews		8000 SF/day			

Redesign Floor System Concrete Finishing Estimate

Shoring			
Horizontal, steel beam, adjustable, 12'-20'			
Material Cost			
650	ea		
Labor Cost			
14.2	ea		
Assume two units per bay.			
# of bays	Units per bay	Material Cost	Labor Cost
215	2	296521.55	6477.8554
First Floor	105		
Second Floor	80		
Third Floor	30		
	215		

Redesign Floor System Shoring Estimate

Assume a 55-ton crane is used for the movement of formwork, rebar and shoring.									
Labor Cost		Equipment Cost							
635	per day	1625	per day						
									Duration
Life Science was constructed from August 11, 2009 to November 12, 2009									98 days
Material Science was constructed from July 29, 2009 to December 11, 2010									70 days
Life Science									
Labor Cost		Equipment Cost		Total					
66019.807		168948.325		402802.5					
Material Science									
Labor Cost		Equipment Cost							
47157.005		120677.375							

Redesign Floor System Crane Estimate

Ductwork Redesign										
Section	Component	Length (ft)	Airflow (cfm)	Width (in)	Height (in)	Hydraulic Diameter (in)	Round Diameter (in)	Assume 22 gauge		
								Wt./LF	Total Weight	
1	Diffuser	SR4-1	4.00	600.00	1.00	1.00	1	12.00		
	90 Diverging Tee	SR5-11								
2			5.00	600.00	14.00	10.00	11.66666667	6	30	
	90 Rounded Elbow	CR3-1								
3			6.00	600.00	14.00	10.00	11.66666667	6	36	
	Transition	SR5-13								
4			10.00	2000.00	18.00	14.00	15.75	8	80	
	90 Diverging Tee	SR5-13								
	Fire Damper	CR9-6								
	90 Rounded Elbow	CR3-1								
5			9.00	2000.00	18.00	14.00	15.75	8	72	
	Transition Diverge	SR4-1								
	Heating Coil	-								
	Transition Converge	SR4-1								
	Supply Valve	-								
	90 Rounded Elbow	CR3-1								
6			5.00	2000.00	18.00	14.00	15.75	8	40	
	Fire Damper	CR9-6								
	90 Converging Tee	SR5-13								
7			40.00	6650.00	30.00	16.00	20.86956522	11.5	460	
	Diverging Tap	SR5-11								
	Diverging Tap	SR5-11								
	Transition	SR4-1								
8			17.00	8800.00	40.00	16.00	22.85714286	14	238	
	Diverging Tap	SR5-11								
	Diverging Tap	SR5-11								
	45 Elbow	CD3-3								
9			9.00	8800.00	40.00	16.00	22.85714286	14	126	
	45 Elbow	CD3-3								
10			9.00	8800.00	40.00	16.00	22.85714286	14	126	
	Fire Damper	CR9-6								
	90 Elbow	CR3-12								
11			16.00	8800.00	40.00	16.00	22.85714286	14	224	
	90 Elbow	CR3-9								
12			8.00	8800.00	40.00	16.00	22.85714286	14	112	
	90 Elbow	CR3-9								
13			22.00	8800.00	40.00	16.00	22.85714286	14	308	
	90 Elbow	CR3-9								
15			9.00	8800.00	40.00	16.00	22.85714286	14	126	
	Bullhead Tee	SR5-15								
16			75.00	14855.00	54.00	20.00	29.18918919	18.5	1387.5	
	Diverging Tap	SR5-13								
	Diverging Tap	SR5-13								
	90 Elbow	CR3-9								
16			6.00	5000.00	54.00	20.00	29.18918919	18.5	111	
	90 Elbow	CR3-9								
17			4.00	5000.00	54.00	20.00	29.18918919	18.5	74	Cost/lb.
	Abrupt Opening	-								
								Total Wt.	3550.5	2.11
								Total Cost	7491.555	
								Insulation		
								\$.20/SF of surface		
								Blanket type, fiberglass flexible, fsk vapor wrap, 1" thick		

Existing Ductwork Estimate, Single Run

[illegible]

Ductwork Estimate, Single Run, 6" increase

[illegible]

Ductwork Estimate, Single Run, 4" increase

[illegible]

Ductwork Estimate, Single Run, 2" increase

[illegible]

Ductwork Estimate, Single Run, 2" Decrease

APPENDIX E: Lighting/Electrical

Window to Wall Ratio Results



WWR 50 Third Floor DA 322.8 lux



WWR 70 Third Floor DA 322.8 lux

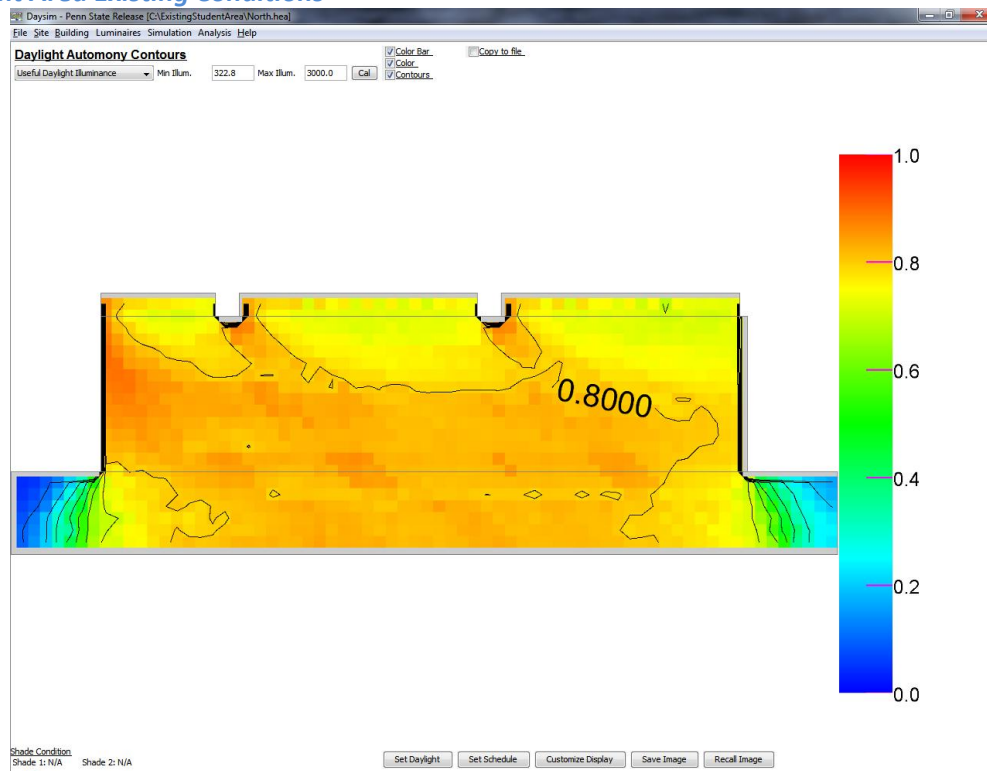


WWR 80 Third Floor DA 322.8 lux

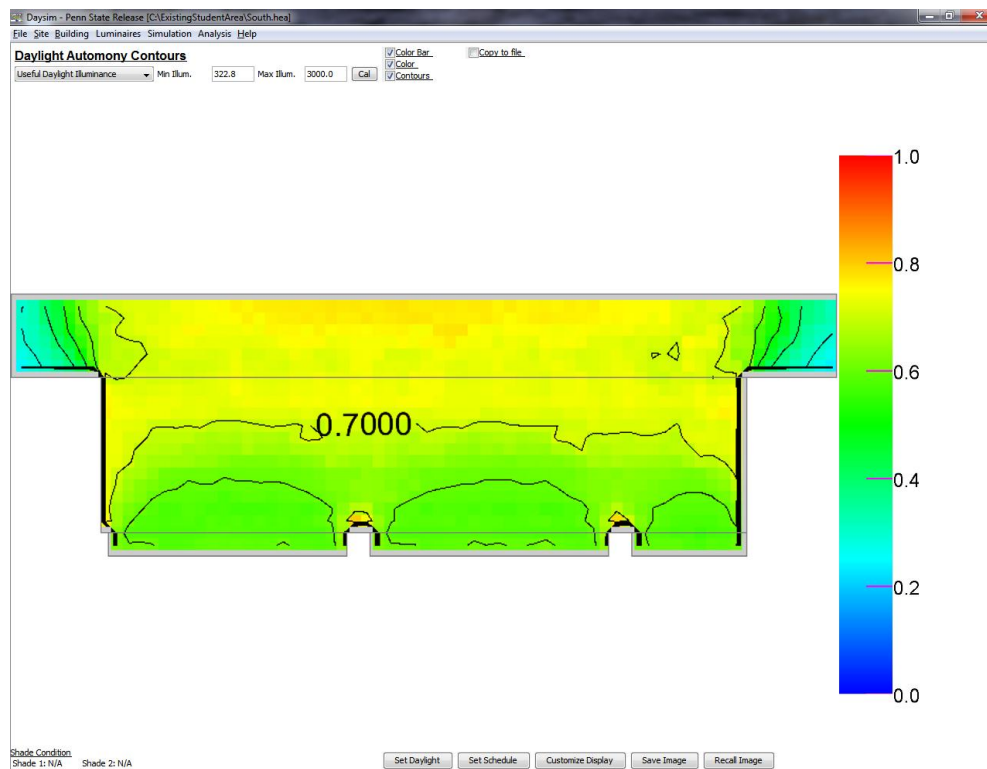


WWR 90 Third Floor DA 322.8 Lux

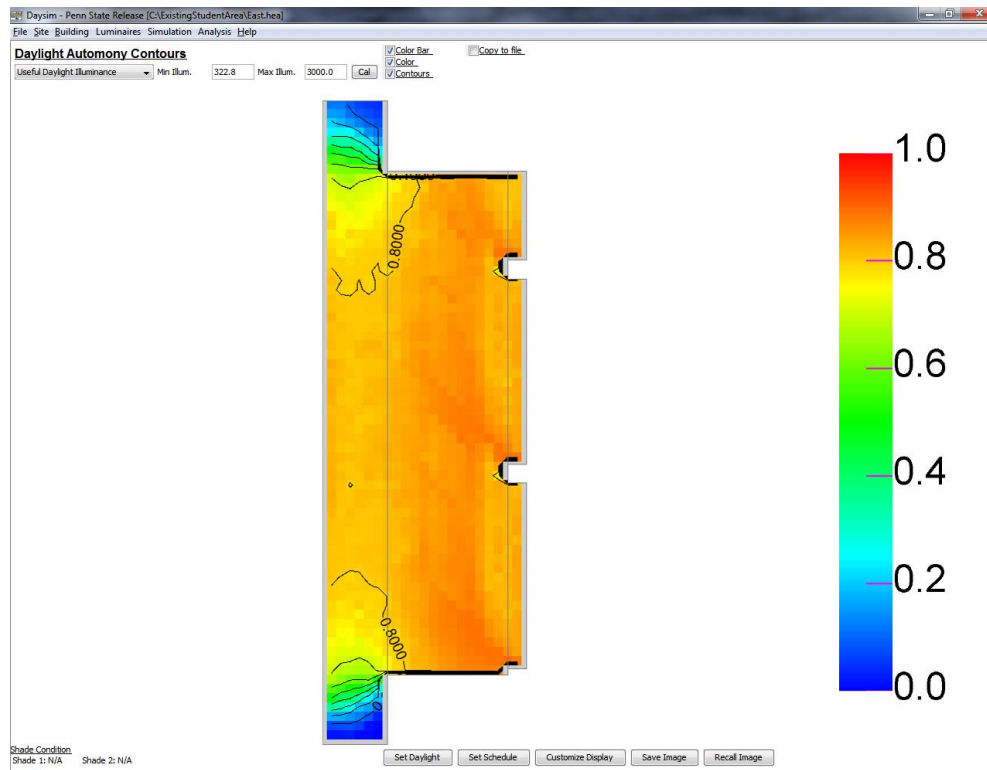
Student Area Existing Conditions



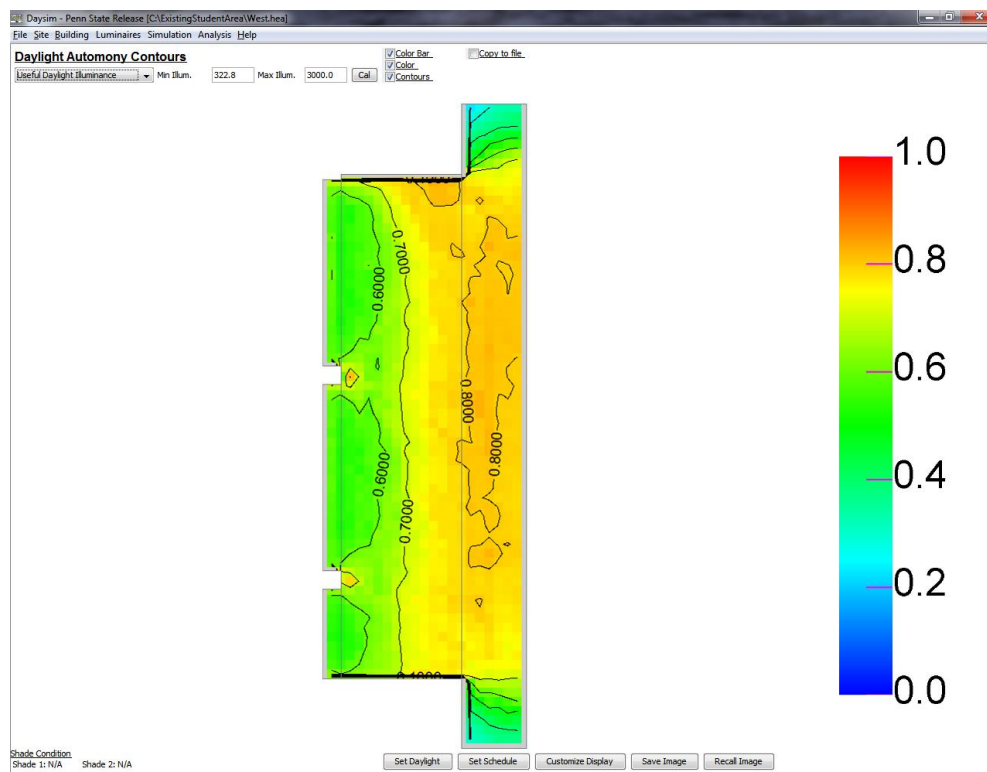
North Façade Useful Illuminance 322.8-3000 lux



South Façade Useful Illuminance 322.8-3000 lux

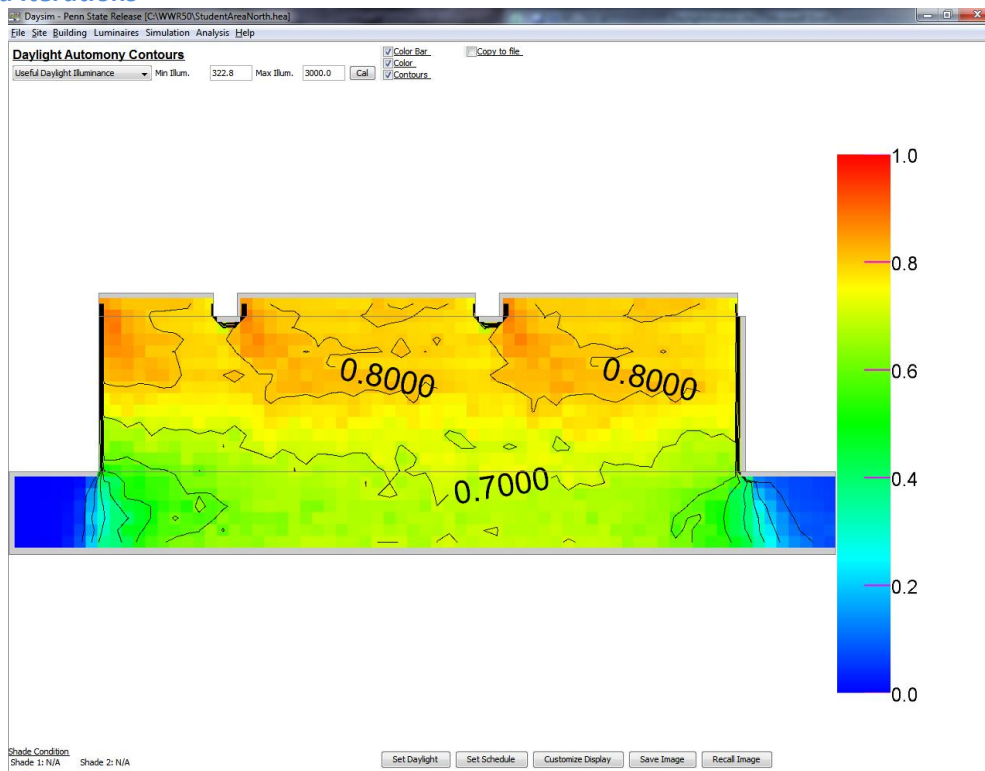


East Façade Useful Illuminance 322-3000 lux

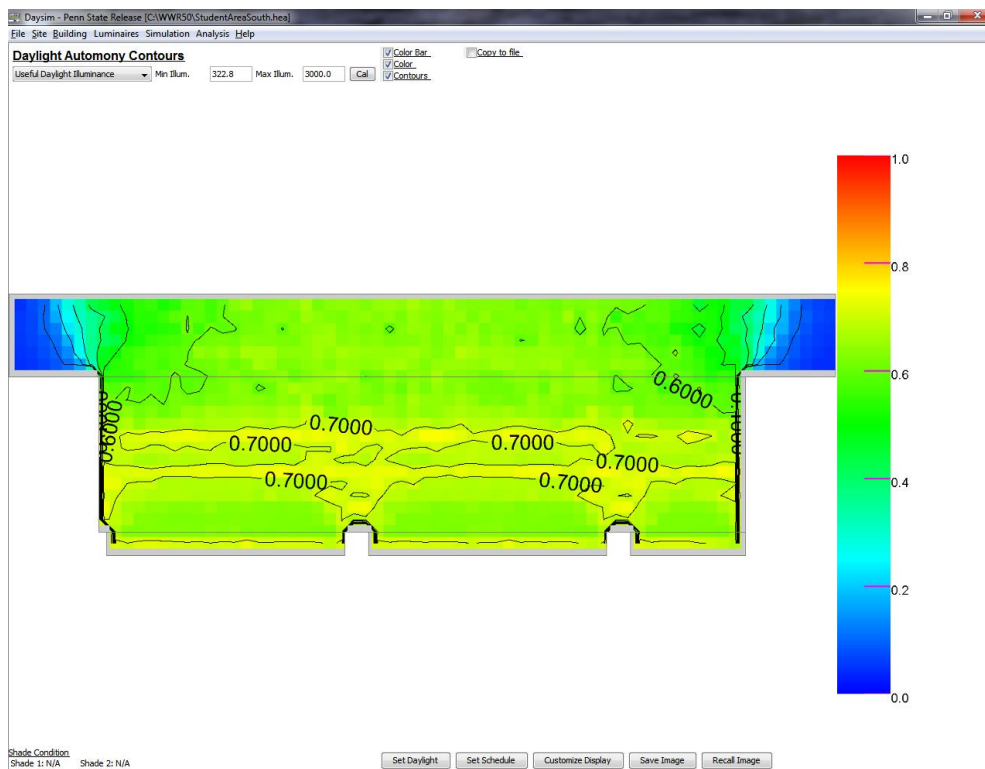


East Façade Useful Illuminance 322.8-3000 lux

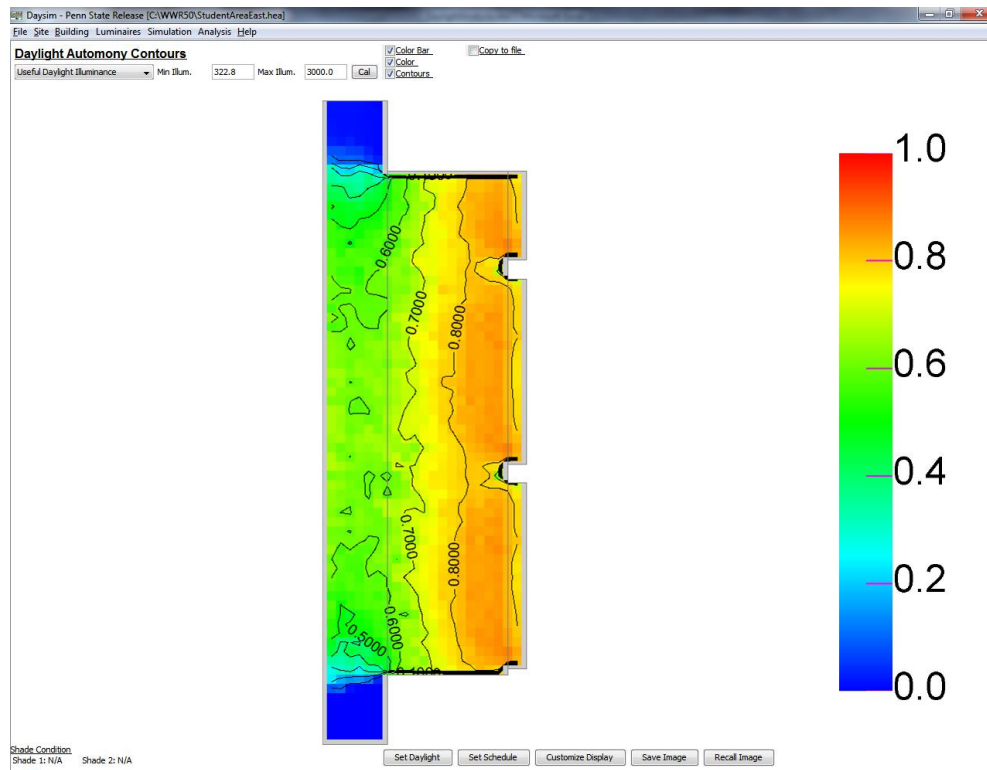
Student Area Iterations



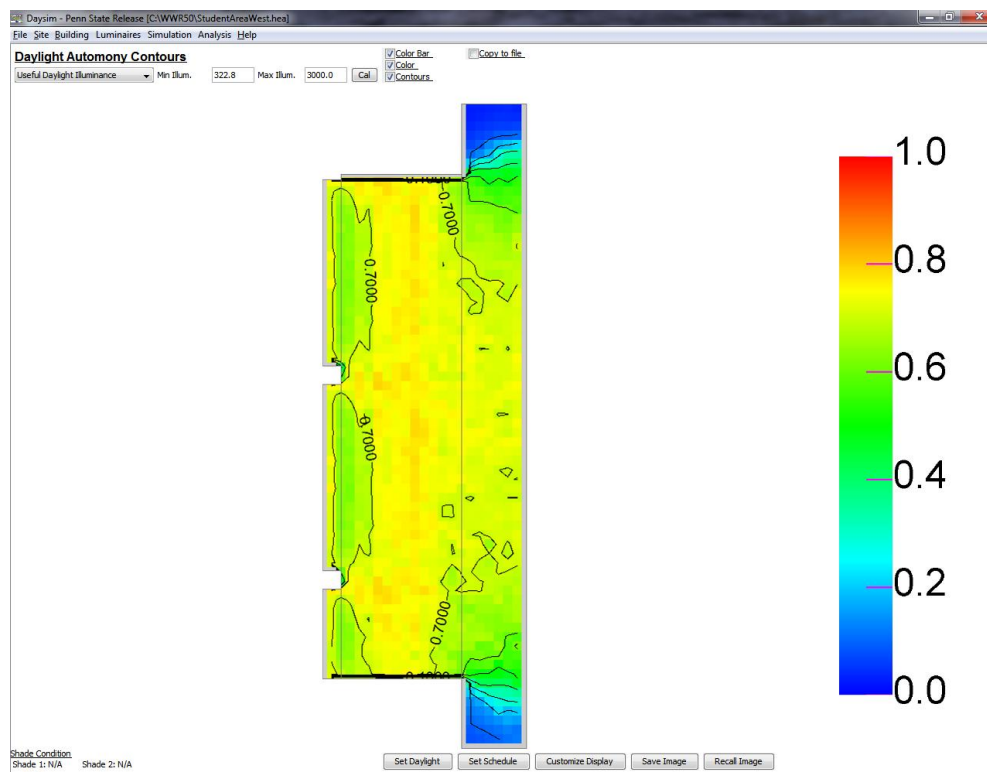
WWR 50 North Façade Useful Illuminance 322.8-3000 lux



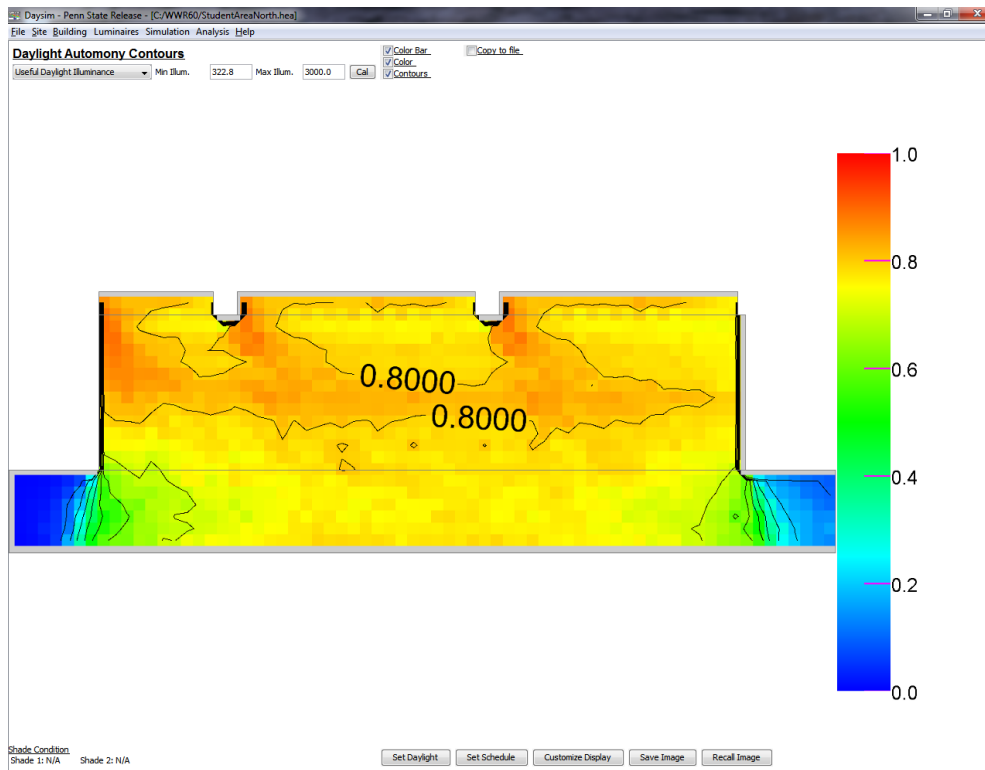
WWR 50 South Façade Useful Illuminance 322.8-3000 lux



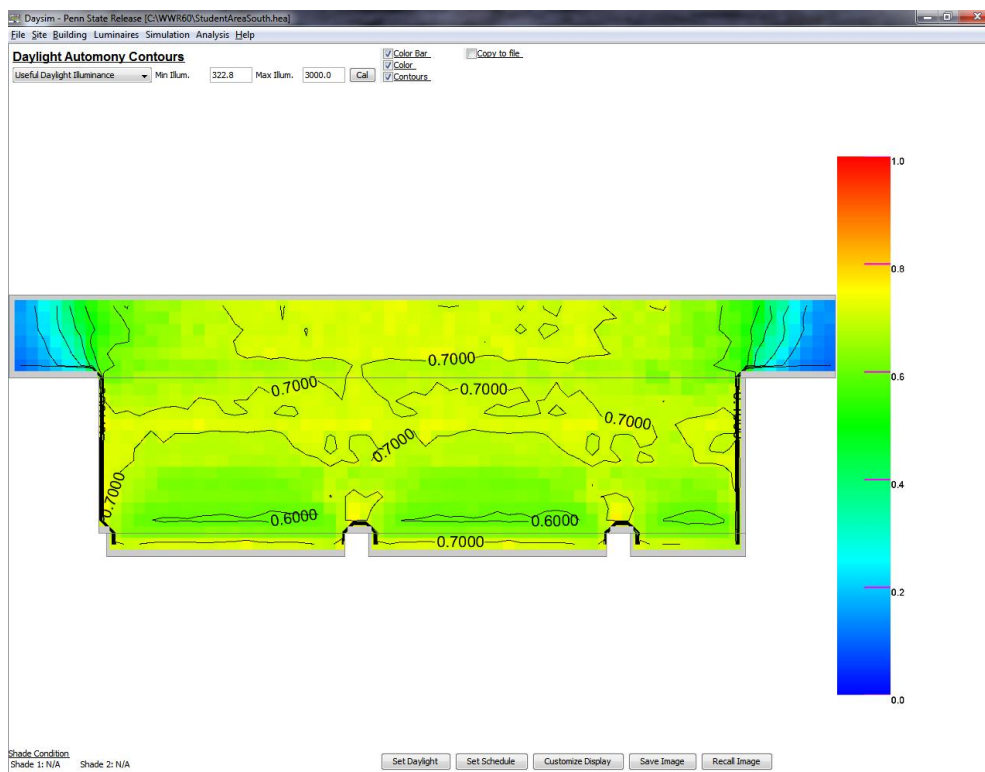
WWR 50 East Façade Useful Illuminance 322.8-3000 lux



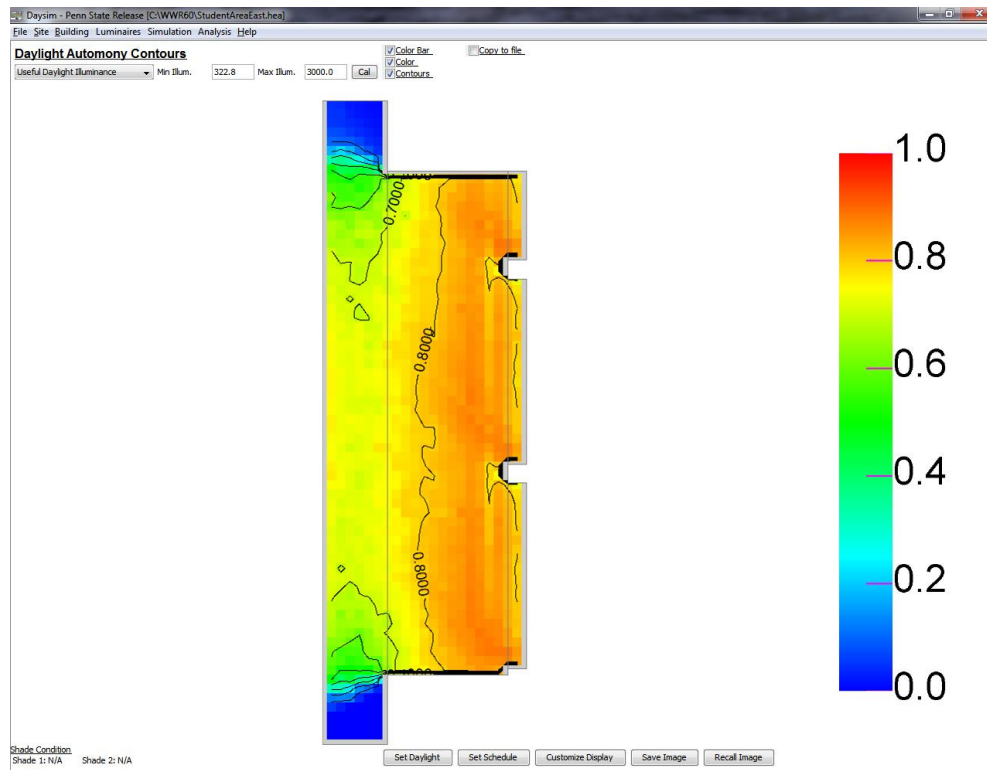
WWR 50 West Façade Useful Illuminance 322.8-3000 lux



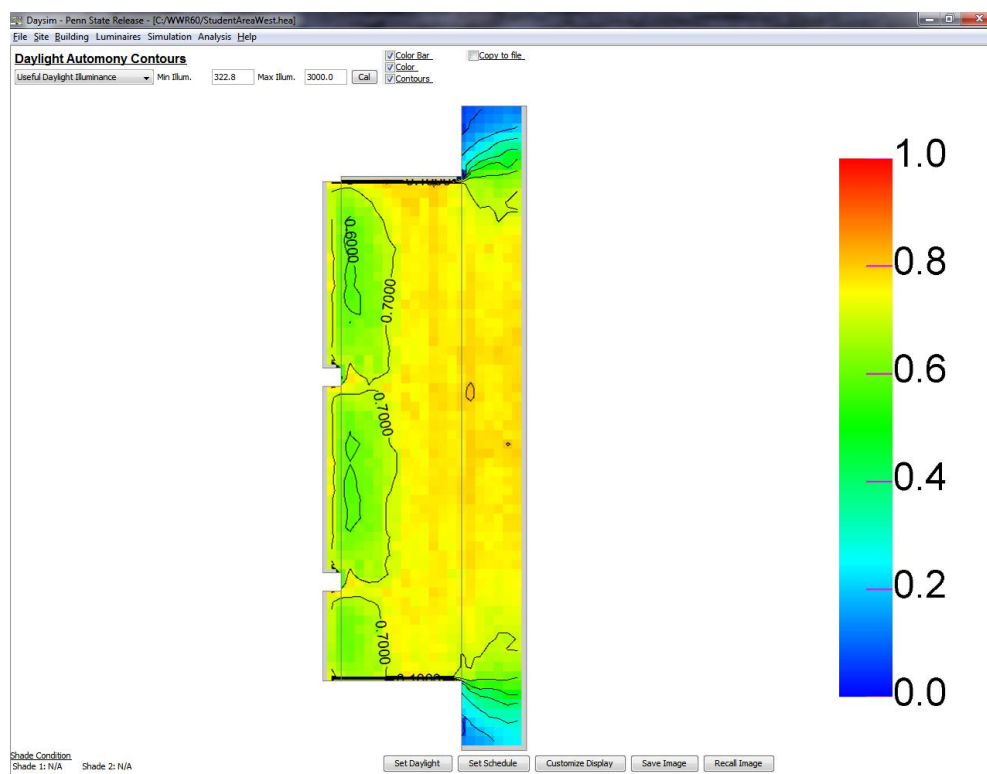
WWR 60 North Façade Useful Illuminance 322.8-3000 lux



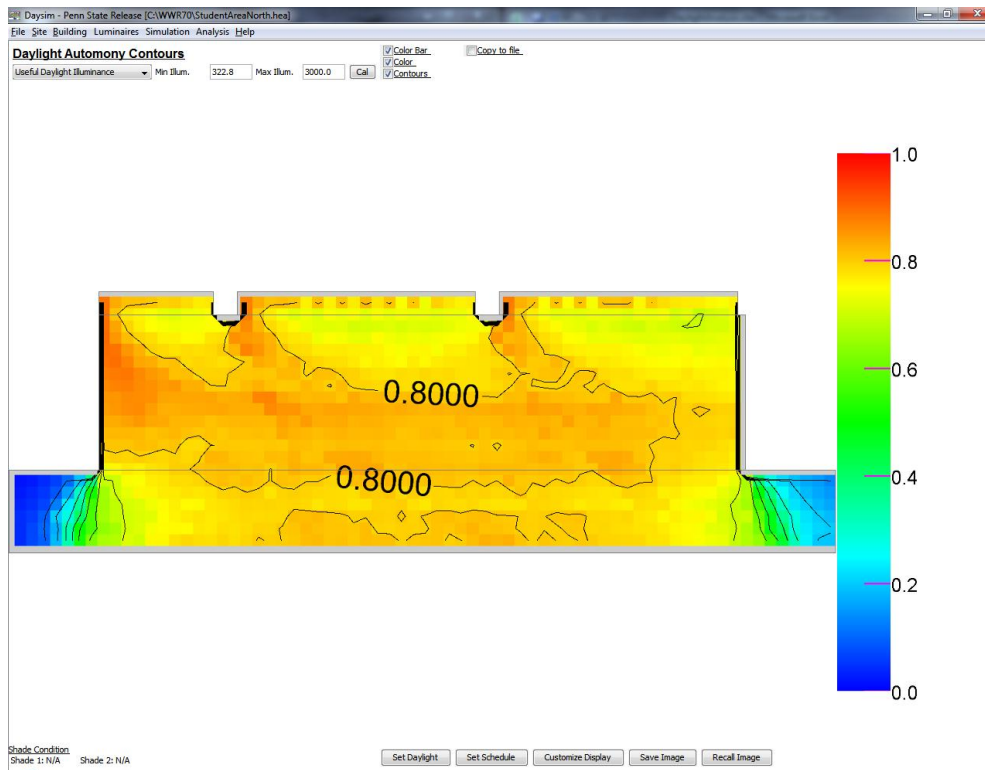
WWR 60 South Façade Useful Illuminance 322.8-3000 lux



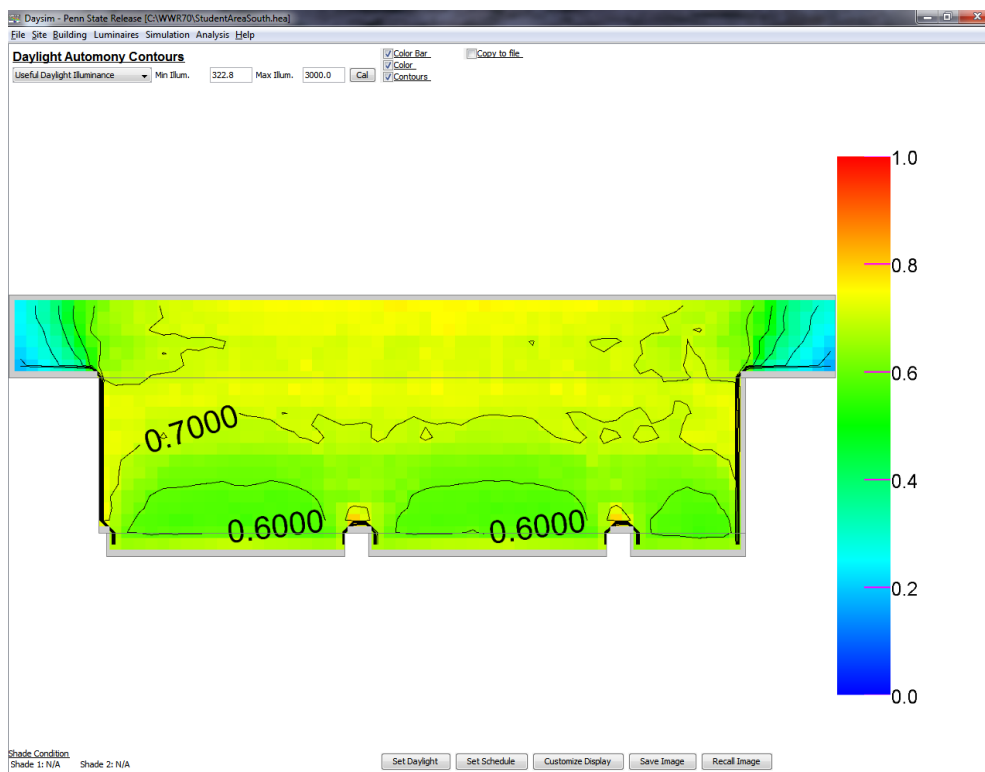
WWR 60 East Façade Useful Illuminance 322.8-3000 lux



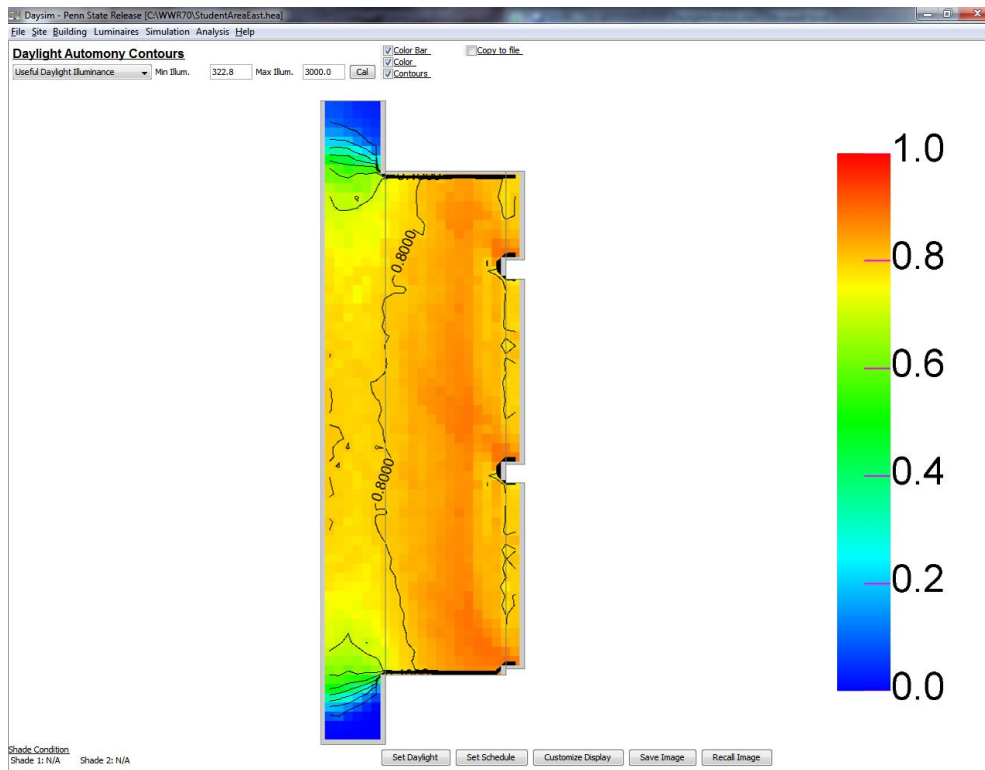
WWR 60 West Façade Useful Illuminance 322.8-3000 lux



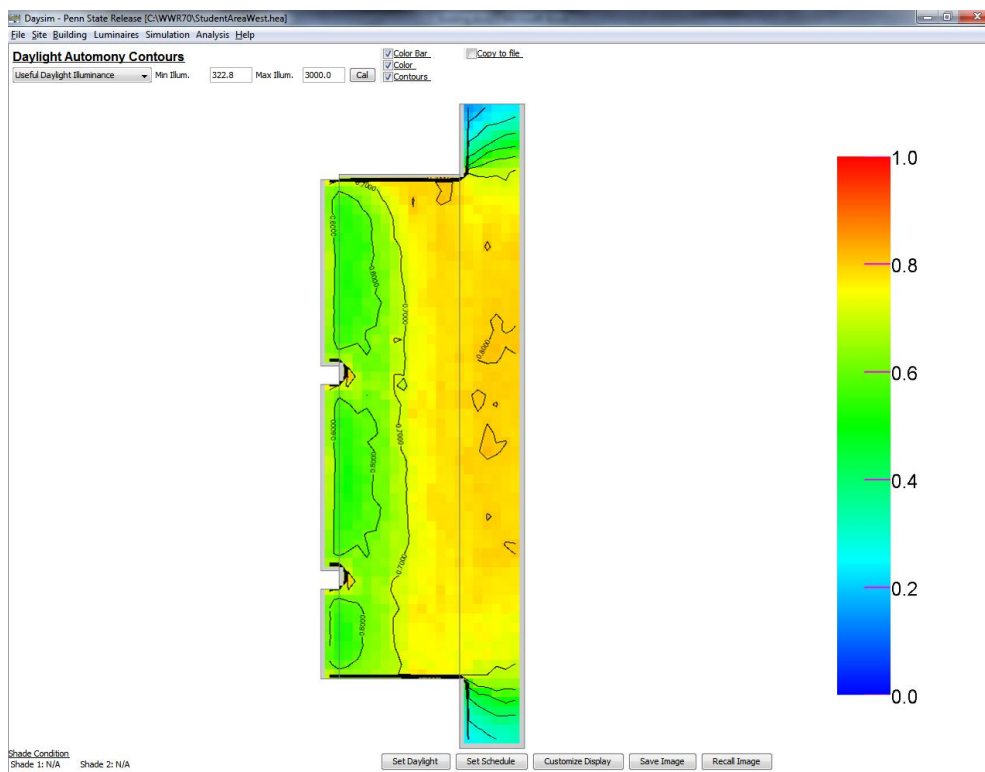
WWR 70 North Façade Useful Illuminance 322.8-3000 lux



WWR 70 South Façade Useful Illuminance 322.8-3000 lux

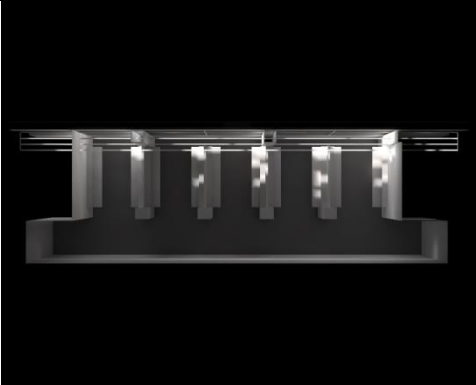
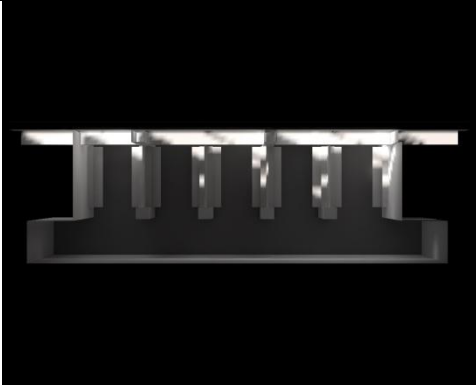


WWR 70 East Façade Useful Illuminance 322.8-3000 lux

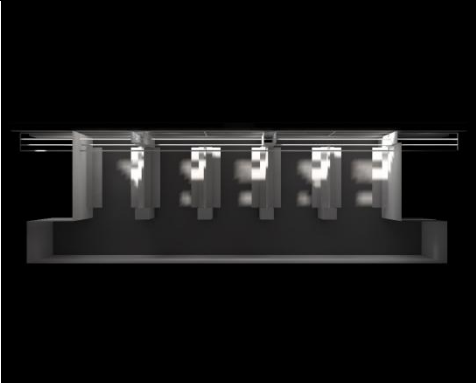
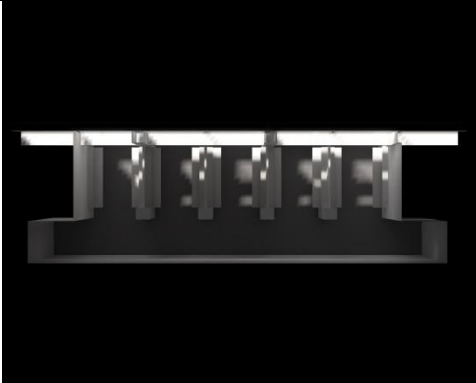
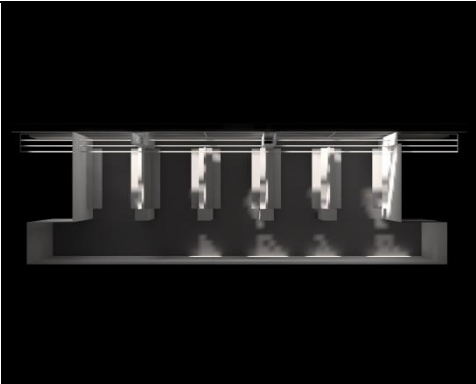
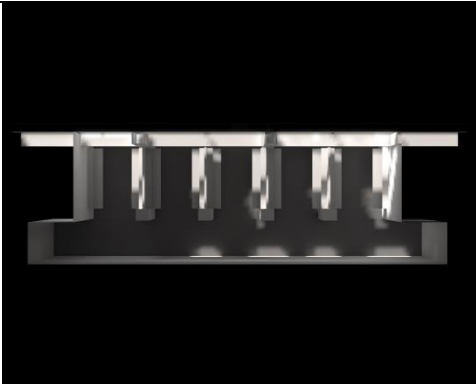


WWR 70 West Façade Useful Illuminance 322.8-3000 lux

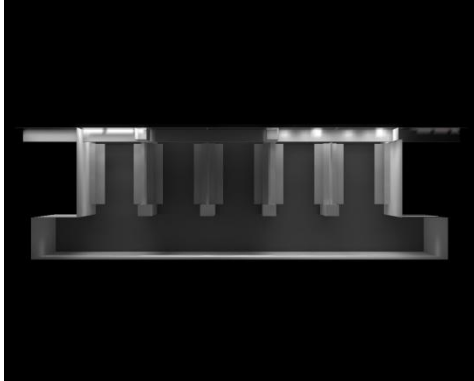
Interior Shelf

North Façade Equinox No Shelf	North Façade Equinox 2' Interior Shelf
 5:00 PM	 5:00 PM
 6:00 PM	 6:00 PM

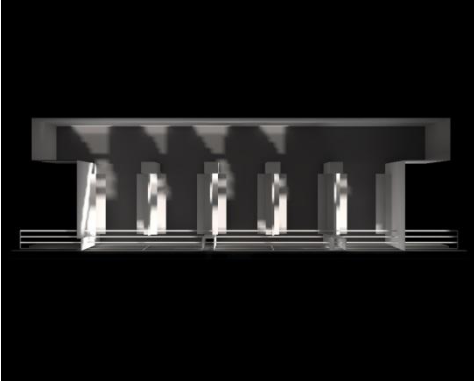
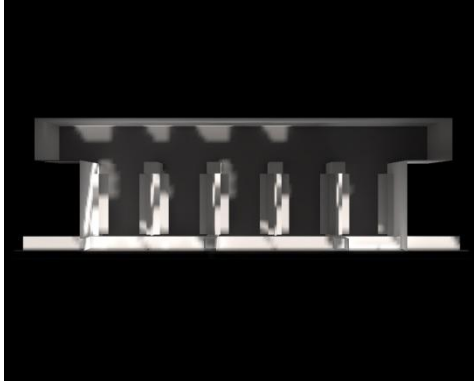
Direct Sunlight Penetration Comparison for North Façade

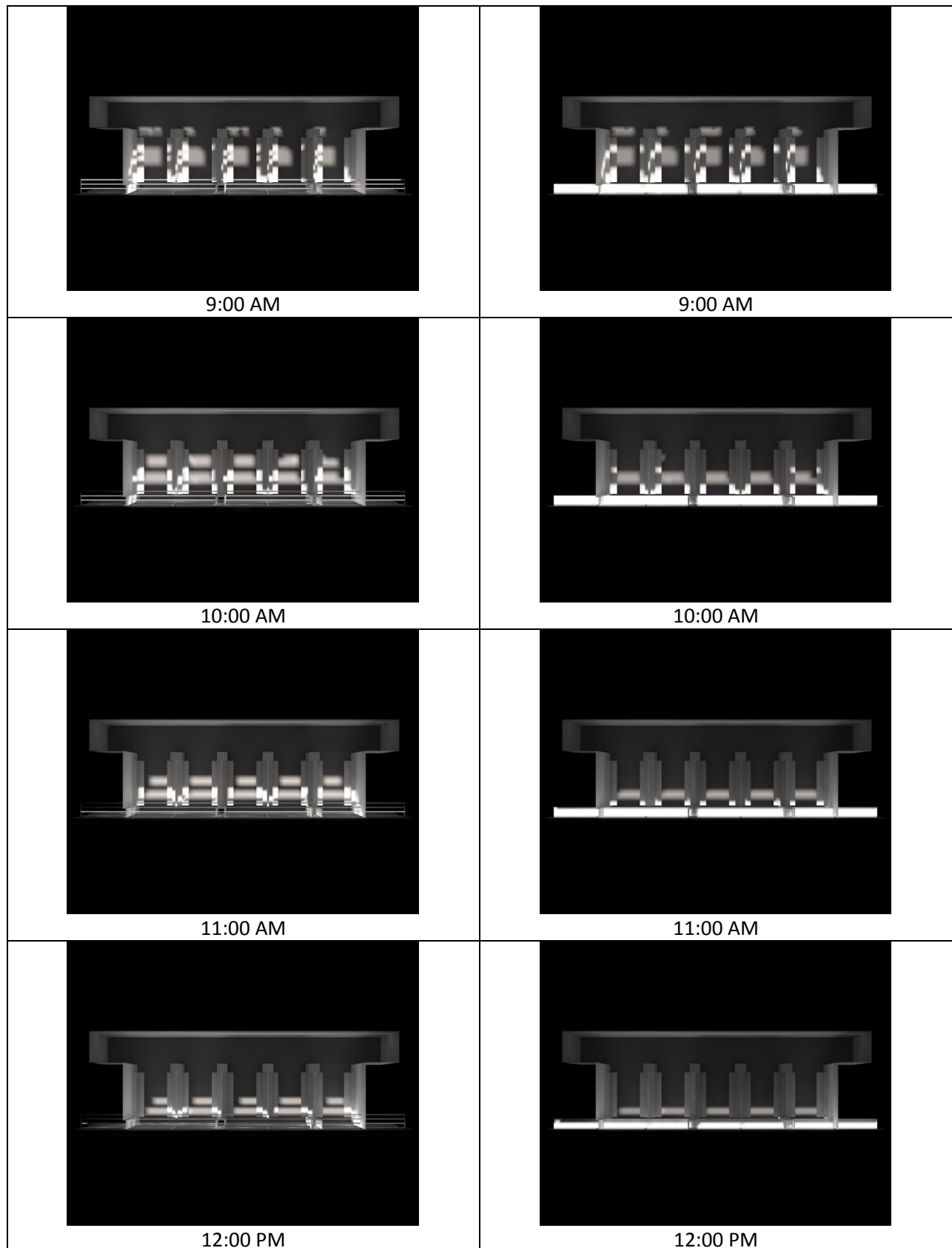
North Façade Summer Solstice No Shelf	North Façade Summer Solstice 2' Interior Shelf
 6:00 PM	 6:00 PM
 7:00 PM	 7:00 PM
 8:00 PM	 8:00 PM

Direct Sunlight Penetration Comparison for North Façade

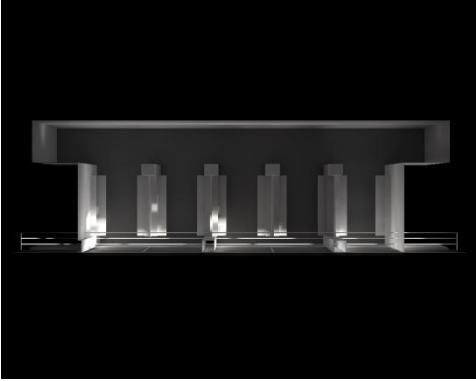
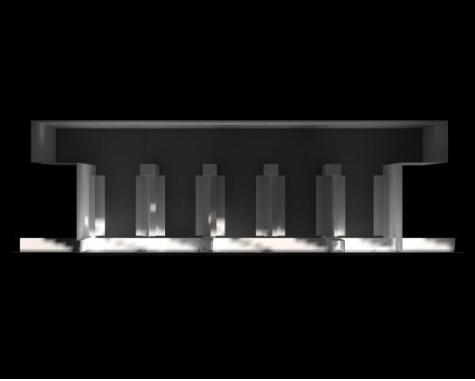
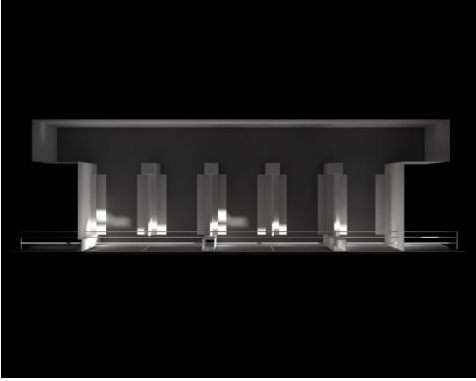
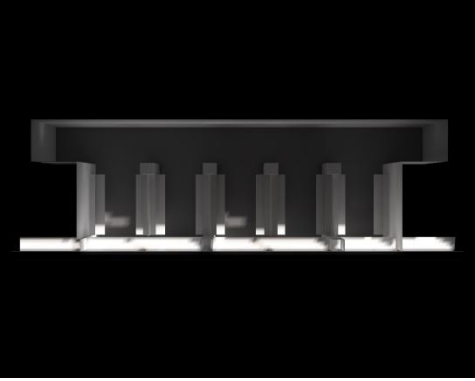
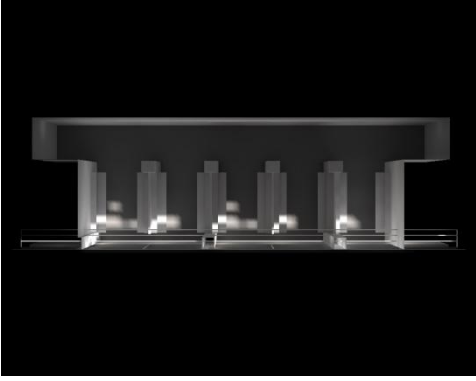
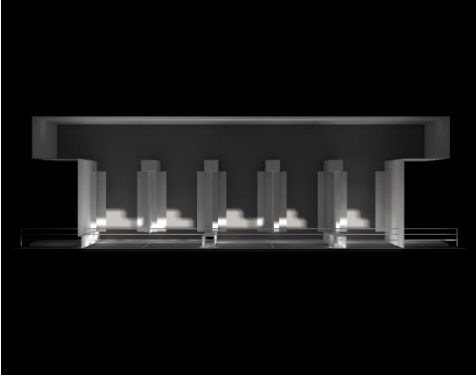
North Façade Winter Solstice No Shelf	North Façade Winter Solstice 2' Interior Shelf
	
8:00 AM	8:00 AM

Direct Sunlight Penetration Comparison for North Façade

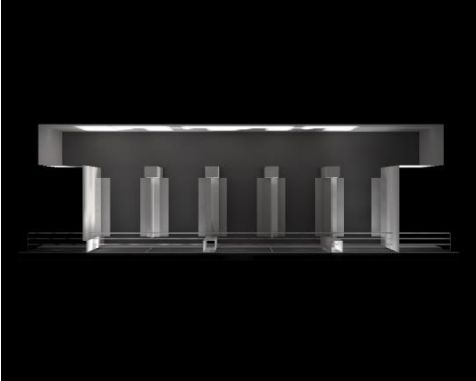
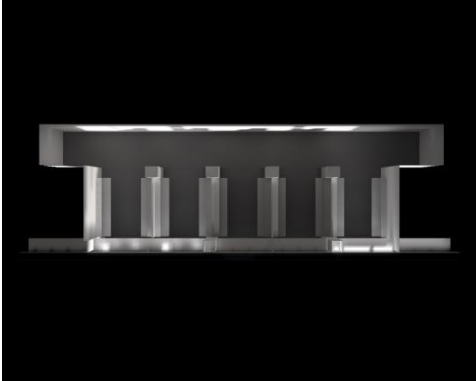
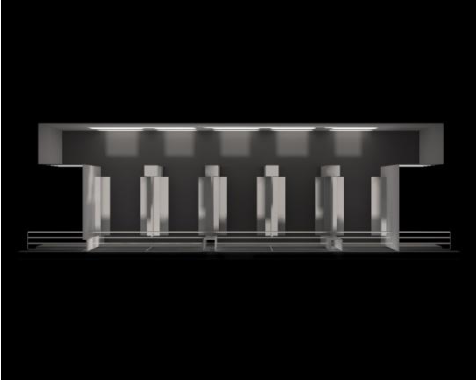
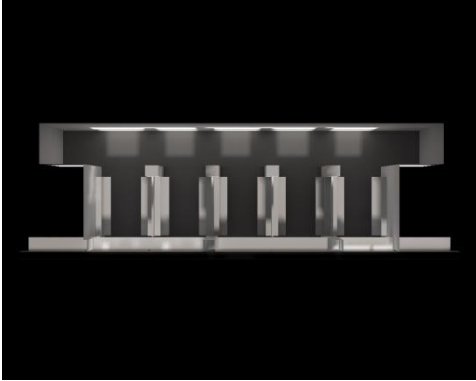
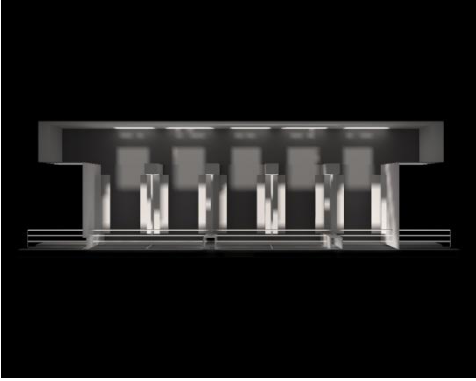
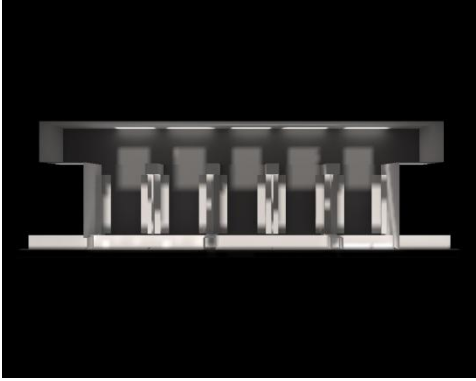
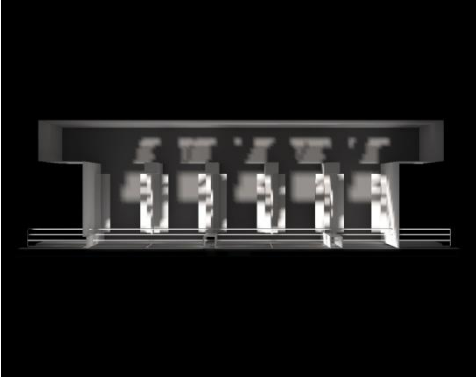
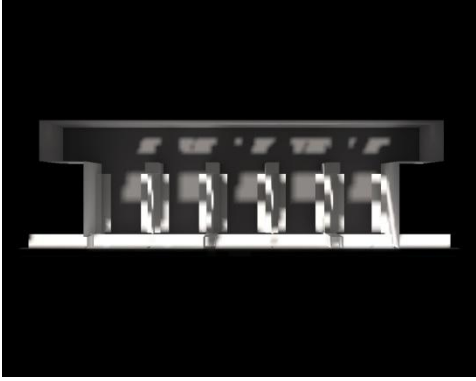
South Façade Equinox No Shelf	South Façade Equinox 2' Interior Shelf
	
7:00 AM	7:00 AM
	
8:00 AM	8:00 AM

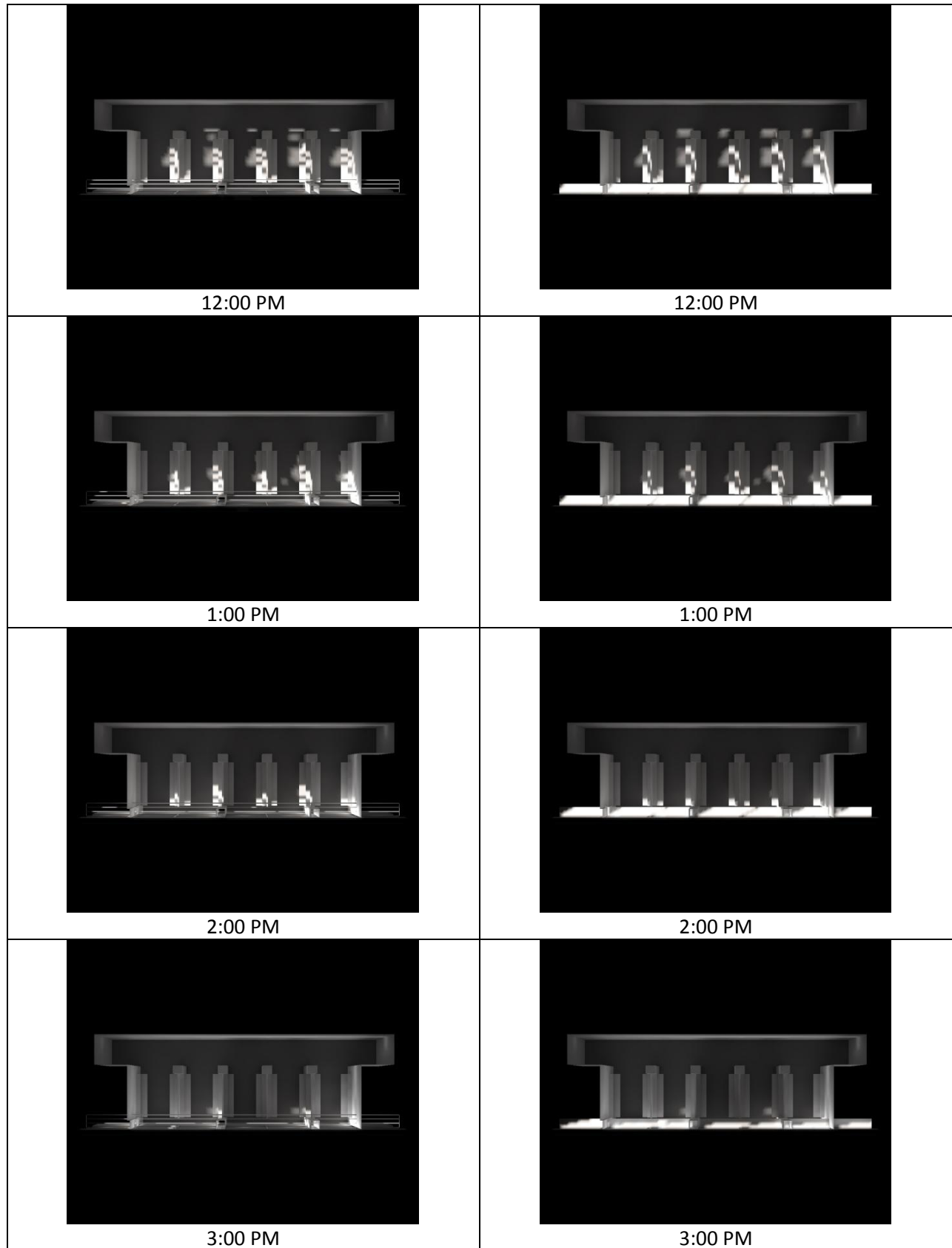


Direct Sunlight Penetration Comparison for South Façade

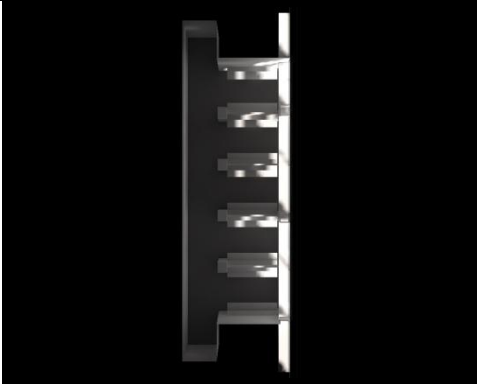
South Façade Summer Solstice No Shelf	South Façade Summer Solstice 2' Interior Shelf
 7:00 AM	 7:00 AM
 8:00 AM	 8:00 AM
 9:00 AM	 9:00 AM
 10:00 AM	 10:00 AM

Direct Sunlight Penetration Comparison for South Façade

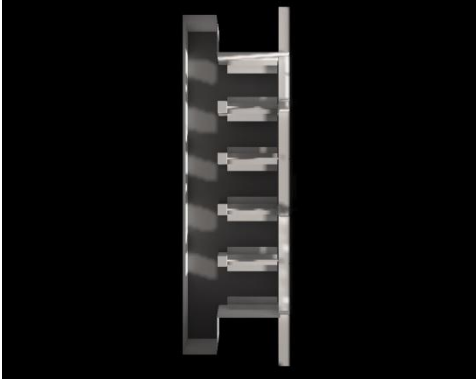
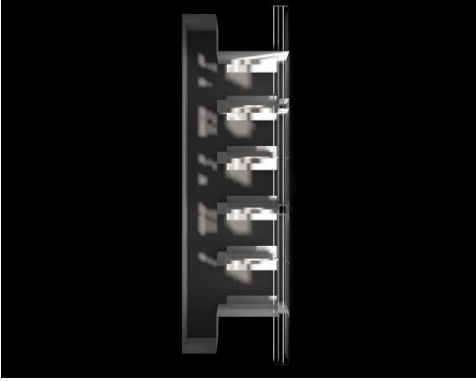
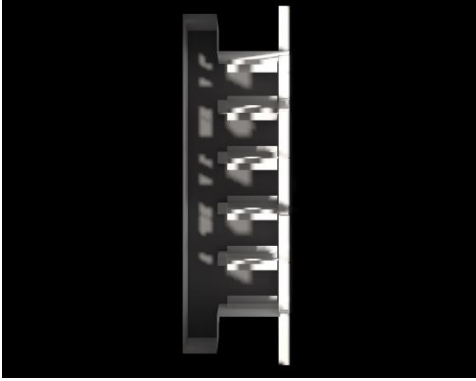
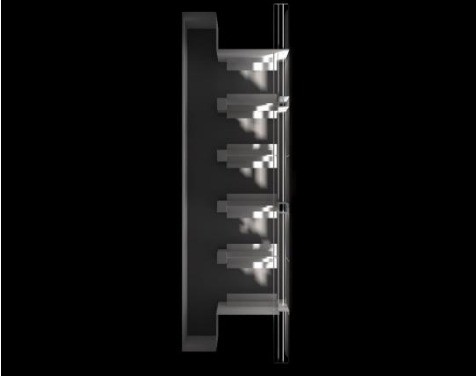
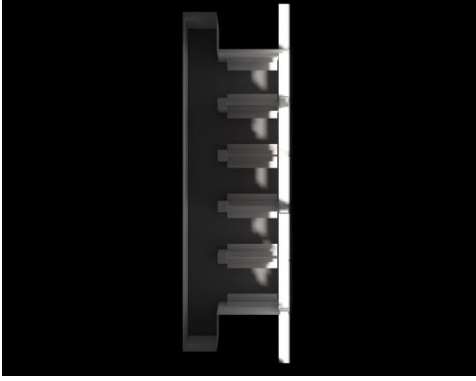
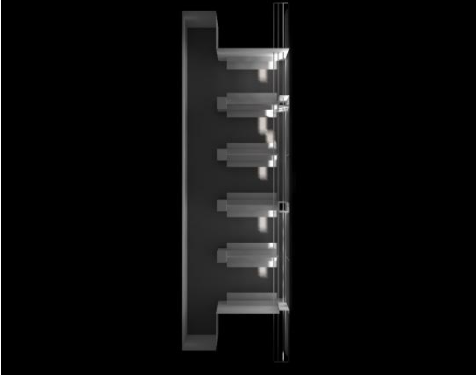
South Façade Winter Solstice No Shelf	South Façade Winter Solstice 2' Interior Shelf
 8:00 AM	 8:00 AM
 9:00 AM	 9:00 AM
 10:00 AM	 10:00 AM
 11:00 AM	 11:00 AM



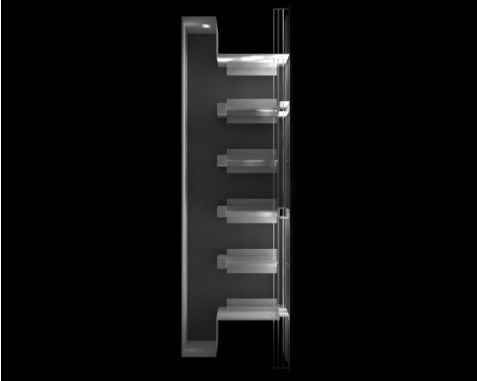
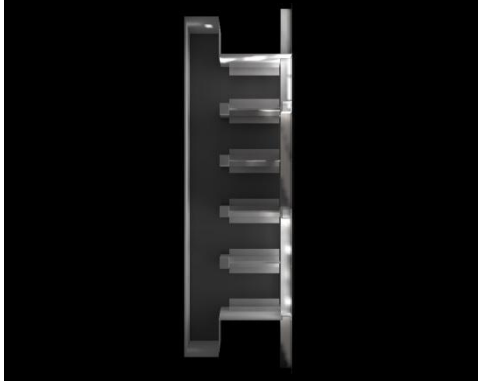
Direct Sunlight Penetration Comparison for South Façade

East Façade Equinox No Shelf		East Façade Equinox 2' Interior Shelf	
	7:00 AM		7:00 AM
	8:00 AM		8:00 AM

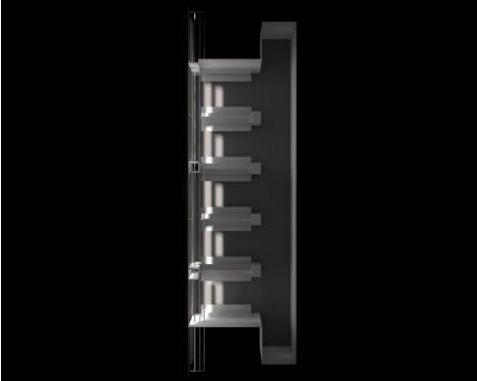
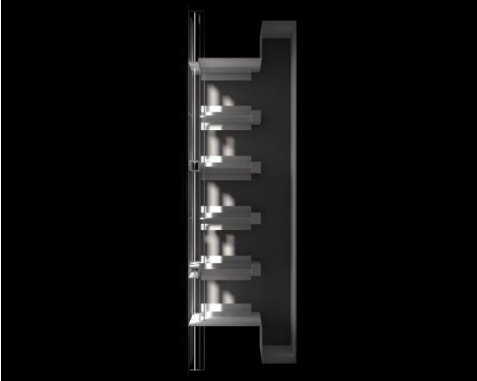
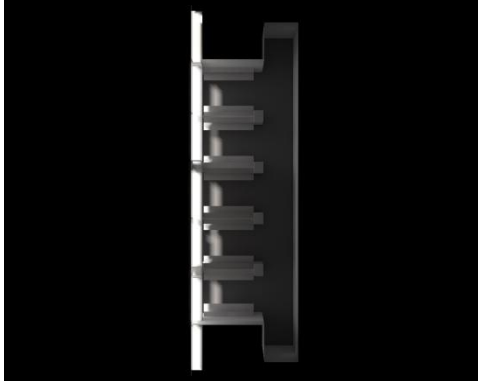
Direct Sunlight Penetration Comparison for East Façade

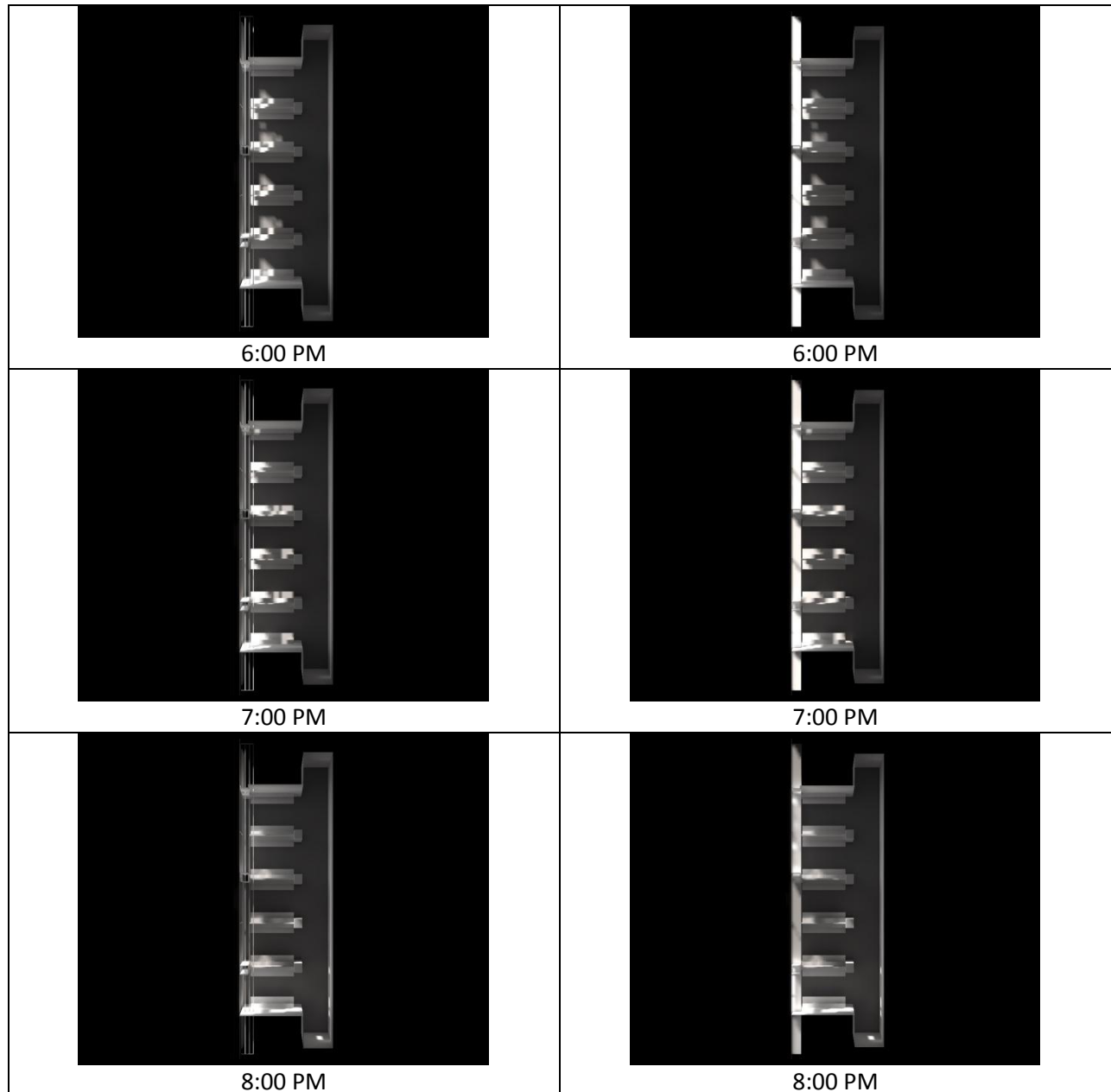
East Façade Summer Solstice No Shelf	East Façade Summer Solstice 2' Interior Shelf
 7:00 AM	 7:00 AM
 8:00 AM	 8:00 AM
 9:00 AM	 8:00 PM
 10:00 AM	 10:00 AM

Direct Sunlight Penetration Comparison for East Façade

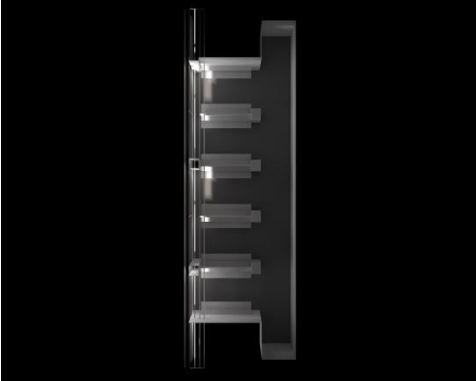
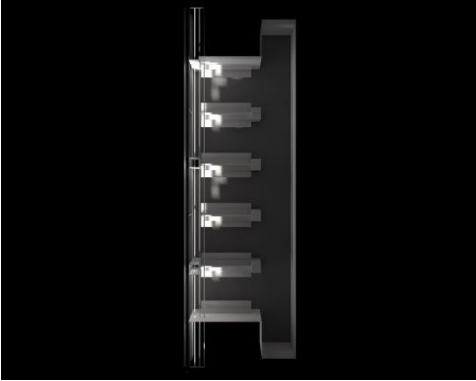
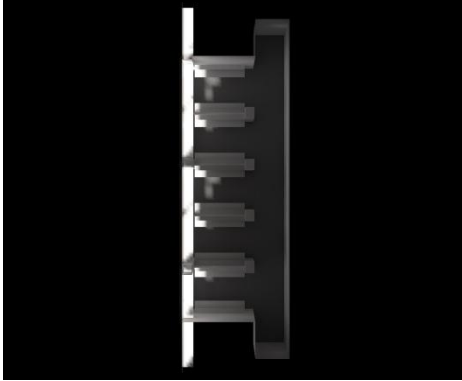
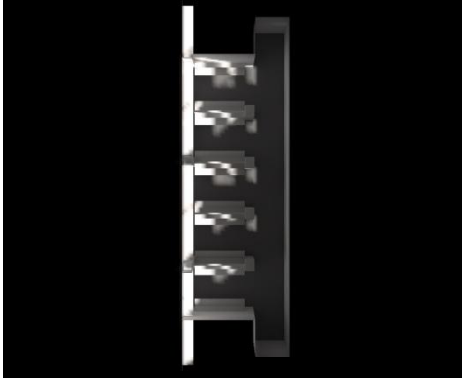
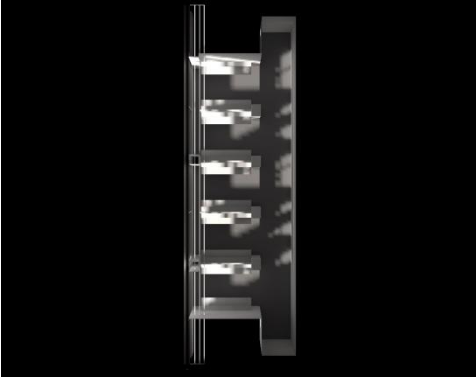
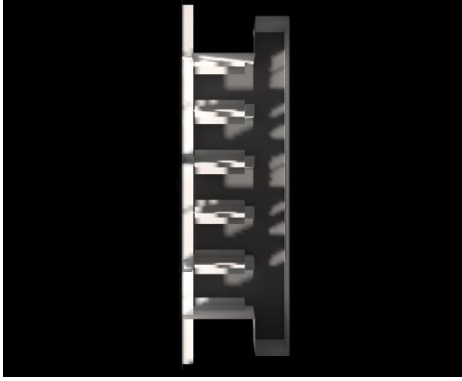
East Façade Winter Solstice No Shelf	East Façade Winter Solstice 2' Interior Shelf
	
8:00 AM	8:00 AM

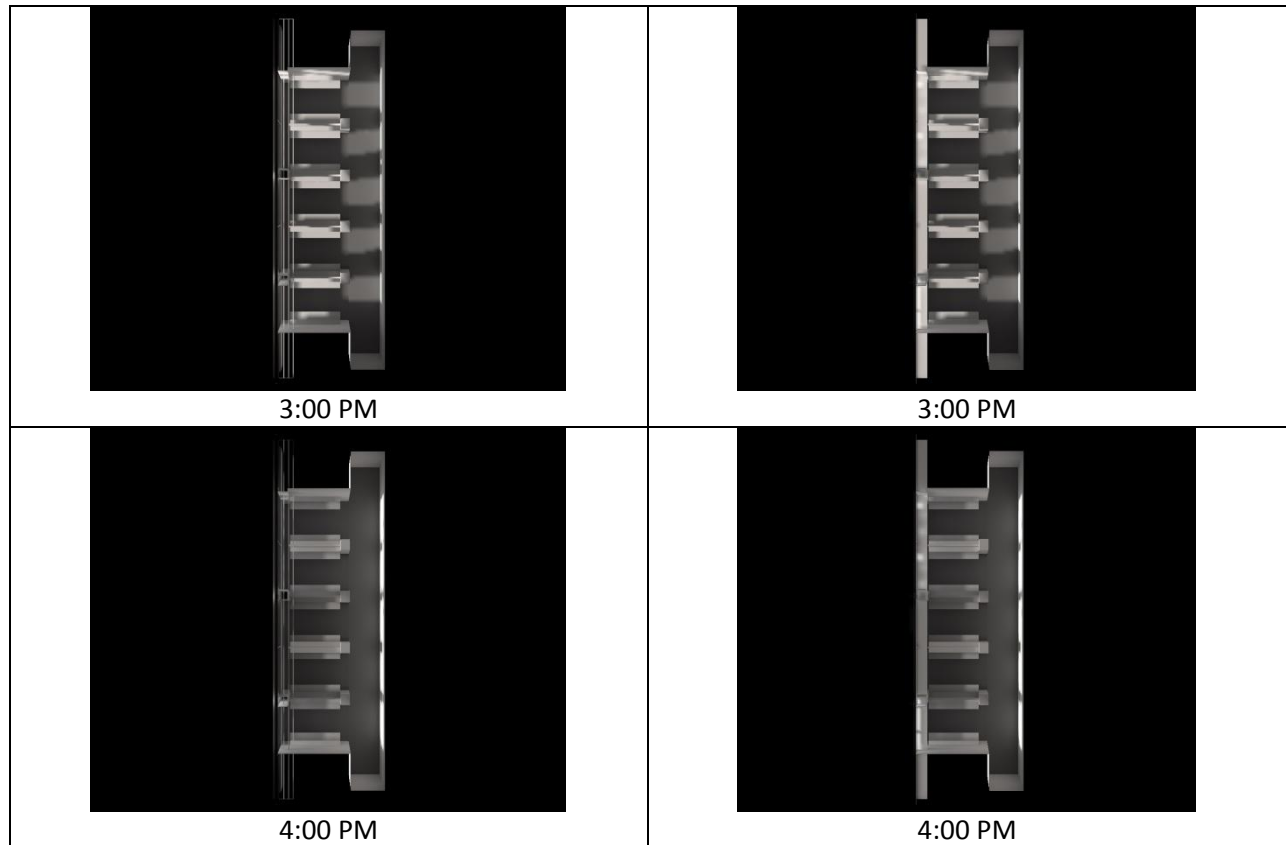
Direct Sunlight Penetration Comparison for East Façade

West Façade Summer Solstice No Shelf	West Façade Summer Solstice 2' Interior Shelf
	
4:00 PM	4:00 PM
	
5:00 PM	5:00 PM



Direct Sunlight Penetration Comparison for West Façade

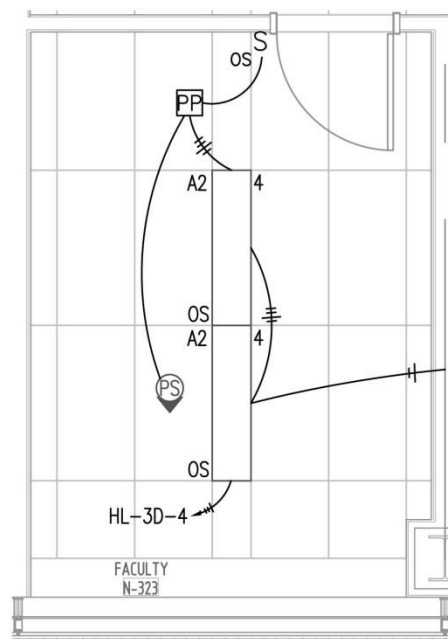
West Façade Winter Solstice No Shelf	West Façade Winter Solstice 2' Interior Shelf
 11:00 AM	 11:00 AM
 12:00 PM	 12:00 PM
 1:00 PM	 1:00 PM
 2:00 PM	 2:00 PM



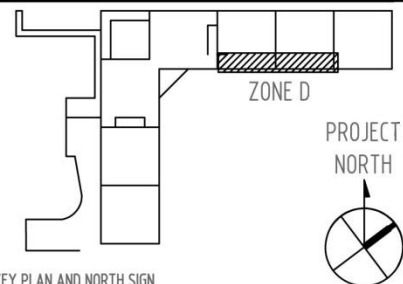
Direct Sunlight Penetration Comparison for West Façade

Lighting Plans

Student Area Place Holder



PENNSYLVANIA STATE UNIVERSITY
MILLENNIUM SCIENCE COMPLEX



1/4" = 1'-0"
SCALE:

PRIVATE OFFICE
LIGHTING PLAN
SHEET TITLE:

E2.2
SHEET NUMBER:

PRIVATE OFFICE LIGHTING PLAN	1
SCALE : 1/4"=1'-0"	

Courtyard A Place Holder

Courtyard B Place Holder

Courtyard C Place Holder

Courtyard D Place Holder

Courtyard E Place Holder

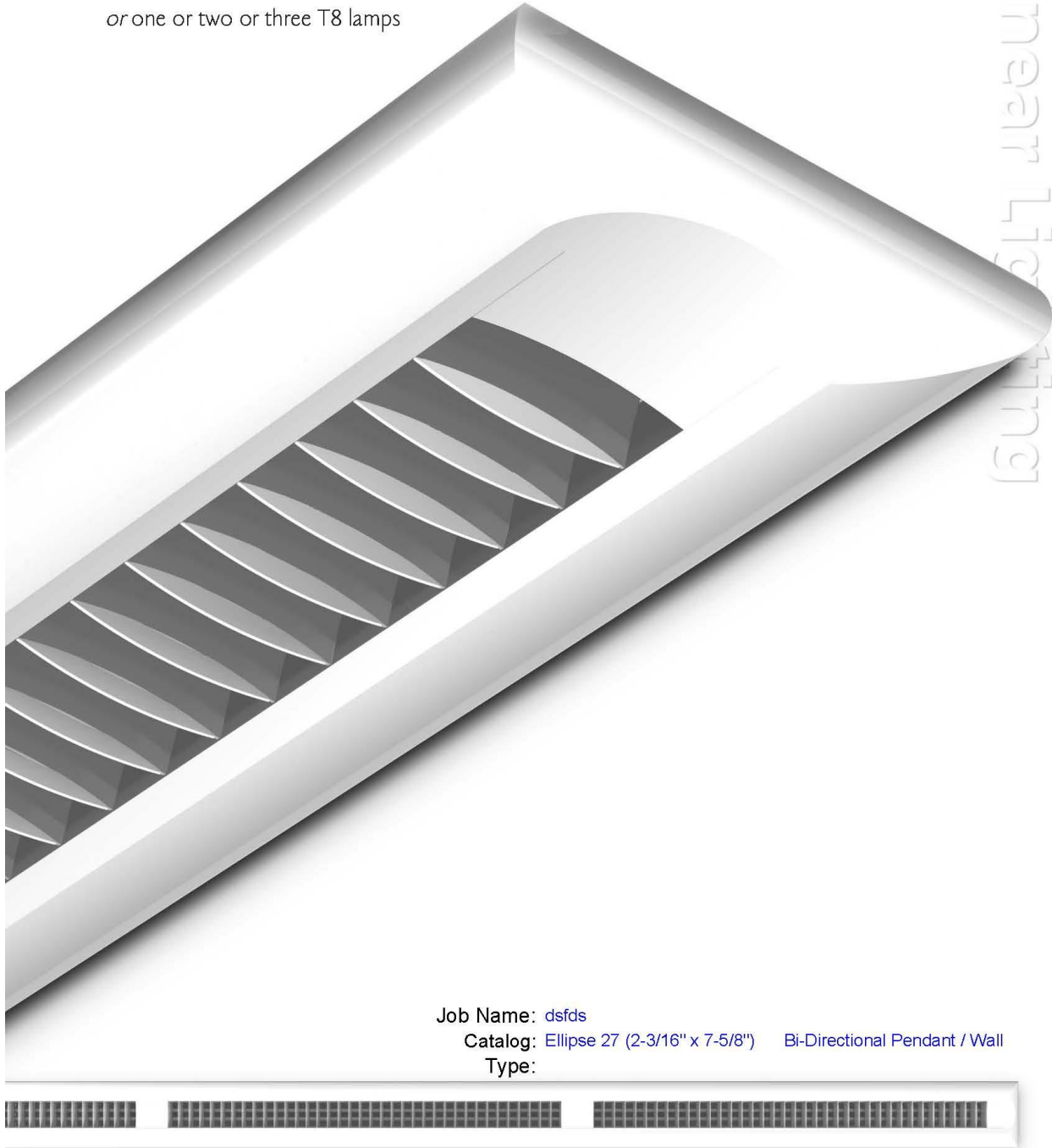
Luminaires

Luminaire Schedule									
Fixture Type	Image	Description	Mounting	Lamp	Voltage	Ballast	Wattage	Notes	
A2		Linear Lighting Ellipse 27. 1'x4' Indirect/Direct Pendant Fixture, Extruded Aluminum Housing, Baked White finish. Concave louver blades with clear convex insert Catalog #: EL27-B-1-ET5-277-PVI_IC	Pendant 9'-0" A.F.F.	(1) 54W T5 CCT 4100K CRI 85	277V	Electronic Advanced Transformer	63W		
A3		Linear Lighting Ellipse 27. 1'x4' Indirect/Direct Pendant Fixture, Extruded Aluminum Housing, Baked White finish. Concave louver blades with clear convex insert Catalog #: EL27-B-1-ET5-277-PVI_IC-LS	Pendant 9'-0" A.F.F.	(1) 28W T5 CCT 4100K CRI 85	277V	Electronic Dimming Advanced Transformer	32W		
B		Ledalite Voice. Recessed 1'x4' Fixture, Die-Formed Cold Rolled Steel Housing, Flat Acrylic Panels Connected to Prismatic Acrylic Diffuser Catalog #: 9814D1-ST-F128-S-1-2-E	Recessed	(1) 28W T5 4100K CRI 85	277V	Electronic Advanced Transformer	31W		
C1		Philips Alko Aris Series. 11" Low Profile LED Fixture, Extruded Aluminum Housing, Pearl Finish, Extruded Clear Polycarbonate Lens. Integrated On/Off Switch Catalog # ARIS-11-40-120-PRL-DWC	Surface	(5) 1W LEDs CCT 4000K CRI 71-73	120V	Integrated Driver	5W	Surface mounted to bottom of shelf at 4'-3" A.F.F.	
C2		Philips Alko Aris Series. 21" Low Profile LED Fixture, Extruded Aluminum Housing, Pearl Finish, Extruded Clear Polycarbonate Lens. Integrated On/Off Switch Catalog # ARIS-21-40-120-PRL-DWC	Surface	(10) 1W LEDs CCT 4000K CRI 71-73	120V	Integrated Driver	10W	Surface mounted to bottom of shelf at 4'-3" A.F.F.	
X1		Louis Poulsen Kipp Post Cutoff. Pole Mounted Fixture, White Spun Aluminum Diffuser, Black Injection Molded ASA Top Shade, Clear Polycarbonate Enclosure, Black Die Cast Aluminum Frame Catalog #: KIP-1-70W-CMH-T6 G12	Pole Mounted 27'-0"	(1) 70W CMH CCT 3000K CRI 90	277V	Electronic Advanced Transformer	79W		
X2		Louis Poulsen Kipp Bollard. Pole Mounted Fixture, Injection Molded White Opal Acrylic Diffuser, Injection Molded Clear Polycarbonate Enclosure, Black Die Cast Aluminum Frame. Catalog #: KIB-1-39W-CMH-T6 G12	Pole Mounted 4'-3"	(1) 39W CMH CCT 3000K CRI 90	277V	Electronic Advanced Transformer	45W		
X3		Winona Lighting Spirit. Black Painted Aluminum, 18" Stem, Area Light. Catalog #: SP-0-12V-BKS-18-SM-STD	Surface 18" Stem	(1) 35W MR8 CCT 3000K CRI 100	12V	--	35W	Provide Series TMI 600 Ingrade Transformer	
X4		Invue Entri LED Triangle Reveals. Black One Piece Die-Cast Aluminum, Injection Molded AccuLED Optical System. Catalog #: ENT-A01-E1-BL4-BK	Wall Mount	(1) LED Bar 4000K CRI >70	277V	Integrated Driver	26W	Wall mounted at 10'-0"	
X5		Lightolier Calculite 6" Recessed Downlight. Array of High Brightness Royal Blue LED's, Phosphory Lens Assembly Converts Blue Light to White. Catalog #: C6L20-DL-30-M-CL-P	Recessed	LED CCT 3000K CRI	277V	Integrated Driver	39W		
X6		Lightolier Calculite 6" Recessed Wallwasher. Array of High Brightness Royal Blue LED's, Phosphory Lens Assembly Converts Blue Light to White. Catalog #: C6L20-WW-30-M-CL-P	Recessed	LED CCT 3000K CRI	277V	Integrated Driver	39W		
X7		Bega Floodlight. 3'x4' Floodlight. Black Die-Cast Aluminum Extruded Housing. Catalog #: 7593P.537BLK-28	Wall Mount	(1) 28W T5HO CCT 3000K CRI 85	277V	Electronic Advanced Transformer	31W	Mount Parallel to underside of cantiliver void.	
X8		MP Lighting. Black Anodized Aluminum Housing, Polycarbonate Lens. Catalog #: L36-3.5W-W30S-BA	Surface	LED CCT 3000K CRI	12V	Remote Driver	3.5W	Provide Remote TLDDL60W5000 Driver	

Luminaire Schedule

Ellipse EL27

one or two or three T5 or T5HO lamps
or one or two or three T8 lamps



Job Name: dsfds

Catalog: Ellipse 27 (2-3/16" x 7-5/8") Bi-Directional Pendant / Wall

Type:

Fixture Type A

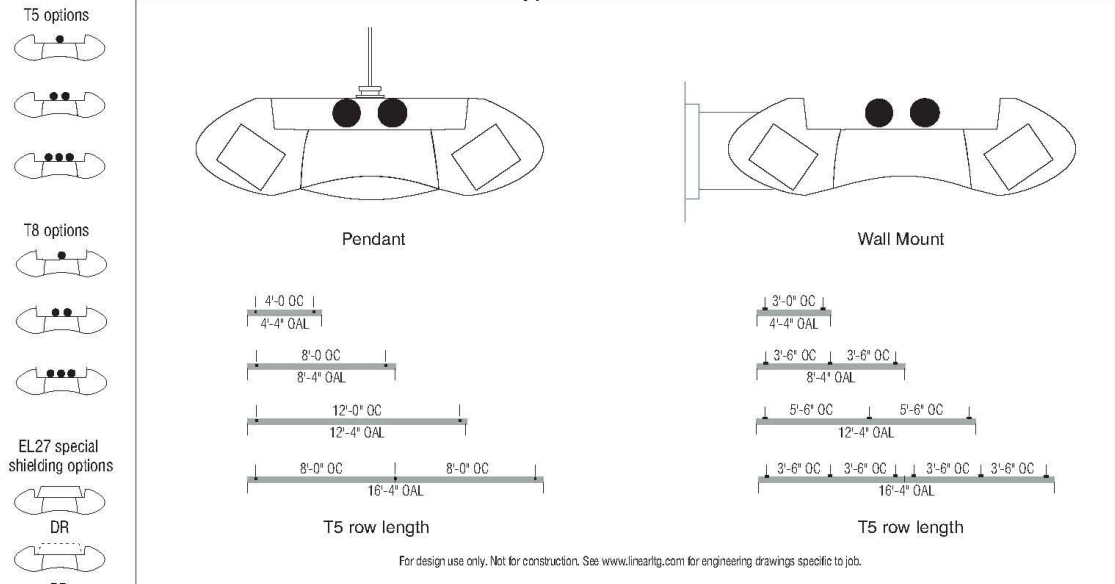
Job Name: dsfds

Catalog: Ellipse 27 (2-3/16" x 7-5/8")

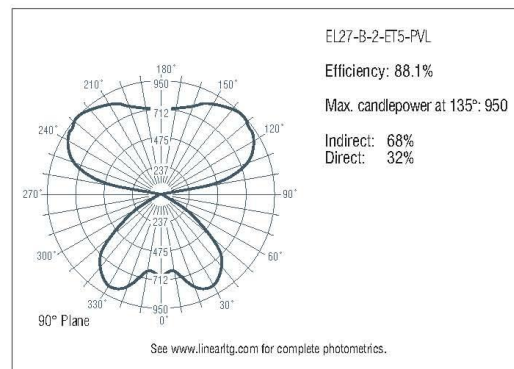
Bi-Directional Pendant / Wall

Type:

Ellipse EL27



- Extruded aluminum housing
- Bidirectional lighting
- 1, 2, or 3 T5/T5HO or T8 lamps
- Die-cast joiners
- Pre-wired with quick-connect plugs
- UL/CUL labels
- Weight per foot: 3.6 lbs. approx.



Catalog No.	Dir.	Lamps	Ballast	Voltage	Shielding	Mounting	Color	Add'l options	Row length
EL27	-	B	-	-	-	-	-	-	-
Fixture	Lamps & Electrical Options				Mechanical & Aesthetic Options				Feet
	Direction	B idirectional			Indirect	NS No Shielding, BR *, DR *			
	Lamps	1, 2 or 3			Shielding	See tab for top shielding illustrations			
	Ballast	ET5 Electronic T5			Direct	PRD, PRT, DIF, PVL, PXL, PBL, PVLIC, PVLIG			
		ET5HO High Output T5			Shielding	See tab for part and lower illustrations			
		ET8 Electronic T8			Mounting	Cxx Cable			
	Voltage	120 or 277				Sxx Stem			
		347				Bxx Stem Ball Aligner			
						WMT Wall Mount			
						xx— inches, ceiling to top of fixture			
					Color	BW Baked White			
						AP Aluminum Paint			
						CC Custom Color			
						See color selector			
						NO No Option			
						FU Fusing			
						EC Emergency Circuits			
						NL Night Light			
						ED Electronic Dimming*			
						EM Emergency Ballast**			
						SC Separate Circuits			
						DC Dust Cover			
						LO Louver Overlay			
						ISB10 Instant Start Ballast <10%			
						PSB10 Program Start Ballast <10%			
						SF Special Feature			
						CB Checkboard Circuit "A" or "B"			
						CBC Checkboard Circuit "C"			
						LS LutronEcoSys Sensor Feed			
						PBPS Prem Ballast Prog Start			
						SF Special Feature			

* Dimming ballasts may not be available for all T5/T5HO lamp lengths. Consult factory.
** EM packs may not be available for all T5/T5HO lamp lengths. Consult factory.

*ISB10 and PSB10 available with T8 only.
**BR and DR not available with 3T8 lamping option.

Designed for acoustical ceilings.
See www.linearlighting.com for IES files and additional information.

Linear Lighting Corp.
31-30 Hunters Point Ave., Long Island City, NY 11101 ©7/08
718-361-7552 Fax 718-937-2747 Web: www.linearlighting.com

Fixture Type A

Voice™

Recessed

1'x4'

1 T5

Project Name

Spec Type

Notes

Order Guide Some combinations of product options may not be available. Consult factory for assistance with your specification.

9814				F128				
Product Series & Size Voice 1'x4'	Version D1 Standard T-Grid	Configuration ST Standalone CR Continuous Row SMS Standalone Master/Satellite CMS Continuous Row Master/Satellite	Lamping 1 T5 (28W)	Housing S Standard (22ga.) N New York (20ga.) C Chicago Plenum T Standard w/ Frame Restraint	Wiring 1 1 cct 5 1 cct w/ Battery Pack 7 1 cct Dimming	Voltage 1 120V 2 277V 3 347V	Ballast E Standard Ballast	
See details on next page					Consult website for complete list of standard wiring options		Consult website for ballast manufacturer information	

Upgrades & Accessories Please indicate with check mark.

☐ Lamps Included ☐ Job Pack ☐ Drywall Kit ☐ Response Daylight For details visit www.ledalite.com/response	☐ Lamps Included & Installed ☐ Flex Whip Can be mounted to wood frame or with hanger wire
--	--

Cross Section

Side View

© 2010 Ledalite Phone: 604.888.6811 Fax: 800.665.5332 Web: www.ledalite.com

Filename: 9814xxxxF128.pdf Rev 2.5

Ledalite is a Philips group brand

PHILIPS

Fixture Type B

Voice™

Recessed
1'x4'
1 TS



Photometry

Report Summary

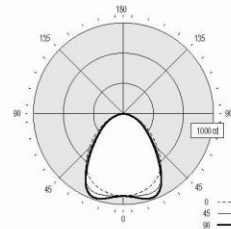
Report # 9900727
Filename 9614D1F128.ies
Efficiency 75.6%

Spacing Criteria 1.28 @ 0° along
1.3 @ 90° across

Meets RP-1-04 recommendations for VDT-Normal spaces

Candela Distribution

Vertical Angle	0	22.5	45	67.5	90	Zonal Lumens
0	906	906	906	906	906	
5	902	905	911	915	919	89
15	877	893	927	957	971	263
25	823	856	906	939	942	411
35	719	738	732	728	699	452
45	541	530	488	472	455	394
55	358	344	314	304	296	290
65	214	208	188	187	181	194
75	94	92	85	88	88	95
85	10	17	14	13	12	18
90	0	0	0	0	0	



Coefficients of Utilization (%)

Ceiling	70	50	30	10	70	50	30	10	0
0 RCR	90	90	90	90	88	88	88	84	84
1	83	80	77	74	81	78	75	72	71
2	76	71	66	62	74	69	65	61	60
3	70	63	57	53	68	62	57	53	51
4	65	56	50	46	63	56	50	45	42
5	60	51	44	40	58	50	44	40	37
6	55	46	40	35	54	45	39	34	31
7	52	42	36	31	50	41	35	30	29
8	48	38	32	28	47	38	32	27	26
9	45	35	29	25	44	35	29	24	23
10	42	33	27	23	41	32	27	22	21

Based on a floor reflectance of 0.2

Avg. Luminance (cd/m²)

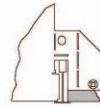
Vertical Angle	0	45	90
55	1882	1633	1540
65	1511	1327	1279
75	1094	980	991
85	342	479	411

IES files for this and other photometric options can be downloaded online at www.ledalite.com

Additional Information

Mounting

Integrates with most common T-bar ceiling types.

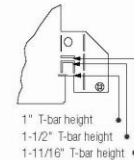


D1 Standard T-Grid

Option D1 works with 9/16" and 15/16" flat T-grid ceilings. It can also be used with slot T-grid ceilings, but it will not sit flush with the bottom of the T-bar.

Ceiling Types

Integrated mounting tabs can be field-adjusted to various T-bar ceiling heights for fastening directly to the T-bar grid and/or tied-off to the building structure.



1" T-bar height
1-1/2" T-bar height
1-11/16" T-bar height

Specifications

Due to continuing product improvements, Ledalite reserves the right to change specifications without notice.

Housing

Die-formed, post-painted, 22 gauge cold-rolled steel (New York City version is 20 gauge). Wire entrances are positioned on the side of the housing to allow easy wiring access for the installer. Multiple wire entrances are available on top or side to allow continuous row mounting of fixtures. Optional frame restraint is available to provide additional support to the optical frame.

Weight

Maximum 30 lbs.

Optical System

The optical frame assembly consists of flat acrylic panels with a layer of protected MesoOptics® film that provides high-angle glare control and high efficiency. The panels are secured to a perforated center shield using a linear prismatic acrylic diffuser. The optical frame ends are constructed from die-formed cold-rolled steel assembled together with extruded aluminum profiles in a sturdy frame. The frame is hinged to allow easy access to the inside of the fixture. Maintenance can be performed from below the ceiling without tools. No hardware is visible.

Mounting

Fixture is compatible with most ceiling types. Integrated bend-out tabs are provided for different T-grid heights. Optional drywall kit is available for non-accessible ceilings. Use screws or hanger wire (supplied by others) to secure fixture.

Ballast

Electronic. Supplied with pre-installed ballast disconnects as per national electric codes.

Wiring

Optional flex whips are supplied in 6' lengths for 1x4, 2x2 and 2x4 fixtures. Flex connectors are supplied in 9' lengths for standard master/satellite configurations.

Air Return

Air return option available in 2'x2' and 2'x4' sizes only. Side rails are finished in black.

Approvals

Certified to UL & CSA Standards.
City of Chicago Approved CCEA (housing option C).
Designed to comply with NYC code requirements (Housing Option N).

Finish

Housing and Frame: Post-painted, high quality powder coat. Available in white only.

Fixture Type B

A14.1

Aris

Low Profile Task Light
LED

ARIS Series

Description

Aris is a low-profile LED luminaire that is ideal for undercabinet, task and display case lighting in both residential and commercial applications. Its 0.86" high x 1.7" cross-section is easy to conceal in cabinetry and casework. With an integrated driver, Aris can be connected directly to line voltage power without the need for external drivers. Jumper cables and mounting clips further simplify system installation. The LED light source offers long life, good color rendition, and low power consumption. With no ultraviolet or infrared radiation, photosensitive objects are safe from damage. Aris provides maintenance-free operation for years.

Additional features:

- Available in two color temperatures: 2700K and 4000K.
- Three fixture lengths
- Line voltage operation – doesn't require an external driver
- Up to 50 linear feet and <324 watts of Aris luminaires can be connected on a single run
- Controllable with commercially available line voltage dimmers (ELV-type)
- LED source provides 50,000 hours of life with 70% of initial lumens

Specifications

Construction Extruded aluminum body with molded polycarbonate endcaps.

Finish The luminaire body has a polyester paint finish in a pearl finish. The endcaps are molded to match.

Lens Extruded clear, polycarbonate lens.

Lamps High efficacy (>40 lumens per watt), high brightness LEDs with a beam angle of 110° x 110° beam angle. The LED source has a life of 50,000 hours (based on manufacturer's test data). ARIS-11 has 5 LEDs, ARIS-21 has 10 LEDs and ARIS-41 has 20 LEDs. Aris is available in a 2700K color temperature with a CRI of 71-73 and a 4000K color temperature with a CRI of 80-81. The CRI varies depending on the length of the fixture.

Listings UL and CUL Damp Listed for both permanent and portable installations.

Electrical Aris has an integrated driver system so that luminaires can be connected directly to 120 volts and can be operated at temperatures ranging from -4°F to 122°F (-20°C to 50°C). Aris is not available for 277 or 347 volt applications.

Dimming Aris can be dimmed with commercially available line voltage dimmers (electronic low voltage load type). See Aris installation instructions for compatible dimmers.

Installation Mounting clips are provided with each Aris luminaire. Once the clips are installed, the Aris luminaire can be snapped into place. Full length mounting brackets are also available as an option.

A hard-wire connection can be made with the optional hard wiring compartment (HWC) which requires a jumper cable to connect the right end of the first fixture or a direct wiring compartment (DWC) which has an on/off switch and connects directly to the right or left end of the first fixture. The switched leader cable (SLC) has an on/off switch and plugs into a standard 120v receptacle. For other installation details, refer to the back of this sheet.

Warranty Aris fixtures (for the original installation) have a driver warranty of 3 years from the date of manufacture and a LED warranty for the specified lumen maintenance for 10 years.



Photo shows right end of luminaire

Ordering Information

Sample Catalog No: ARIS-11 - 27 - 120 - PRL - HWC - AJC6

NOH. LENGTH	Model Number	LED Color Temp.	Voltage	Finish (standard color is PRL)	Options
11"	ARIS-11	27 2700K 40 4000K	120	PRL Pearl	DWC ¹ Direct wiring compartment (with on/off switch) HWC ^{2,3} Hard wiring compartment SLC ⁴ Switched leader cable (10' cord) AFC Flush connector AJC6 6" Jumper cable AJC12 12" Jumper cable AJC18 18" Jumper cable AJC60 60" Jumper cable AJCY ² 11" Jumper cable ATRM ⁴ Termination plug AMB11 9" Full length mounting bracket (for ARIS-11) AMB21 19" Full length mounting bracket (for ARIS-21) AMB41 39" Full length mounting bracket (for ARIS-41)
21"	ARIS-21				
41"	ARIS-41				

¹ Supplied with 2 Termination Rugs, (ATRM) allows power from the left or right side.

² Supplied with a Termination Rug for the left side (ATRM) power must come from the right side.

³ Requires one of the Jumper Cables to connect to the first luminaire. The Flush connector (AFC) cannot be used with the HWC.

⁴ A Termination Plug is required to be plugged into the left side connector of the last luminaire in the run before energizing the system. One ATRM is supplied with HWC, SLC and AJCY options.

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Fixture Type C

A14.1

Aris

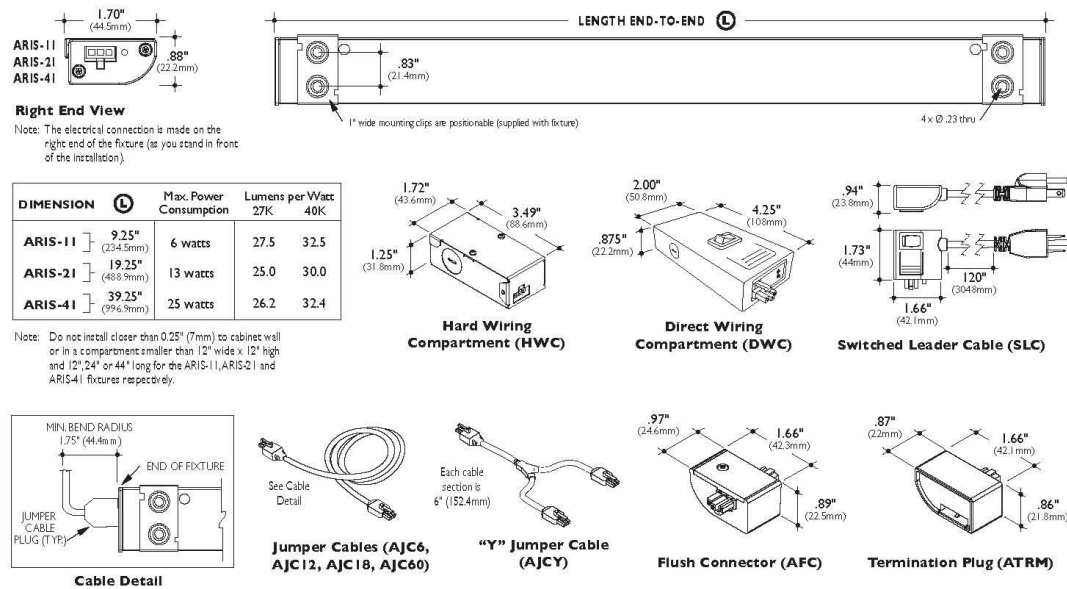
Low Profile Task Light
LED

ARIS Series

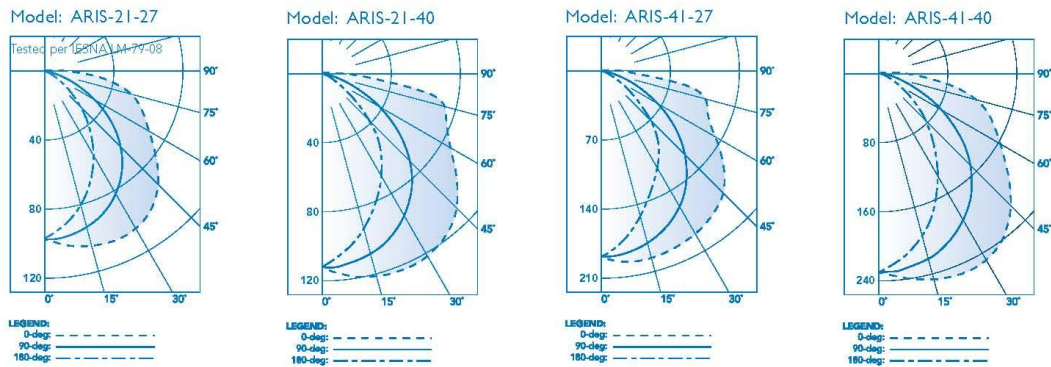


Project	Type
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Dimensional Data



Photometric Data



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PHILIPS
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Fixture Type C

A14.1

Aris

Low Profile Task Light
LED

ARIS Series

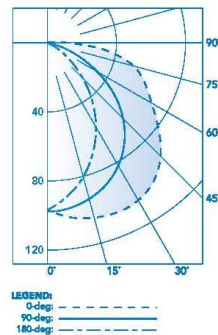


Project	Type
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Photometric Data

ARIS-21-27

(10) White LEDs
Report No.: ITL60514
Tested per IESNA LM-79-08



CO-EFFICIENTS OF UTILIZATION | Effective floor cavity reflectance=20%

rc	rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	0	118	118	118	118	115	115	115	115	110	110	110	105	105	105	101	101	101	99
	1	108	103	98	94	105	100	96	93	96	92	89	92	89	86	88	86	84	81
	2	98	89	82	77	95	87	81	76	84	78	74	80	76	72	77	73	70	68
	3	89	79	70	64	87	77	69	63	74	67	62	71	65	61	68	63	59	57
	4	82	70	61	54	79	68	60	54	66	57	53	63	57	52	61	56	51	49
	5	75	62	53	47	73	61	53	46	59	51	46	57	50	45	55	49	45	42
	6	70	56	47	41	68	55	47	41	53	46	40	52	45	40	50	44	39	37
	7	64	51	42	36	63	50	42	36	48	41	36	47	40	35	46	40	35	33
	8	60	47	38	32	58	46	38	32	44	37	32	43	36	32	42	36	31	29
	9	56	43	35	29	55	42	34	29	41	34	29	40	33	28	39	33	28	26
	10	53	39	32	26	51	39	31	26	38	31	26	37	30	26	36	30	26	24

CANDLEPOWER DISTRIBUTION

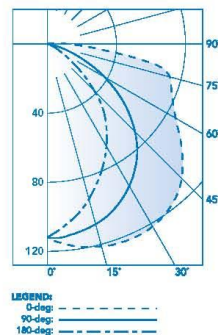
Vertical Angle	Horizontal Angle	0°	45°	90°	135°	180°
0°	0°	97	97	97	97	97
5°	0°	100	99	97	94	92
15°	0°	105	101	94	84	81
25°	0°	106	101	87	72	66
35°	0°	103	96	77	56	48
45°	0°	93	87	63	39	30
55°	0°	78	71	45	21	15
65°	0°	64	51	25	9	6
75°	0°	53	35	9	3	2
85°	0°	28	17	2	1	1
90°	0°	13	10	0	0	0

ZONAL LUMEN SUMMARY

Zone	Lumens	% Fixt.
0-30	75	27.4
0-40	123	44.8
0-60	212	77.2
0-90	271	98.7
90-180	3	1.3
0-180	275	100.0

ARIS-21-40

(10) White LEDs
Report No.: ITL60517
Tested per IESNA LM-79-08



CO-EFFICIENTS OF UTILIZATION | Effective floor cavity reflectance=20%

rc	rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	101	101	101	99
	1	108	103	98	94	105	101	96	93	96	93	90	92	89	87	88	86	84	82
	2	98	90	83	77	95	88	81	76	84	78	74	80	76	72	77	73	70	68
	3	89	79	70	67	87	77	69	63	74	67	62	71	65	60	68	63	59	57
	4	82	70	61	54	79	68	60	53	66	58	53	63	57	52	61	55	51	49
	5	75	62	53	46	73	61	53	46	59	51	45	57	50	45	55	49	44	42
	6	70	56	47	41	68	55	47	40	53	46	40	51	45	39	50	44	39	37
	7	65	51	42	36	63	50	42	36	48	41	35	47	40	35	45	39	35	33
	8	60	46	38	32	58	46	38	32	44	37	32	43	36	31	42	36	31	29
	9	56	43	34	29	55	42	34	29	41	34	28	40	33	28	38	32	28	26
	10	53	39	31	26	51	39	31	26	38	31	26	37	30	26	36	30	25	24

CANDLEPOWER DISTRIBUTION

Vertical Angle	Horizontal Angle	0°	45°	90°	135°	180°
0°	0°	112	112	112	112	112
5°	0°	116	114	112	108	106
15°	0°	121	116	108	97	93
25°	0°	123	116	100	83	77
35°	0°	120	111	89	67	60
45°	0°	110	101	72	49	40
55°	0°	94	85	51	27	17
65°	0°	80	64	27	10	6
75°	0°	74	47	10	4	2
85°	0°	29	21	2	1	1
90°	0°	14	10	0	0	0

ZONAL LUMEN SUMMARY

Zone	Lumens	% Fixt.
0-30	87	26.6
0-40	142	43.7
0-60	248	76.2
0-90	322	98.8
90-180	4	1.2
0-180	325	100.0

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Fixture Type C

A14.1

Aris

Low Profile Task Light
LED

ARIS Series

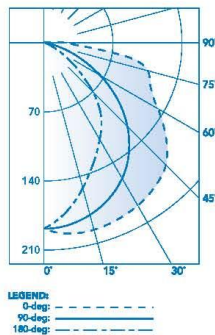


Project	Type
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Photometric Data

ARIS-41-27

(20) White LEDs
Report No.: ITL60515
Tested per IESNA LM-79-08



CO-EFFICIENTS OF UTILIZATION | Effective floor cavity reflectance=20%

rc	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	0	119	119	119	119	116	116	116	116	110	110	110	105	105	105	101	101	99
1	108	103	98	94	105	100	96	93	96	92	89	92	89	86	88	86	84	81
2	98	89	82	77	95	87	81	75	84	78	74	80	76	72	77	73	70	68
3	89	79	70	64	87	77	69	63	74	67	62	71	65	60	68	63	59	57
4	82	70	61	54	79	68	60	54	66	58	53	63	57	52	61	55	51	49
5	75	62	53	47	73	61	53	46	59	51	46	57	50	45	55	49	44	42
6	69	56	47	41	67	55	47	40	53	46	40	51	45	40	50	44	39	37
7	64	51	42	36	63	50	42	36	48	41	35	47	40	35	45	39	35	33
8	60	46	38	32	58	46	38	32	44	37	32	43	36	31	42	36	31	29
9	56	43	34	29	55	42	34	29	41	34	29	40	33	28	39	33	28	26
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CANDLEPOWER DISTRIBUTION

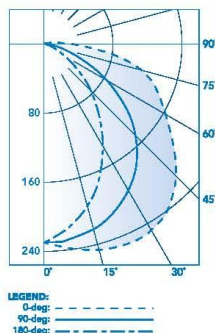
Vertical Angle	Horizontal Angle	0°	45°	90°	135°	180°
0°	188	188	188	188	188	188
5°	193	191	187	181	178	178
15°	196	191	180	161	152	152
25°	193	185	167	134	124	124
35°	187	172	147	108	102	102
45°	174	156	120	83	70	70
55°	148	133	85	50	34	34
65°	121	97	47	21	13	13
75°	109	70	18	7	4	4
85°	43	32	3	1	1	1
90°	22	17	0	0	0	0

ZONAL LUMEN SUMMARY

Zone	Lumens	% Fixt.
0-30	142	27.1
0-40	231	44.1
0-60	402	76.7
0-90	517	98.7
90-180	7	1.3
0-180	524	100.0

ARIS-41-40

(20) White LEDs
Report No.: ITL60518
Tested per IESNA LM-79-08



CO-EFFICIENTS OF UTILIZATION | Effective floor cavity reflectance=20%

rc	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	101	101	99
1	108	103	98	95	105	101	97	93	97	93	90	92	90	87	89	86	84	82
2	99	90	83	77	96	88	82	76	84	79	74	81	77	73	78	74	71	69
3	90	79	71	65	87	78	70	64	74	68	63	72	66	61	69	64	60	58
4	82	70	65	55	80	69	61	54	66	59	54	64	58	53	62	56	52	50
5	76	63	54	47	74	62	53	47	60	52	46	57	51	46	55	50	45	43
6	70	57	48	41	68	56	47	41	54	46	41	52	45	40	50	44	40	38
7	65	52	43	37	63	51	42	36	49	42	36	47	41	36	46	40	35	33
8	61	47	39	33	59	46	38	33	45	38	32	44	37	32	42	36	32	30
9	57	43	35	29	55	43	35	29	41	34	29	40	34	29	39	33	29	27
10	53	40	32	27	52	39	32	27	38	31	26	37	31	26	36	30	26	24

CANDLEPOWER DISTRIBUTION

Vertical Angle	Horizontal Angle	0°	45°	90°	135°	180°
0°	230	230	230	230	230	230
5°	236	234	230	224	220	220
15°	247	239	222	204	194	194
25°	251	239	206	174	157	157
35°	243	229	183	136	114	114
45°	216	206	149	93	76	76
55°	179	166	106	54	40	40
65°	148	117	58	24	15	15
75°	116	79	22	8	5	5
85°	54	35	4	2	1	1
90°	28	20	0	0	0	0

ZONAL LUMEN SUMMARY

Zone	Lumens	% Fixt.
0-30	179	27.7
0-40	293	45.2
0-60	505	77.9
0-90	640	98.8
90-180	8	1.2
0-180	648	100.0

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Fixture Type C

A14.1

Aris

Low Profile Task Light
LED

ARIS Series

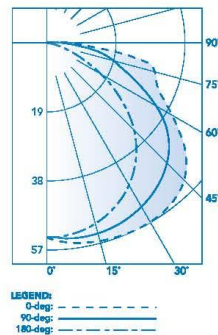


Project	Type
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Photometric Data

ARIS-11-27

(5) White LEDs
Report No.: ITL60513
Tested per IESNA LM-79-08



CO-EFFICIENTS OF UTILIZATION | Effective floor cavity reflectance=20%

rc	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	0	118	118	118	118	115	115	115	115	110	110	110	105	105	105	101	101	99
1	107	102	98	94	104	100	96	92	96	92	89	92	89	86	88	86	84	81
2	98	89	82	76	95	87	81	75	84	78	74	80	76	72	77	73	70	68
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4	82	70	61	54	79	68	60	54	66	58	53	63	57	52	61	56	51	49
5	75	62	53	47	73	61	53	46	59	51	46	57	50	45	55	49	45	43
6	69	56	47	41	67	55	47	41	53	46	40	52	45	40	50	44	39	37
7	64	51	42	36	63	50	42	36	48	41	36	47	40	35	46	40	35	33
8	60	46	38	32	58	46	38	32	44	37	32	43	36	32	42	36	31	29
9	56	43	35	29	55	42	34	29	41	34	29	40	33	29	39	33	28	27
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CANDLEPOWER DISTRIBUTION

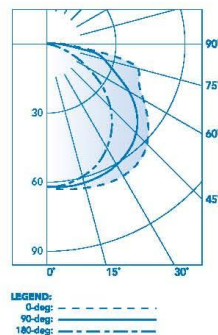
Vertical Angle	Horizontal Angle	0°	45°	90°	135°	180°
0°	53.5	53.5	53.5	53.5	53.5	53.5
5°	54.9	53.9	53.3	52.4	51.7	51.7
15°	56.3	54.1	51.4	48.3	46.8	46.8
25°	56.9	53.0	47.7	42.1	38.9	38.9
35°	56.4	50.6	42.0	33.7	28.6	28.6
45°	53.4	46.6	33.9	22.6	16.0	16.0
55°	45.3	40.0	23.2	10.9	7.4	7.4
65°	34.9	28.7	11.9	4.4	2.9	2.9
75°	30.8	18.9	4.3	1.6	1.0	1.0
85°	13.0	8.7	0.8	0.3	0.3	0.3
90°	6.4	4.6	0.0	0.0	0.0	0.0

ZONAL LUMEN SUMMARY

Zone	Lumens	% Fixt.
0-30	41.5	27.7
0-40	67.9	45.2
0-60	116.8	77.8
0-90	148.3	98.8
90-180	1.8	1.2
0-180	150.1	100.0

ARIS-11-40

(5) White LEDs
Report No.: ITL60516
Tested per IESNA LM-79-08



CO-EFFICIENTS OF UTILIZATION | Effective floor cavity reflectance=20%

rc	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR	0	118	118	118	118	115	115	115	115	110	110	110	105	105	105	101	101	99
1	107	102	98	94	104	100	96	92	96	92	89	92	89	86	88	86	84	82
2	98	89	82	76	95	87	81	75	84	78	74	80	76	72	77	73	70	68
3	89	78	70	64	86	77	69	63	74	67	62	71	65	61	68	63	59	57
4	81	69	61	54	79	68	60	53	65	58	53	63	57	52	61	56	51	49
5	75	62	53	46	73	61	52	46	59	51	46	57	50	45	55	49	45	42
6	69	56	47	41	67	55	47	40	53	46	40	51	45	40	50	44	39	37
7	64	51	42	36	62	50	42	36	48	41	35	47	40	35	46	39	35	33
8	60	46	38	32	58	46	38	32	44	37	32	43	36	31	42	36	31	29
9	56	43	34	29	54	42	34	29	41	34	29	40	33	28	39	33	28	26
10	52	39	31	26	51	39	31	26	38	31	26	37	30	26	36	30	26	24

CANDLEPOWER DISTRIBUTION

Vertical Angle	Horizontal Angle	0°	45°	90°	135°	180°
0°	61.9	61.9	61.9	61.9	61.9	61.9
5°	63.3	62.3	61.9	60.3	60.2	60.2
15°	64.6	62.4	59.7	55.8	54.4	54.4
25°	66.0	61.5	55.3	48.9	46.4	46.4
35°	65.7	59.3	48.5	40.3	36.6	36.6
45°	61.5	54.8	39.1	29.6	23.1	23.1
55°	53.1	46.8	27.1	16.5	10.6	10.6
65°	44.5	35.0	14.2	6.6	4.2	4.2
75°	41.1	25.9	5.1	2.4	1.5	1.5
85°	12.9	9.7	0.9	0.5	0.4	0.4
90°	6.9	5.2	0.0	0.0	0.0	0.0

ZONAL LUMEN SUMMARY

Zone	Lumens	% Fixt.
0-30	48.2	26.7
0-40	79.3	43.9
0-60	138.5	76.8
0-90	178.4	98.9
90-180	2.1	1.1
0-180	180.4	100.0

► Go to www.alkco.com for additional Photometric Data

11500 Melrose Avenue Franklin Park, Illinois 60131
Phone: 847-451-0700 Toll-Free: 1-866-50ALKCO
Fax: 847-451-7512 www.alkco.com 01/11
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PHILIPS
ALKCO

Fixture Type C

184 Kipp Post Cutoff

post tops/poles & cable hung

**louis
poulsen**



Weblink
167

Design
Alfred Homann

Concept
Kipp Post Cutoff emits symmetrical, downward illumination. The relationship between the slightly curved design of the top shade and the calculated distance to the light source ensures a uniform and wide distribution of light. The design of the internal diffuser ensures an optimal and glare free illumination. The opaque diffuser satisfies cutoff requirements.

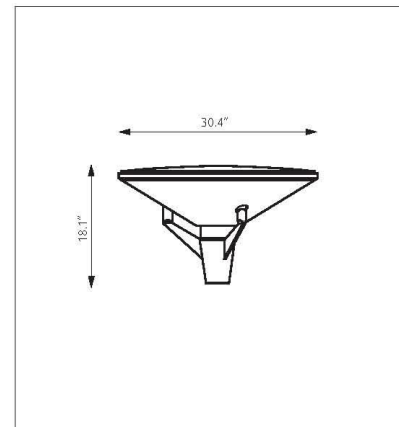
Finish
Natural painted aluminum or black, powder coated.

Material
Diffuser: White, spun aluminum. Top shade: Black or white, injection molded ASA. Enclosure: Injection molded clear polycarbonate. Frame: Die cast aluminum.

Mounting
Post top: Mounted on dual round aluminum (DRA) or round straight aluminum (RSA) pole.

Weight
Max. 24 lbs.

Label
cUL, Wet location, IBEW.



Product code	Light source	Voltage	Finish	Distribution	Transition to pole
KIP	1/150W/CMH/T-6 G12 1/175W/WH/ED-17 medium 1/85W/QL	120/277V 120V 277V	BLK NAT PAINT ALU	CUTOFF	T-DRA-5"-3" T-RSA-4.5"

Specification notes:
a. QL variants provided with 120V or 277V HF integral generator and can only be used with RSA-4.5" pole.
b. CMH and MH variants provided with one 120/277V F-can style ballast to be mounted in RSA-4.5" or DRA-5"-3" poles.

Info notes:
I. Black top shade is provided with black finish.
II. White top shade is provided with natural painted aluminum finish.
III. Enclosure is U.V. stabilized polycarbonate.
IV. The comparable EU version has the following classification: Ingress Protection Code: IP66.
V. For pole selection, refer to pages 204 and 205.

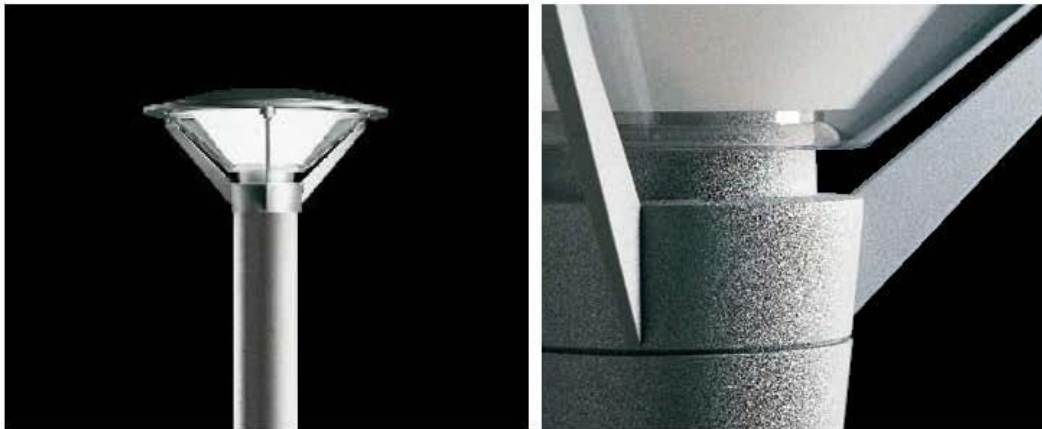


Fixture Type X1

162 Kipp Bollard

bollards

louis
poulsen



Web link
145

Project page
290, 340, 348

Design
Alfred Homann

Concept:
Kipp bollard emits symmetrical, downward illumination. The relationship between the curved design of the top shade and the calculated distance to the light source ensures a uniform and wide distribution of light. The design of the internal diffuser ensures an optimal even and glare free illumination.

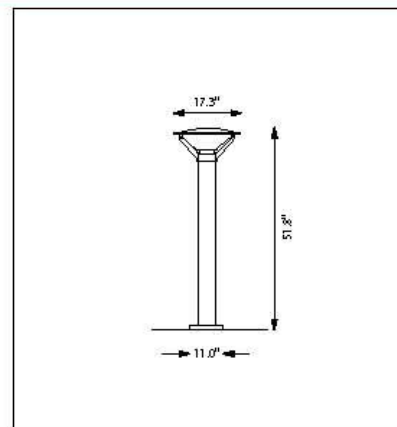
Finish:
Black or natural painted aluminum, powder coated.

Material:
Diffuser: Injection molded white opal acrylic. Top shade: Die cast aluminum. Enclosure: Injection molded clear polycarbonate. Frame: Die cast aluminum. Post: Extruded aluminum. Base plate: Die cast aluminum.

Mounting:
Base plate dimension: 11" diameter. Base plate: Mounted to a concrete base with 3 anchor bolts.

Weight:
Max. 41 lbs.

Label:
CUL, Wet location, 18EW.



Product code	Dimension	Light source	Voltage	Finish
K18	51.8"	1/70W /CMH/T-6 G12 1/100W /MH/ED-17 medium 1/37W LED, 4000K	120/277V	BLK NAT PAINT ALU

Specification notes:
a. CMH and MH variants provided with one 120/277V F-can style ballast.

Info notes:
I. The bollard is supplied without basecover.
II. The comparable EU version has the following classification: Ingress Protection code: IP 55.



Fixture Type X2

12V MR-8 SPIRIT



QUICK FIND #: QF-13



UL Listed: Wet location
Outdoor = 35W

SP - SPIRIT

SERIES
SP - Spirit

LAMP - 12V MR-8 - (see inside back cover p.162)
0 43 46

VOLTAGE
12V - 12 Vdc

FINISH - (see inside back cover p.162)
BKS BKT BRS BRT WHS WHT SIS IRS CHS NBS VET SAT CPF

COLOR FILTER - (see inside back cover p.162)
FD FMI FR FRD FP FA FG FGD FLB FMB FMBD

STEM LENGTH

S6 - 6" Stem
S12 - 12" Stem
S18 - 18" Stem
S24 - 24" Stem

MOUNT STYLE

PM1 - Power Mount™ 60
PM2 - Power Mount™ 60 Transformer Housing & 60W Transformer
PM3 - Power Mount™ 60 Adjustable Stem
SM - Surface Mount

SPECIAL

STD - Standard
MOD - Modified

SPIRIT / SPIRIT BRASS

- Luminaire manufactured from ALUMINUM or BRASS
- Ceramic socket rated 250V, 12A, 750W with 18 ga. SEW-1 250°C leads
- Field replaceable lens
- Reflector top designed to give maximum distribution
- 12V TRANSFORMER required to function properly (purchased separately, see pages 128-129) except when using PM2 mount which includes integral 120V transformer
- For mounting information & restrictions, consult Specification page on web
- When using a color filter consult Specification page on web for wattage restrictions
- Technical lamp / photometric information (see pages 130-151)

SEE PRODUCT SPECIFICATION PAGE ON WEB FOR COMPLETE PRODUCT INFORMATION

SERIES	LAMP	12V VOLTAGE	FINISH	COLOR FILTER	STEM LENGTH	MOUNT STYLE	SPECIAL
--------	------	----------------	--------	-----------------	----------------	----------------	---------

12V MR-8 SPIRIT BRASS



QUICK FIND #: QF-13



www.inonighting.com
for complete product
information



UL Listed: Wet location
Outdoor = 35W

SPBR - SPIRIT BRASS

SERIES
SPBR - Spirit Brass

LAMP - 12V MR-8 - (see inside back cover p.162)
0 43 46

VOLTAGE
12V - 12 Vdc

FINISH - (see inside back cover p.162)
POL NAT BRZ CPF

COLOR FILTER - (see inside back cover p.162)
FD FMI FR FRD FP FA FG FGD FLB FMB FMBD

STEM LENGTH

S6 - 6" Stem
S12 - 12" Stem
S18 - 18" Stem
S24 - 24" Stem

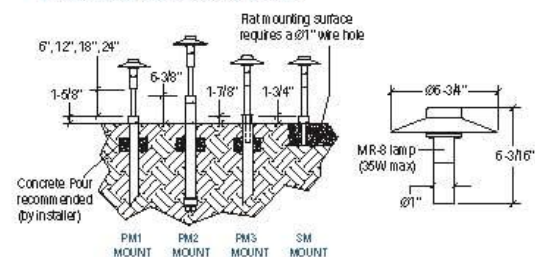
MOUNT STYLE

PM1 - Power Mount™ 60
PM2 - Power Mount™ 60 Transformer Housing & 60W Transformer
PM3 - Power Mount™ 60 Adjustable Stem
SM - Surface Mount

SPECIAL

STD - Standard
MOD - Modified

MOUNT STYLE - SPIRIT / SPIRIT BRASS



WINSCAPE™
www.inonighting.com

41

Fixture Type X3

CODES

LAMP	DESCRIPTION	BEAM SPREAD
0-	Lamp By Others	
XX-	Custom Lamping	
96-	No Lamp, 39W Ballast	
97-	No Lamp, 70W Ballast	
98-	No Lamp, 100W Ballast	
99-	No Lamp, 150W Ballast	
100-	No Lamp, 20W Ballast	
MR-8		
42-	20W/10° MR8	10°
43-	20W/23° MR8	23°
44-	35W/13° MR8	13°
45-	35W/26° MR8	26°
MR-11		
35-	12W/8° MR11	8°
36-	FSS/20W/10° MR11	10°
37-	FST/20W/17° MR11	17°
38-	FSV/20W/30° MR11	30°
39-	GDX/35W/10° MR11	10°
40-	GDY/35W/20° MR11	20°
41-	GDX/35W/30° MR11	30°
MR-16		
10-	ESX/20W/12° MR16	12°
11-	BAB/20W/36° MR16	36°
12-	FRB/35W/12° MR16	12°
13-	FRA/35W/24° MR16	24°
14-	FMW/35W/36° MR16	36°
15-	EYR/42W/12° MR16	12°
16-	EYS/42W/23° MR16	23°
17-	EYP/42W/36° MR16	36°
18-	EXT/60W/12° MR16	12°
19-	EXZ/60W/24° MR16	24°
20-	EXN/60W/36° MR16	36°
21-	FNW/60W/60° MR16	60°
22-	EYF/75W/12° MR16	12°
23-	EYJ/75W/24° MR16	24°
24-	EYC/75W/36° MR16	36°
130-	BBF/20W/24° MR16 10,000HR	24°
131-	BAB/20W/36° MR16 10,000HR	36°
65-	FMW/35W/24° MR16 10,000HR	24°
66-	FMW/35W/36° MR16 10,000HR	36°
132-	35W/60° MR16 10,000HR	60°
67-	EXT/60W/12° MR16 10,000HR	12°
68-	EXZ/60W/24° MR16 10,000HR	24°
69-	EXN/60W/36° MR16 10,000HR	36°
133-	FNW/60W/60° MR16 10,000HR	60°
T-3/T-4		
90-	5W T3 Halogen	N/A
91-	10W T3 Halogen	N/A
92-	20W T3 Halogen	N/A
94-	35W T4 Halogen	N/A
PAR-16		
112-	45W PAR16/H/SP10	10°
113-	45W PAR16/H/NFL27	27°
114-	60W PAR16/H/SP10	10°
115-	60W PAR16/H/FL30	30°
116-	75W PAR16/H/SP10	10°
117-	75W PAR16/H/FL30	30°
PAR-20		
46-	50W PAR20/H/NSP10	10°
48-	50W PAR20/H/FL30	30°
PAR-30		
49-	50W PAR30/H/NSP10	10°
50-	50W PAR30/H/SP16	16°
51-	50W PAR30/H/FL30	30°
52-	50W PAR30/H/WFL40	40°
53-	75W PAR30/H/NSP10	10°
54-	75W PAR30/H/SP16	16°
55-	75W PAR30/H/FL30	30°
56-	75W PAR30/H/WFL40	40°
PAR-36		
118-	35W PAR36/H/NSP5	5°
119-	35W PAR36/H/NSP8	8°
120-	35W PAR36/H/FL30	30°
121-	50W PAR36/H/NSP5	5°
122-	50W PAR36/H/NSP8	8°
123-	50W PAR36/H/FL30	30°

LAMP	DESCRIPTION	BEAM SPREAD
AR-111		
104-	50W AR111/H/NSP8	8°
105-	50W AR111/H/FL25	25°
106-	75W AR111/H/NSP8	8°
107-	75W AR111/H/FL25	25°
108-	75W AR111/H/WFL45	45°
109-	100W AR111/H/NSP8	8°
110-	100W AR111/H/FL25	25°
111-	100W AR111/H/WFL45	45°
PAR-38		
57-	90W PAR38/H/NSP10	10°
59-	90W PAR38/H/FL30	30°
60-	120W PAR38/H/NSP10	10°
61-	120W PAR38/H/FL30	30°
62-	120W PAR38/H/WFL55	55°
PAR-20 MH		
88-	20W PAR20/MH/SP8	8°
89-	20W PAR20/MH/FL25	25°
70-	39W PAR20/MH/SP10	10°
71-	39W PAR20/MH/FL30	30°
PAR-30 MH		
72-	39W PAR30/MH/SP10	10°
73-	39W PAR30/MH/FL30	30°
74-	70W PAR30/MH/SP10	10°
75-	70W PAR30/MH/FL40	40°
PAR-38 MH		
76-	70W PAR38/MH/SP15	15°
77-	70W PAR38/MH/FL25	25°
78-	70W PAR38/MH/WFL60	60°
79-	100W PAR38/MH/SP15	15°
80-	100W PAR38/MH/FL25	25°
81-	100W PAR38/MH/WFL60	60°
82-	150W PAR38/MH/SP20	20°
83-	150W PAR38/MH/FL35	35°
84-	150W PAR38/MH/WFL65	65°
T-4/T-4.5 MH		
125-	CMH20/T4.5MH	N/A
126-	CDM39/T4.5MH	N/A
127-	CDM70/T4.5MH	N/A
T-6 MH		
85-	CMD39/T6MH	N/A
86-	CMD70/T6MH	N/A
87-	CMD150/T6MH	N/A

LIGHT SOURCE	DESCRIPTION	BEAM SPREAD
XXXX	Custom Light Source	
LED-T1		
Warm White, 3000K, 120 lumen		
1002-	2.5W/10° SP/WW LED	10°
1003-	2.5W/20° NFL/WW LED	20°
1004-	2.5W/36° FL/WW LED	36°
Cool White, 6500K, 150 lumen		
1005-	2.5W/10° SP/CW LED	10°
1006-	2.5W/20° NFL/CW LED	20°
1007-	2.5W/36° FL/CW LED	36°
LED-T6		
Warm White, 3000K, 360 lumen		
3002-	7.5W/10° SP/WW LED	10°
3003-	7.5W/20° NFL/WW LED	20°
3004-	7.5W/36° FL/WW LED	36°
Cool White, 6500K, 450 lumen		
3005-	7.5W/10° SP/CW LED	10°
3006-	7.5W/20° NFL/CW LED	20°
3007-	7.5W/36° FL/CW LED	36°

	FINISH
Aluminum Finish	BKS- Black Smooth
	BKT- Black Textured
	BRS- Bronze Smooth
	BRT- Bronze Textured
	WHS- White Smooth
	WHT- White Textured
	SIS- Silver Smooth
	IVS- Ivory Smooth
	CHS- Chrome Smooth
	NBS- Natural Bronze
Brass Finish	VET- Verde Textured
	SAT- Sand Textured
	BAL- Brushed Aluminum
	CPF- Custom Finish
Stainless Steel Finish	POL- Polished Brass w/ Gloss Clear
	NAT- Natural Brass w/ Satin Clear
	BRZ- Satin Bronze w/ Satin Clear
	CPF- Custom Finish
	PSS- Polished Stainless
Stainless Steel Finish	NSS- Natural Stainless
	BSS- Brushed Stainless
	CPF- Custom Finish

COLOR FILTER
F0- None
FM- Mercury Vapor
FR- Red
FRD- Red Dichroic
FP- Pink
FA- Amber
FG- Green
FGD- Green Dichroic
FLB- Light Blue
FMB- Medium Blue
FMBD- Medium Blue Dichroic

CAP STYLE
C1- Short Flush
C2- Lens Recessed
C3- 45° Cutoff
C4- Long Flush
C5- 45° Scalloped

REFLECTOR
SP8°- Spot 8°
NF23°- Narrow Flood 23°
FL30°- Flood 30°
WF50°- Wide Flood 50°

BALLAST OPTIONS
0- None
PC- Concrete Pour Collar (B1 & B4 only)

BALLAST HOUSING
B3- Remote Wall Mount
B4- Remote Ingrade
B4PC- Remote Ingrade w/ Pour Collar



DESCRIPTION

Entri LED features a classic and stylish design with the added benefits of solid state lighting technology, offering outstanding uniformity and energy savings. Using Cooper Lighting's proprietary LED LightBAR™ technology and AccuLED optical systems, Entri LED offers designers vast versatility in system design, function and performance. Use Entri LED for wall mount architectural lighting applications and egress lighting requirements. UL and cUL listed for use in wet locations.

Catalog #	Type
Project	
Comments	Date
Prepared by	

SPECIFICATION FEATURES

Construction

HOUSING: Heavy wall, one piece die-cast aluminum construction for precise tolerance control and repeatability in manufacturing. Integral extruded aluminum heat sink provides superior thermal heat transfer in +40°C ambient environments. Housing and heat sink are designed to offer various options for down lighting, up lighting or a combination of both up and down. **FACEPLATE / DOOR:** One-piece die-cast aluminum construction. Captive, side hinged faceplate swings open via release of one (1) flush mount die-cast aluminum latch on housing side panel. Door closure and seal is ensured through a robust and positive retention bale latch which upon closing can be heard through distinct sound. **GASKET:** One-piece molded silicone gasket mates perfectly between the door and housing for repeatable seal. Silicone wire way plug on housing back wall seals incoming electrical leads to prevent moisture and dust entry. **LENS:** Uplight lens is impact resistant, 5/32" thick tempered frosted glass sealed to housing with continuous bead silicone gasket. Downlight lens is LED board integrated acrylic over-optics, each individually sealed for IP66 rating. **HARDWARE:** Stainless steel mounting screws and latch hardware allow access to electrical components for installation and servicing.

Optics

DISTRIBUTION: Primary downlight distribution offers a choice of eight (8) high efficiency AccuLED optical systems, featuring patented designs that maximize light collection and directional distribution onto the application region. Each optical lens is precision manufactured via injection molding then precisely arranged and sealed on the board media. Optional uplight LED distribution features a diffuse soft glow for enhancing architectural scenes or accentuating structural features. **LED's:** High output LED's, 50,000+ hours life at >70% lumen maintenance, offered standard in 4000°K (+/- 275K) CCT and >70 CRI.

Electrical

DRIVER: LED drivers are potted and heat sunk for optimal performance and prolonged life. Standard drivers feature electronic universal voltage (120-277V/50-60hz), greater than 0.9 power factor, less than 20% harmonic distortion and feature ambient temperature range of +40°C (104°F) down to minimum starting temperature of -30°C (-22°F). Shipped standard with Cooper Lighting proprietary circuit module designed to withstand 10kV of transient line surge. Options to control light levels, energy savings and egress capabilities (battery pack and separate circuit) are available. All LED LightBARs™ and drivers are mounted to a primary mounting plate and are easily replaced by use of quick disconnects for ease of wiring.

Mounting

JUNCTION BOX: Standard with zinc plated quick-mount junction box plate that mounts directly to 4" J-Box. LightBARs mount facing downward. Fixture slides over mounting plate and is secured with two (2) stainless steel fasteners. Mounting plate features a one-piece EPDM gasket on back side of plate to firmly seal fixture to wall surface, forbidding entry of moisture and particulates. Optional mounting arrangements utilize a die-cast mounting adaptor box to allow for LED battery pack, surface conduit and through branch wiring. Entri LED is approved for mounting on combustible surfaces.

Finish

Housing is finished in 5 stage super premium TGIC polyester powder coat paint, 2.5 mil nominal thickness for superior protection against fade and wear. LightBAR™ cover plates are standard white and may be specified to match finish of luminaire housing. Standard colors include black, bronze, grey, white, dark platinum and graphite metallic. RAL and custom color matches available. Consult Outdoor Architectural Colors brochure for a complete selection.

Warranty

Entri LED features a 5 year limited warranty.



ENTRI LED TRIANGLE REVEALS

1 - 2 LightBARs
Solid State LED

ARCHITECTURAL WALL LUMINAIRE

Sustainable Design

CERTIFICATION DATA

40°C Ambient Temperature Rating
UL and cUL Listed
ISO 9001
IP66 LightBARs
ARRA Compliant
LM79 / LM80 Compliant

ENERGY DATA

Electronic LED Driver
>0.9 Power Factor
<20% Total Harmonic Distortion
120-277V/50 & 60hz, 347V/60hz,
480V/60hz
-30°C Minimum Temperature

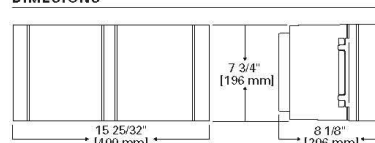
SHIPPING DATA

Approximate Net Weight:
16 lbs. (7.3 kgs.)

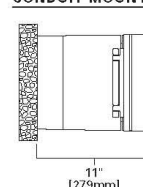


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DIMENSIONS



CONDUIT MOUNT / BATTERY BACK BOX



Fixture Type X4

ENT ENTRI LED TRIANGLE REVEALS

POWER AND LUMENS BY BAR COUNT

# of Bars	System Watts	Type BL2 Lumens	Type BL3 Lumens	Type BL4 Lumens	Ambient Temperature	Lumen Multiplier
1 Bar	26	1,626	1,724	1,677	10°C	1.04
2 Bars	53	3,252	3,447	3,354	15°C	1.03
					25°C	1.00
					40°C	0.96
Options	System Watts	Lumens				
ULG	8	315				

NOTE: Lumen values based upon 4000K CCT, 350mA drive current, 25°C ambient operating temperature.

ORDERING INFORMATION

Sample Number: ENT-A02-LED-E1-BL3-GM

Product Family	Number of ¹ Lightbars	Voltage	Finish ³	Options ⁴	Accessories ¹⁰
ENT: Entri Triangle Reveals	A01: 1 Bar A02: 2 Bars	E1: Electronic (120-277V) 347: 347V ² 480: 480V ²	BK: Black AP: Grey BZ: Bronze WH: White DP: Dark Platinum GM: Graphite Metallic	ULG: Uplight Glow PC: Button Type Photocell (specify voltage) WG: Wire Guard 2L: Bi-Level Switching ⁵ TP: Tamper Resistant Hardware LCF: LightBAR Cover Plate Matches Housing Finish 7060: 70 CRI/6000K CCT ⁶ OSB: Occupancy Sensor with ⁷ Back Box BBB: Battery Pack with Back ⁸ Box (Specify 120 or 277) CWB: Cold Weather Battery ⁹ Pack with Back Box (Specify 120 or 277)	VA2001-XX: Thru-Way Conduit Adaptor Box VA6172: Wire Guard VA6173: Tamper Resistant Driver Bits MA1253: 10kV Circuit Module Replacement
	Lamp Type LED: Solid State Light Emitting Diodes	Distribution BL2: Type II w/Back Light Control BL3: Type III w/Back Light Control BL4: Type IV w/Back Light Control GZW: Wall Grazer Wide SLL: 90 Degree Spill Light Eliminator Left SLR: 90 Degree Spill Light Eliminator Right			

- Notes: 1 Standard 4000 K CCT and greater than 70 CRI. LightBARS for downlight use only.
2 Consult factory for availability.
3 Custom and RAL color matching available upon request. Consult your customer service representative for further information.
4 Add as suffix in the order shown.
5 Low-level output varies by bar count, consult factory. Not available with 347V or 480V. Available with 2 Bars (A02) only.
6 Consult customer service for lead times and lumen multiplier.
7 Available with A02, only (1) LightBAR on street side will be wired to sensor. Time Delay factory setting 15 minutes. When ordered with Option PC, both light bars will connected to photocell as primary switching means. Standard sensor lens covers 8-foot mount height, 360-degree coverage, maximum 48-foot diameter. Not available in all configurations or with BBB or CWB options.
8 Specify 120 or 277V. LED standard integral battery pack is rated for minimum operating temperature 32°F (0°C). Operates (1) lightbar for 90 minutes, minimum 1300 initial lumens. Not available in all configurations or with OSB option. Consult factory.
9 Specify 120 or 277V. LED cold weather integral battery pack is rated for minimum operating temperature -4°F (-20°C). Operates (1) lightbar for 90 minutes, minimum 1300 initial lumens. Not available in all configurations or with OSB option.
10 Order separately, replace XX with color suffix.



NOTE: Specifications and dimensions subject to change without notice.
Visit our web site at www.cooperlighting.com
Customer First Center 1121 Highway 74 South Peachtree City, GA 30269 770.486.4800 FAX 770.486.4801

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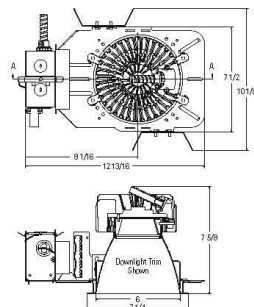
Fixture Type X4

Calculite LED Frame-In Kit **C6L20/CUL20**

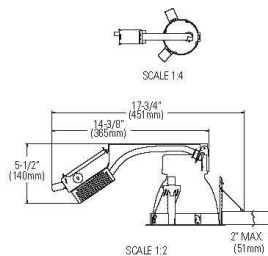
Page 1 of 1

2000 Lumen, 6" Aperture Remote Phosphor LED

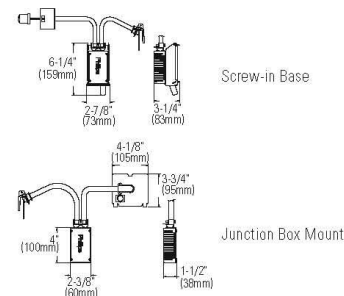
New Construction Frames



Remodeler Frames



Retrofit Frames



Ordering Guide: Frame-in Kits

Frame-in Kit Series	Installation Options	Input Voltage	Options
C6L20 (2000 Lumen)	N (New construction) R (Remodeler)	1 (120V) 2 (277V)	Blank (0-10 volt dimming) EM (Emergency)
CUL20 (2000 Lumen)	J (J-box mount retrofit) S (Screw-in base retrofit (120V only))	1 (120V) 2 (277V)	Blank (0-10 volt dimming)

Example: C6L15N1EM

Features

Ceiling Cutout: 6 9/16" (167mm)

Depth (including Light Engine): See Light Engine specification sheet for details.

Power Connection: Attaches to light engine via push-in connector (on frame). Removable cover provides access.

Junction Box: UL listed for 8 No. 12 AWG, 90°C through branch circuit connectors. Allows inspection from below.

Thermal Protector: Meets NEC & UL requirements. Do not install insulation above nor within 3" of any part of luminaire.

New Construction Frame:

Mounting Frame: Galvanized stamped steel for dry or plaster ceilings.

Vertical Adjustment: Light engine adjusts in frame below ceilings up to 1 1/8".

Mounting Brackets: Galvanized steel. Adjustable through aperture. Use 3/4" or 1 1/2" lathing channel, 1/2" EMT or optional mounting bars.

Remodeler Frame:

Power Pack: Swivel junction box for tight plenum spaces. Snap-off covers permits wiring from top.

Spring Holder: Galvanized steel. Accepts up to 2 1/2" (64mm) ceiling thickness.

Retrofit Frame:

Capability: Converts 6" (153mm) or 7" (178mm) Lightolier incandescent frame-in kit without additional wiring using existing Calculite E26 base.

Socket Cup Support: Spun steel. Holds Calculite incandescent socket cup.

Socket Extender: Phenolic E26 base. Connect to existing lampholder.

Electrical

Electronic Power Supply: 120 or 277V, 50/60Hz, enclosed, overload and short circuit protected, thermal regulation to protect against overheating, sound rating "A", -20°C minimum starting temperature, 70°C maximum operating temperature, dimmable with 0-10V dimmer. Dimming compatibility: See LED-DIM specification sheet.

Electrical (continued)

Input Voltage	Input Frequency	Input Current	LED Drive Current	Input Power	LED Power	THD	Power Factor
120V	50/60Hz	0.36	520mA	39W	35.4W	<1%	>0.9
277V	50/60Hz	0.17	520mA	39W	35.4W	<1%	>0.9

Rated Life: 100,000 hours

Options and Accessories

Dimming Capability: 0-10V. See LED-DIM specification sheet.

Emergency Capability (Integral): Add "EM" suffix. See LED-EM spec sheet.

Emergency Capability (Inverter): See LED-LMI specification sheet.

Sloped Ceilings: See specification sheet SCA.

Mounting Bars: 1950-18" Set of (2)

1951-27" Set of (2)

T-Bar Anchor Clips: 1956-Set of (4), for use with above

Labels

UL, cUL, I.B.E.W.

5 Year Warranty

Job Information	Type:
Job Name:	
Cat. No.:	
Lamp(s):	
Notes:	

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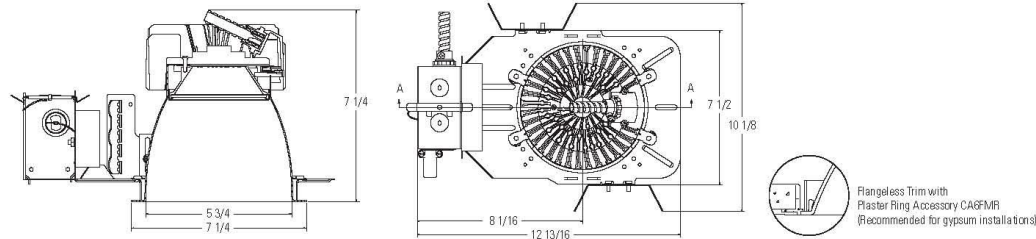
PHILIPS
LIGHTOLIER®

Fixture Type X5

Calculite LED Open Wall Washer **C6L1520WW**

Page 1 of 2

1500/2000 Lumen, 6" Aperture Remote Phosphor LED



Ordering Guide: Light Engines

Light Engine Series	Style	Color Temperature	Reflector Finish	Flange	Options
C6L1520	WW (Open Wall Washer)	27K (2700K) 30K (3000K) 35K (3500K) 40K (4000K)	CL (Clear) CCL (Comfort Clear) CCD (Comfort Clear Diffuse) CCZ (Champagne Bronze) WH (Painted White)	W (Painted white) P (Aperture-matching/polished) FT (Flush-mount/flangeless) ¹	EM (Integral emergency test switch)

Example: C6L1520WW35KCCCLWEM

¹Accessory CA6FMR recommended for gypsum applications. Reflector flange is 1/8".

Ordering Guide: Frame-in Kits

Frame-in Kit Series	Installation Options	Input Voltage	Options
C6L15 (1500 Lumen) C6L20 (2000 Lumen)	N (New construction) R (Remodeler)	1 (120V) 2 (277V)	Blank (0-10 volt dimming) EM (Emergency)
CUL15 (1500 Lumen) CUL20 (2000 Lumen)	J (J-box mount retrofit) S (Screw-in base retrofit (120V only))	1 (120V) 2 (277V)	Blank (0-10 volt dimming)

Example: C6L15N1EM

Features

Aperture: 5 3/4" (146mm) I.D., 7 1/4" (184mm) O.D.

Input Wattage: 27W (1500 Lumens), 39W (2000 Lumens).

Reflector Cone: Aluminum. Provides 50° cutoff to source & source image. Self-flanged.

Depth (including Frame-in kit): 6 5/8" (168mm)

Power Connection: Attaches to frame-in kit via push-in connector (on frame). Removable cover provides access.

Technology

LED Board: Array of high brightness royal blue LED's.

Remote Phosphor Technology: Patented remote phosphor technology provides increased efficiency and color consistency. Phosphor lens assembly positioned in front of LED array converts blue light to white. Color shift will not exceed +/- 100K over life.

Optical Mixing Chamber: Lightolier-specific mixing chamber redirects back-reflected light through aperture resulting in 20% increase in efficiency.

Thermal Management: Proprietary heat sink and thermal design along with clean room assembly ensures specified performance.

Rated Life: Based on IESNA LM-80-2008

1500 Lumen – 60,000 hours at 70% lumen maintenance.

2000 Lumen – 57,000 hours at 70% lumen maintenance.

Photometric Performance: Tested in accordance to IESNA LM-79-2008

Options

Dimming Capability: 0-10V. See LED-DIM specification sheet

Emergency Capability (Integral): Add "EM" suffix. See LED-EM spec sheet.

Emergency Capability (Inverter): See LED-LMI specification sheet

Labels

UL (suitable for wet locations), cUL, I B.E.W.

5 Year Warranty

Job Information	Type:
Job Name:	
Cat. No.:	
Lamp(s):	
Notes:	

PHILIPS
LIGHTOLIER®

Fixture Type X6

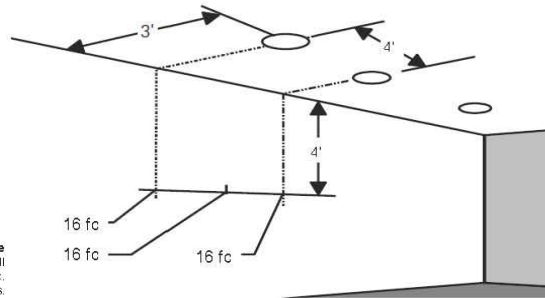
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Calculite LED Open Wall Washer **C6L1520WW**

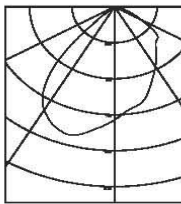
Page 2 of 2

1500/2000 Lumen, 6" Aperture Remote Phosphor LED

Lighting Data - Example
C6L1520WW30KCLW/C6L15N1 illumination on the wall
4' down from the ceiling is 16 f.c.
beneath and 16 f.c. between fixtures.



1500LM LED, 3000K, CL FINISH TRIM



Downlight
Side

Wall Wash
Side

Trim:
C6L1520WW30KCLW

Frame:
C6L15N1

Reflector Finish:
Specular Clear

Correlated Color Temp¹:
3000K

Input Watts²:
26.6 w

CR³:
78

CERTIFIED TEST REPORT NO. F10027³

Multiple Units - Footcandles On Wall

	2' from Wall - 3' On Center	3' from Wall - 3' On Center
1	30	18
2	38	34
3	28	30
4	23	25
5	19	19
6	16	15
7	13	13
8	11	11
9	10	10
10	9	9
12	7	7
14	6	6

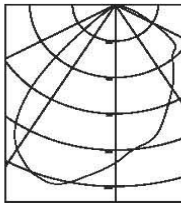
Multiple Units - Footcandles On Wall

	3' from Wall - 3' On Center	3' from Wall - 3' On Center
1	10	9
2	25	23
3	25	24
4	21	22
5	19	19
6	17	17
7	15	15
8	13	13
9	11	11
10	10	10
12	9	9
14	8	8

Multiple Units - Footcandles On Wall

	3' from Wall - 4' On Center	4' from Wall - 4' On Center
1	8	6
2	20	15
3	19	18
4	16	16
5	13	15
6	12	12
7	11	10
8	9	9
9	8	8
10	7	7
12	6	6
14	5	5

2000LM LED, 3000K, CL FINISH TRIM



Downlight
Side

Wall Wash
Side

Trim:
C6L1520WW30KCLW

Frame:
C6L20N1

Reflector Finish:
Specular Clear

Correlated Color Temp¹:
3000K

Input Watts²:
39.8 w

CR³:
78

CERTIFIED TEST REPORT NO. F10028³

Multiple Units - Footcandles On Wall

	2' from Wall - 3' On Center	3' from Wall - 3' On Center
1	41	25
2	53	47
3	39	42
4	31	34
5	26	26
6	22	21
7	18	18
8	15	15
9	13	13
10	12	12
12	10	10
14	9	9

Multiple Units - Footcandles On Wall

	3' from Wall - 3' On Center	3' from Wall - 3' On Center
1	14	13
2	35	32
3	35	34
4	29	30
5	27	26
6	23	23
7	20	20
8	18	18
9	16	16
10	14	14
12	12	12
14	10	10

Multiple Units - Footcandles On Wall

	3' from Wall - 4' On Center	4' from Wall - 4' On Center
1	11	8
2	28	21
3	26	25
4	22	22
5	18	20
6	17	17
7	15	14
8	13	13
9	11	11
10	10	10
12	8	8
14	7	7

¹ Correlated Color Temperature within specs as defined in ANSI/NEMA/ANSI C78.377-2008: Specifications for the Chromaticity of Solid-State Lighting Products.

² Wattage controlled to within 5%.

³ Tested using absolute photometry as specified in LM79-IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.

⁴ Color Rendering Index within +/- 2%.

Job Information

Type:

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**PHILIPS
LIGHTOLIER®**

Fixture Type X6

Floodlights for linear fluorescent lamps

Housing: Die-cast aluminum end caps and an aluminum extrusion. The end caps are gasketed to provide a watertight housing. All aluminum used in the construction is marine grade and copper free.

Mounting: Canopy mount fixtures are yoke mounted to a fully gasketed mounting canopy. The housing is connected to the canopy with cable. The canopy mounts over a BEGA 537 box.

Enclosure: Faceplate is constructed of die-cast aluminum secured to the housing with captive stainless steel fasteners. Tempered glass, $\frac{3}{16}$ " thick. Fully gasketed with a molded silicone gasket.

Electrical: Lampholders; Fluorescent T5 HO, G5 miniature bi-pin. Ballasts; integral electronic, universal voltage 120 V through 277 V, Class P, HPF, program start, minimum start temperature of 0°F (-20°F start temperature available with the 54 W lamp, consult factory). Ballasts have circuitry to reliably shut down the system at the end of lamp life. Standard T5 lamping available on request.

Finish: These luminaires are available in four standard BEGA colors: Black (BLK); White (WHT); Bronze (BRZ); Silver (SLV).

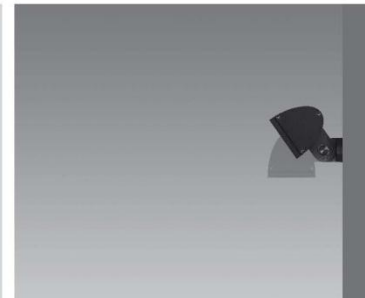
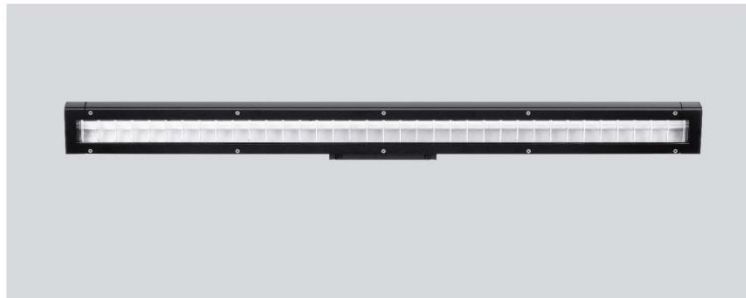
To specify, add appropriate suffix to catalog number. Custom colors supplied on special order.

UL listed, suitable for wet locations. Protection class: IP65.

Type:
BEGA Product:
Project:
Voltage:
Color:
Options:
Modified:



These luminaires mount over a custom BEGA recessed box. This box can be shipped ahead of the luminaire.



Floodlights with mounting canopy							
	Lamp	Lumen	A	B	C	D	Wiring box*
7593P.537	1 54 W FL T5 HO	5000	47 3/4	3 3/4	5 7/8	2	537

*Small opening wiring box 537 included

BEGA-US 1000 BEGA Way, Carpinteria, CA 93013 (805) 684-0533 FAX (805) 566-9474 www.bega-us.com
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Fixture Type X7



3.5W / 6.5W Walkway

L36

SPEC SHEET

Application: Wall, stair, and walkway illumination for indoor and outdoor applications.

Electrical: 3.5W LED powered by 120V, 350mA non-dimmable integral driver, or 6.5W LED powered by 120V, 700mA non-dimmable integral driver.

Input Current: 350mA (3.5W) / 700mA (6.5W)

Input Voltage: 12V DC

Power Consumption: 3.5W / 6.5W

Recommended Dimmable Driver: TLDAV60W9 with TLC010i dimming controller. Dimmable driver not included. Consult factory.

Weight: 1.4lbs (0.636kg).

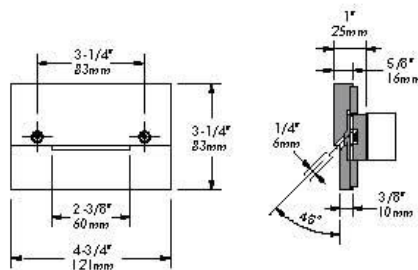
Material: Anodized aluminum and polycarbonate lens.

Mounting: Face plate mounts vertically or horizontally to single gang switch box (not included). Comes with flush mounted tamper proof screws.

Approval: Wet and dry locations. Approved to US and Canadian standards by CSA.



Note: Fixture may require remote driver for use in cold weather applications. Can be used as emergency backup lighting in conjunction with Bodine emergency LED driver (sold separately). Consult MP Lighting factory.



Type:

Project:

Modified:

Quantity:

Notes:

CODE	WATTAGE	COLOR	FINISH
L36			
	3 = 3.5W	W808 = 3000K, std CRI	MA = matte clear anodized
	6 = 6.5W	W608 = 5000K, std CRI	BA = black anodized

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01-2011

Fixture Type X8

3.5W / 6.5W Walkway

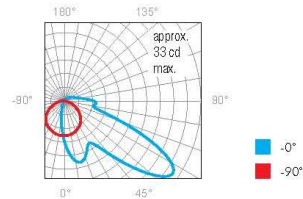
L36

SPEC SHEET

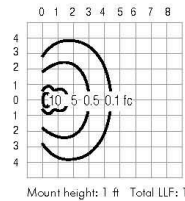
Photometric Data

L36
3.5W
3000K Std
250 lm

Polar Candela Distribution



Isofootcandle Plot



Height Conversion Formula

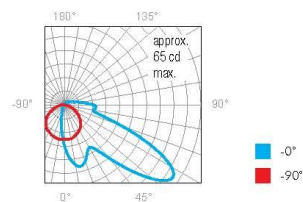
$$\text{Step 1} \quad \frac{\text{Existing Mounting Height}^2}{\text{New Mounting Height}^2} = \text{Correction Factor (CF)}$$

$$\text{Step 2} \quad \text{CF} \times \text{Footcandle} = \text{New Mounting Height FC}$$

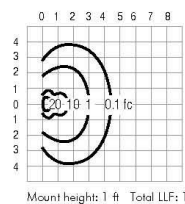
Note: Information is based on the most current data available; however, various operating factors such as reflectance and application type may cause differences between lab and field results. Due to continuous improvements, specifications may change without notice. Consult www.mplighting.com for the most current information.

L36
6.5W
3000K Std
475 lm

Polar Candela Distribution



Isofootcandle Plot



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Note: Various operating factors may cause differences between lab and field results. As specifications may change without notice, please refer to the LED Lamp Index located in the "Downloads" section of each product webpage for the most current information.

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01-2011

Fixture Type X8

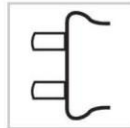


GE
Lighting

81522 - F54T5841HOECO/CT

GE Ecolux® Starcoat® T5 - Cold Temperature

• Passes TCLP, which can lower disposal costs.



GENERAL CHARACTERISTICS

Lamp Type	Linear Fluorescent - Straight
	Linear
Bulb	T5
Base	Miniature Bi-Pin (G5)
Rated Life	30000 hrs
Bulb Material	Soda lime
LEED-EB MR Credit	35 picograms Hg per mean lumen hour
Additional Info	Cold Temperature/TCLP compliant
Primary Application	Cold Temperature

PHOTOMETRIC CHARACTERISTICS

Initial Lumens	4500
Mean Lumens	4275
Nominal Initial Lumens per Watt	83
Color Temperature	4100 K
Color Rendering Index (CRI)	85
S/P Ratio (Scotopic/Photopic Ratio)	1.7

ELECTRICAL CHARACTERISTICS

Wattage	54
Voltage	117
Cathode Resistance Ratio - Rh/Rc (MIN)	4.25
Cathode Resistance Ratio - Rh/Rc (MAX)	6.5
Lamp Current	460 A
Current Crest Factor	1.7

DIMENSIONS

Maximum Overall Length (MOL)	45.8 cm
Nominal Length	45.2 cm
Bulb Diameter (DIA)	0.625 cm
Bulb Diameter (DIA) (MAX)	0.67 cm
Max Base Face to Base Face (A)	45.24 cm
Face to End of Opposing Pin (B) (MIN)	45.42 cm
Face to End of Opposing Pin (B) (MAX)	45.52 cm

PRODUCT INFORMATION

Product Code	81522
Description	F54T5841HOECO/CT
Standard Package	Case
Standard Package GTIN	10043168815229
Standard Package Quantity	36
Sales Unit	Unit
No Of Items Per Sales Unit	1
No Of Items Per Standard Package	36
UPC	043168815222

NOTES

- Blocks 100% of UV-B and UV-C. Blocks from 75 to 99% of UV-A depending on lamp type.
- Jacketed "Cold Temperature" lamps (as indicated by -CT) are designed for use where ambient temperatures do not rise above 32°F (0°C).
- Lumen rating based on approximate 3% reduction in light output with jacket.



CAUTIONS & WARNINGS

Caution

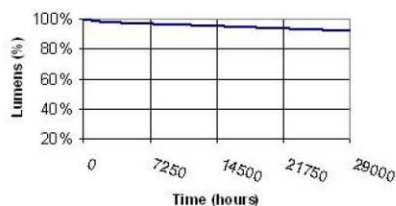
- Lamp may shatter and cause injury if broken
- Wear safety glasses and gloves when handling lamp.
- Do not use excessive force when installing lamp.

Warning

- Risk of Electric Shock
- Turn power off before inspection, installation or removal.

GRAPHS & CHARTS

Lumen Maintenance



Lamp Mortality



For additional information, visit www.gelighting.com

GENERAL CHARACTERISTICS

Lamp Type	Linear Fluorescent - Straight
Bulb	Linear
Base	T5
Rated Life	Miniature Bi-Pin (G5)
Rated Life (rapid start) @ Time	30000 hrs
	30000.0 @ 3.0/36000.0 @ 12.0 h
Bulb Material	Soda lime
Starting Temperature	-20 °C (-4 °F)
LEED-EB MR Credit	31 picograms Hg per mean lumen hour
Additional Info	TCLP compliant

PHOTOMETRIC CHARACTERISTICS

Initial Lumens	2900
Mean Lumens	2660
Nominal Initial Lumens per Watt	103
Color Temperature	4100 K
Color Rendering Index (CRI)	85
S/P Ratio (Scotopic/Photopic Ratio)	1.3

ELECTRICAL CHARACTERISTICS

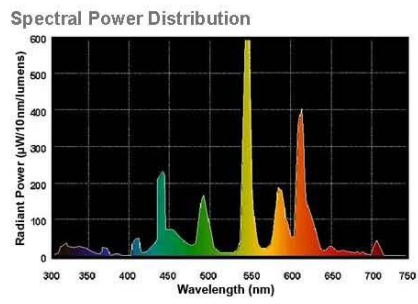
Wattage	28
Voltage	167
Open Circuit Voltage (rapid start) Min @ Temperature	425 V @ 10 °C
Cathode Resistance Ratio - Rh/Rc (MIN)	4.25
Cathode Resistance Ratio - Rh/Rc (MAX)	6.5
Current Crest Factor	1.7

DIMENSIONS

Maximum Overall Length (MOL)	45.8000 in(1163.3 mm)
Nominal Length	45.200 in(1148.1 mm)
Bulb Diameter (DIA)	0.625 in(15.9 mm)
Bulb Diameter (DIA) (MAX)	0.670 in(17.0 mm)
Max Base Face to Base Face (A)	45.240 in(1149.1 mm)
Face to End of Opposing Pin (B) (MIN)	45.420 in(1153.7 mm)
Face to End of Opposing Pin (B) (MAX)	45.520 in(1156.2 mm)

PRODUCT INFORMATION

Product Code	46706
Description	F28W/T5/841/ECO
Standard Package	Case
Standard Package GTIN	10043168467060
Standard Package Quantity	40
Sales Unit	Unit
No Of Items Per Sales Unit	1
No Of Items Per Standard Package	40
UPC	043168467063



Mar 2, 2011 1:47:47 PM
For additional information, visit www.gelighting.com

Page 2

Philips - MasterColor CDM-T Elite 70W/930 T6 1CT

Page 1 of 3

MasterColor® CDM-T T6 Elite

MasterColor CDM-T Elite 70W/930 T6 1CT

The Elite family is at the very top of the MasterColor® CDM range, and gives a unique combination of unbeatable light quality and consistent performance over lifetime. While keeping running costs low, MasterColor metal halide lamps deliver consistent white light and higher color rendering than any standard metal halide source for architectural lighting.

[See full range](#)



Images



Diagrams

[Add to Project Planner](#) [Print this page](#) [Contact us](#)



Specifications

Range

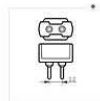
Product Data

Product number	148361	*
Full product name	MasterColor CDM-T Elite 70W/930 T6 1CT	*

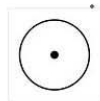
[+ More info / Hide info](#)

General Characteristics

Base	G12	*
Bulb	T6 [Diameter: 6/8 inch /19mm]	*
Bulb Finish	Clear	*
Operating Position	Universal [Any or Universal (U)]	*
Life to 5% failures	9000 hr	*
Life to 10% failures	10000 hr	*
Life to 20% failures	11000 hr	*
Avg. Hrs. Life	12000 hr	*
Life to 5% failures EL	6000 hr	*
Life to 20% failures EL	9000 hr	*



[+ Zoom](#)



[+ Zoom](#)

Downloads

- [Leaflet](#)
- [Family - full data sheet](#)
- [Material Safety Data Sheets](#)
- [Product Images](#)
- [Product Diagrams](#)

Electrical Characteristics

System Power EL	80 W	*
Watts	70 W	*

<http://www.ecat.lighting.philips.com/1/catalog/catalog.jsp?&userLanguage=en&userCountr...> 4/2/2011

Philips - MasterColor CDM-T Elite 70W/930 T6 1CT

Page 2 of 3

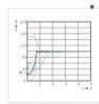
Lamp Wattage	75 W	*
Lamp Wattage EL	73 W	*
Lamp Voltage	87 V	*
Lamp Current EM	0.840 A	*
Lamp Current EL	0.840 A	*
Ignition Time	30 s	*
Run-up time 90%	3 min	*
Ignition Peak Voltage	3500 V	*
Re-ignition Time [min]	15 min	*
Dimmable	No	*

Environmental Characteristics

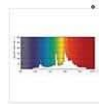
Mercury (Hg) Content	8.5 mg	*
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Light Technical Characteristics

Color Code	930 [CCT of 3000K]	*
Color Rendering Index	90 Ra8	*
Color Designation	Warm White	*
Color Temperature	3000 K	*
Color Temperature technical	3000 K	*
Chromaticity Coordinate X	0.434 -	*
Chromaticity Coordinate Y	0.395 -	*
Initial Lumens	7300 Lm	*
Luminous Efficacy Lamp EM	98 Lm/W	*
Luminous Efficacy Lamp EL	100 Lm/W	*
Lumen Maintenance EM 2000h	95 %	*
Lumen Maintenance EL 2000h	95 %	*
Lumen Maintenance EM 5000h	88 %	*
Lumen Maintenance EL 5000h	88 %	*
Lumen Maintenance 10000h	83 %	*
Lumen Maintenance 12000h	80 %	*



+ Zoom



MASTER Colour
CDM-T Elite
70W /930
+ Zoom

UV-related Characteristics

PET (NIOSH)	64 h.klx	*
Damage Factor D/fc	0.22 -	*

Product Dimensions

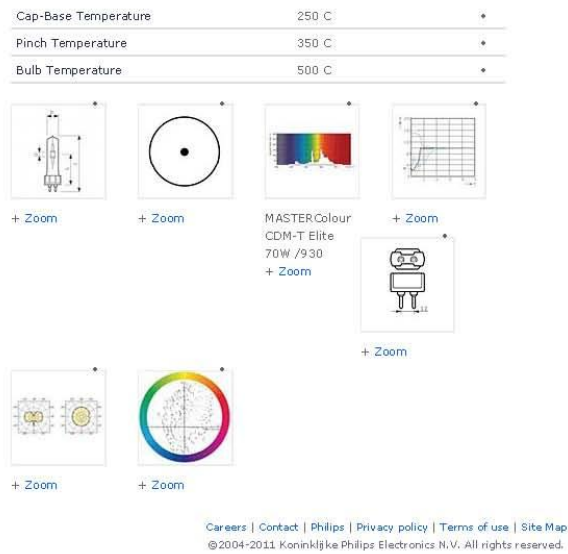
Reference Length A	90 mm	*
Overall Length C	103 mm	*
Diameter D	20 mm	*
Light Center Length L	55 (min), 56 (nom), 57 (max) mm	*
Arc Length O	6 mm	*
Light Center Length L	2.2 in	*
Max Overall Length (MOL) - C	3.94 in	*
Diameter D	0.75 in	*

Luminaire Design Requirements

<http://www.ecat.lighting.philips.com/1/catalog/catalog.jsp?&userLanguage=en&userCountr...> 4/2/2011

Philips - MasterColor CDM-T Elite 70W/930 T6 1CT

Page 3 of 3



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Philips - MasterColor CDM-T Elite 35W/930 T6 1CT

Page 1 of 3

MasterColor® CDM-T T6 Elite

MasterColor CDM-T Elite 35W/930 T6 1CT

The Elite family is at the very top of the MasterColor® CDM range, and gives a unique combination of unbeatable light quality and consistent performance over lifetime. While keeping running costs low, MasterColor metal halide lamps deliver consistent white light and higher color rendering than any standard metal halide source for architectural lighting.

[See full range](#)



Images

Diagrams

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Specifications

Range

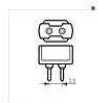
Product Data

Product number	404830	*
Full product name	MasterColor CDM-T Elite 35W/930 T6 1CT	*

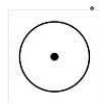
[+ More info / Hide info](#)

General Characteristics

Base	G12	*
Bulb	T6 [Diameter: 6/8 inch /19mm]	*
Bulb Finish	Clear	*
Operating Position	Universal [Any or Universal (U)]	*
Avg. Hrs. Life	12000 hr	*
Life to 5% failures EL	9000 hr	*
Life to 20% failures EL	11000 hr	*
Life to 10% failures EL	10000 hr	*



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Downloads

- [Leaflet](#)
- [Family - full data sheet](#)
- [Material Safety Data Sheets](#)
- [Product Images](#)
- [Product Diagrams](#)

Electrical Characteristics

System Power EL	43 W	*
Watts	35 W	*
Lamp Wattage EL	39 W	*
Lamp Voltage	85 V	*

<http://www.ecat.lighting.philips.com/1/catalog/catalog.jsp?&userLanguage=en&userCountr...> 4/2/2011

Philips - MasterColor CDM-T Elite 35W/930 T6 1CT

Page 2 of 3

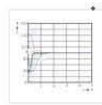
Lamp Current EL	0.45 A	*
Ignition Time	30 s	*
Run-up time 90%	3 min	*
Ignition Peak Voltage	3500 V	*
Re-ignition Time [min]	15 min	*
Dimmable	No	*

Environmental Characteristics

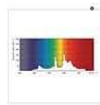
Mercury (Hg) Content	3.5 mg	*
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Light Technical Characteristics

Color Code	930 [CCT of 3000K]	*
Color Rendering Index	90 Ra8	*
Color Designation	Warm White	*
Color Temperature	3000 K	*
Color Temperature technical	3000 K	*
Chromaticity Coordinate X	0.432 -	*
Chromaticity Coordinate Y	0.396 -	*
Initial Lumens	3500 Lm	*
Luminous Efficacy Lamp EL	90 Lm/W	*
Lumen Maintenance 2000h	95 %	*
Lumen Maintenance EL 2000h	95 %	*
Lumen Maintenance EL 5000h	88 %	*
Lumen Maintenance 10000h	83 %	*
Lumen Maintenance EL 10000h	80 %	*
Lumen Maintenance 12000h	80 %	*



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MASTER Colour
CDM-T Elite
35W /930
+ Zoom

UV-related Characteristics

PET (NIOSH)	44 h.klx	*
Damage Factor D/fc	0.27 -	*

Product Dimensions

Reference Length A	90 mm	*
Overall Length C	103 mm	*
Diameter D	20 mm	*
Light Center Length L	55 (min), 56 (nom), 57 (max) mm	*
Arc Length O	4 mm	*
Light Center Length L	2.2 in	*
Max Overall Length (MOL) - C	4.055 in	*
Diameter D	0.75 in	*

Luminaire Design Requirements

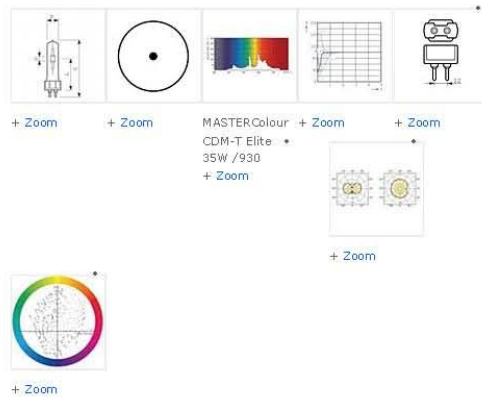
Pinch Temperature	350 C	*
Bulb Temperature	500 C	*

* * * * *

<http://www.ecat.lighting.philips.com/1/catalog/catalog.jsp?&userLanguage=en&userCountr...> 4/2/2011

Philips - MasterColor CDM-T Elite 35W/930 T6 1CT

Page 3 of 3



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Click to show one page at a time

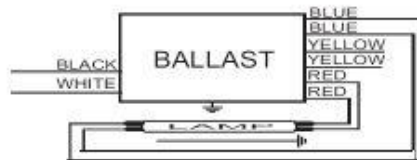


Electrical Specifications

ICN2S5490CSC@277	
Brand Name	CENTIUM T5
Ballast Type	Electronic
Starting Method	Programmed Start
Lamp Connection	Series
Input Voltage	120-277
Input Frequency	50/60 HZ
Status	Active

Lamp Type	Num. of Lamps	Rated Lamp Watts	Min. Start Temp (*F/C)	Input Current (Amps)	Input Power (ANSI Watts)	Ballast Factor	MAX THD %	Power Factor	MAX Lamp Current Crest Factor	B.E.F
* F54T5/HO	1	54	-20/-29	0.23	62	1.02	10	0.96	1.7	1.65
F54T5/HO	2	54	-20/-29	0.43	117	1.00	10	0.88	1.7	0.85
F54T5/HO/ES (49W)	1	49	-20/-29	0.23	58	1.02	10	0.96	1.7	1.76
F54T5/HO/ES (49W)	2	49	-20/-29	0.43	108	1.00	10	0.88	1.7	0.93

Wiring Diagram

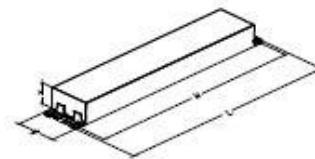


The wiring diagram that appears above is for the lamp type denoted by the asterisk (*)

Standard Lead Length (inches)

	in.	cm.		in.	cm.
Black	35	88.9	Yellow/Blue		0
White	35	88.9	Blue/White		0
Blue	31	78.7	Brown		0
Red	32	81.3	Orange		0
Yellow	52	132.1	Orange/Black		0
Gray		0	Black/White		0
Violet		0	Red/White		0

Enclosure



Enclosure Dimensions

OverAll (L)	Width (W)	Height (H)	Mounting (M)
9.50 "	1.7 "	1.18 "	8.90 "
9 1/2	1 7/10	1 9/50	8 9/10
24.1 cm	4.3 cm	3 cm	22.6 cm

Revised 03/02/2010



Data is based upon tests performed by Philips Lighting Electronics N.A. in a controlled environment and is representative of relative performance. Actual performance can vary depending on operating conditions. Specifications are subject to change without notice. All specifications are nominal unless otherwise noted.

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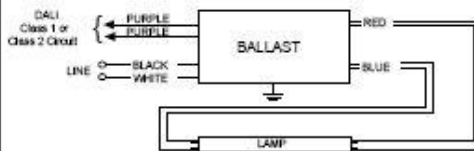


Electrical Specifications

IDA-128-D@120V	
Brand Name	ROVR
Ballast Type	Electronic Dimming
Starting Method	Programmed Start
Lamp Connection	Series
Input Voltage	120-277
Input Frequency	50/60 HZ
Status	Active

Lamp Type	Num. of Lamps	Rated Lamp Watts	Min. Start Temp (*F/C)	Input Current (Amps)	Input Power (Watts) (min/max)	Ballast Factor (min/max)	MAX THD %	Power Factor	Lamp Current Crest Factor	B.E.F.
F14T5	1	14	50/10	0.15	06/19	0.03/1.00	10	0.98	1.7	5.26
F21T5	1	21	50/10	0.20	08/25	0.03/1.00	10	0.98	1.7	4.00
* F28T5	1	28	50/10	0.27	07/32	0.03/1.00	10	0.98	1.7	3.13
F28T5/ES (25W)	1	25	50/10	0.25	07/30	0.03/1.00	10	0.98	1.7	3.33

Wiring Diagram

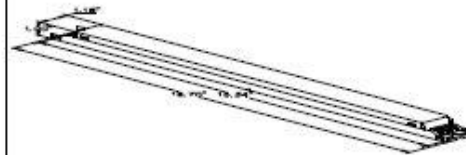


Diag. 55B
The wiring diagram that appears above is for the lamp type denoted by the asterisk (*)

Standard Lead Length (inches)

	in.	cm.		in.	cm.
Black	0	0	Yellow/Blue	0	0
White	0	0	Blue/White	0	0
Blue	0	0	Brown	0	0
Red	0	0	Orange	0	0
Yellow	0	0	Orange/Black	0	0
Gray	0	0	Black/White	0	0
Violet	0	0	Red/White	0	0

Enclosure



Enclosure Dimensions

OverAll (L)	Width (W)	Height (H)	Mounting (M)
16.70 "	1.18 "	1.00 "	16.34 "
16.7/10	1.9/50	1	16.17/50
42.4 cm	3 cm	2.5 cm	41.5 cm

Revised 01/18/2011



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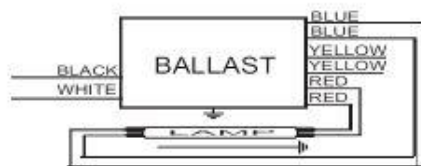


Electrical Specifications

ICN-2S28-N@120	
Brand Name	CENTIUM T5
Ballast Type	Electronic
Starting Method	Programmed Start
Lamp Connection	Series
Input Voltage	120-277
Input Frequency	50/60 HZ
Status	Active

Lamp Type	Num. of Lamps	Rated Lamp Watts	Min. Start Temp (*F/C)	Input Current (Amps)	Input Power (ANSI Watts)	Ballast Factor	MAX THD %	Power Factor	MAX Lamp Current Crest Factor	B.E.F
F14T5	1	14	0/-18	0.14	17	1.07	10	0.98	1.7	6.29
F14T5	2	14	0/-18	0.28	33	1.04	10	0.98	1.7	3.15
F21T5	1	21	0/-18	0.22	25	1.06	10	0.98	1.7	4.24
F21T5	2	21	0/-18	0.39	49	1.02	10	0.98	1.7	2.08
* F28T5	1	28	0/-18	0.29	31	1.05	10	0.98	1.7	3.39
F28T5	2	28	0/-18	0.53	62	1.00	10	0.98	1.7	1.61
F28T5/ES (25W)	1	25	32/00	0.25	30	1.00	10	0.98	1.7	3.33
F28T5/ES (25W)	2	25	32/00	0.49	58	1.00	10	0.98	1.7	1.72

Wiring Diagram

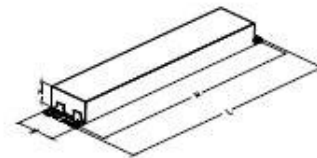


The wiring diagram that appears above is for the lamp type denoted by the asterisk (*)

Standard Lead Length (inches)

	in.	cm.		in.	cm.
Black	23	58.4	Yellow/Blue		0
White	23	58.4	Blue/White		0
Blue	27	68.6	Brown		0
Red	27	68.6	Orange		0
Yellow	42	106.7	Orange/Black		0
Gray		0	Black/White		0
Violet		0	Red/White		0

Enclosure



Enclosure Dimensions

OverAll (L)	Width (W)	Height (H)	Mounting (M)
9.5"	1.3"	1.0"	8.9"
9 1/2"	1 3/10"	1"	8 9/10"
24.1 cm	3.3 cm	2.5 cm	22.6 cm

Revised 09/07/2010



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Revised: 3/5/2009

				e-Vision® Electronic Ballast for Metal Halide Lamps			Catalog Number: IMH-70-D For 70W Metal Halide Lamps ANSI M98, M139 or M143 120-277 50/60Hz Electronic Status: RELEASED									
DIMENSIONS AND DATA																
Lamp		Input Volts	Catalog Number*	Line Current (Amps)	Input Power (Watts)	Min Power Factor	Wiring Diag	Fig.	Weight (lb)	Max. Distance to Lamp (ft)						
Number	Watts															
70W Watt Lamp, ANSI Code M98, M139 or M143 Minimum Starting Temp -30°C/-20°F																
1	70	120 277	IMH-70-D-XXX	0.67 0.29	80 79	0.9	3	D	1.6	5						
				Wiring Diagram 3												
Case Figure	Overall Length	Case Length	Case Width	Height	Mountin Length	Mounting Width										
D	128mm [5.0"]	108mm [4.3"]	77mm [3.0"]	38mm [1.5"]	118mm [4.6"]	19mm [0.7"]										
Case Temperature Measurement Location																
INSTALLATION & APPLICATION NOTES: 1. Maximum allowable case temperature is 85°C. See figure above for measurement location 2. Ignition pulse is 4 kV max 3. All leads are 12 inches long 4. Ballast output will shutdown after 20 minutes if lamp fails to ignite 5. Power must be cycled off – then on, after replacing lamp							*Ordering Information <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Order Suffix</th> <th style="text-align: left;">Description</th> </tr> <tr> <td style="text-align: center;">-LF</td> <td>Ballast with side exit leads and mounting feet</td> </tr> <tr> <td style="text-align: center;">-BLS</td> <td>Ballast with bottom exit leads and mounting studs</td> </tr> </table>				Order Suffix	Description	-LF	Ballast with side exit leads and mounting feet	-BLS	Ballast with bottom exit leads and mounting studs
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-LF	Ballast with side exit leads and mounting feet															
-BLS	Ballast with bottom exit leads and mounting studs															
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Revised: 3/5/2009

				e-Vision® Electronic Ballast for Metal Halide Lamps			Catalog Number: IMH-39-G For 39W Metal Halide Lamps ANSI M130 120-277 50/60Hz Electronic Status: RELEASED											
DIMENSIONS AND DATA																		
Lamp		Input Volts	Catalog Number*	Line Current (Amps)	Input Power (Watts)	Min Power Factor	Wiring Diag	Fig.	Weight (lb)	Max. Distance to Lamp (ft)								
Number	Watts																	
39W Watt Lamp, ANSI Code M130 Minimum Starting Temp -30°C/-20°F																		
1	39	120 277	IMH-39-G-XXX	0.39 0.18	46 45	0.9	3	G	0.9	5								
				Wiring Diagram 3														
Case Figure	Overall Length	Case Length	Case Width	Height	Mountin Length	Mounting Width												
G	97mm [3.8"]	90mm [3.5"]	77mm [3.0"]	30mm [1.2"]	87mm [3.4"]	67mm [2.6"]												
Case Temperature Measurement Location																		
INSTALLATION & APPLICATION NOTES: 1. Maximum allowable case temperature is 90°C. See figure above for measurement location 2. Ignition pulse is 4 kV max 3. All leads are 9 inches long 4. Ballast output will shutdown after 20 minutes if lamp fails to ignite 5. Power must be cycled off – then on, after replacing lamp 6. Connect the red lead to the center terminals of the lamp when using screw base lamps							*Ordering Information <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Order Suffix</th> <th style="text-align: left;">Description</th> </tr> <tr> <td style="text-align: center;">-LF</td> <td>Ballast with side exit leads and mounting feet</td> </tr> <tr> <td style="text-align: center;">-BLS</td> <td>Ballast with bottom exit leads and mounting studs</td> </tr> <tr> <td> </td> <td> </td> </tr> </table>				Order Suffix	Description	-LF	Ballast with side exit leads and mounting feet	-BLS	Ballast with bottom exit leads and mounting studs		
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TRANSFORMERS

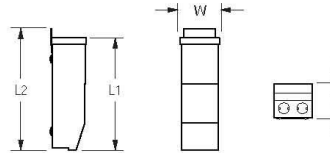
MAGNETIC TRANSFORMER (100W or less)



SERIES	L1 *	L2 *	D *	W *
TM40	5-1/4"	6"	2"	2-1/4"
TM100	6-1/4"	6.5"	2-1/4"	2-5/8"

*All dimensions are subject to change without prior notice.

Construction: All STEEL construction. Magnetic transformer completely encased in waterproof potting compound.
Finishes: All transformers come in black powdercoat finish only.
Features: Each circuit has a resetable internal circuit breaker in case of overload. All housings feature two 3/4" "knock-outs", one in each side. Housing is built to "NEMA 3R" specification.
General: It is recommended that these transformers are only loaded to 85% of their maximum capacity. These recommendations will allow the transformer to function at its optimum level. All "TM" series transformers must be mounted a minimum of 12" above finished grade with wire connection terminals facing down.



TM	SERIES
	TM - Magnetic Transformer
	WATTAGE
	40 - 40VA
	100 - 100VA
	VOLTAGE
	120V - 120 Volt Primary
	277V - 277 Volt Primary

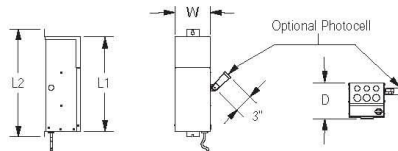
MAGNETIC TRANSFORMER (200W and above)



SERIES	L1 *	L2 *	D *	W *
TM200	15-3/16"	17-1/8"	5-3/4"	5-5/8"
TM300	15-3/16"	17-1/8"	5-3/4"	5-5/8"
TM600	15-3/16"	17-1/8"	5-3/4"	6-5/8"
TM900	17-3/16"	19-1/8"	5-3/4"	6-5/8"

*All dimensions are subject to change without prior notice.

Construction: All STAINLESS STEEL construction. Magnetic transformer completely encased in waterproof potting compound.
Finishes: Transformers come in brushed stainless only. Custom "wet" paint finishes are available (contact factory for more information).
Features: "TM" series transformers have multi-tap secondary output, 12V (11.8V), 13V (12.8V) and 15V (14.5V). Each 300VA circuit has an on/off switch to reset internal circuit breaker in case of overload. All housings feature six "knock-outs" in bottom cover plate (3-1/2", 3-3/4"). Housing is built to "NEMA 3R" specification.
General: It is recommended that these transformers are only loaded to 85% of their maximum capacity (i.e. 200VA = 170W max. load, 300VA = 255W max. load). It is also recommended that the minimum load should be greater than 40% of the total capacity of transformer (i.e. 200VA = 80W min. load, 300VA = 120W min. load). These recommendations will allow the transformer to function at its optimum level. All "TM" series transformers must be mounted a minimum of 12" above finished grade with wire connection terminals facing down.



TM	SERIES
	TM - Magnetic Transformer
	WATTAGE
	200 - 200VA
	201 - 200VA w/ Timer
	202 - 200VA w/ Timer & Photocell
	300 - 300VA
	301 - 300VA w/ Timer
	302 - 300VA w/ Timer & Photocell
	600 - 2 x 300VA
	601 - 2 x 300VA w/ Timer
	602 - 2 x 300VA w/ Timer & Photocell
	900 - 3 x 300VA
	901 - 3 x 300VA w/ Timer
	902 - 3 x 300VA w/ Timer & Photocell
	VOLTAGE
	120V - 120 Volt Primary
	277V - 277 Volt Primary

MOUNTING & ACCESSORIES

MAGNETIC INGRADE TRANSFORMER (Direct Burial Rated)

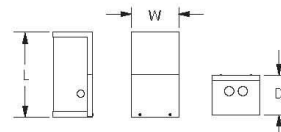


SERIES	L *	D *	W *
TM300	10-1/4"	4-3/4"	5-3/4"
TM600	10-1/4"	4-3/4"	5-3/4"

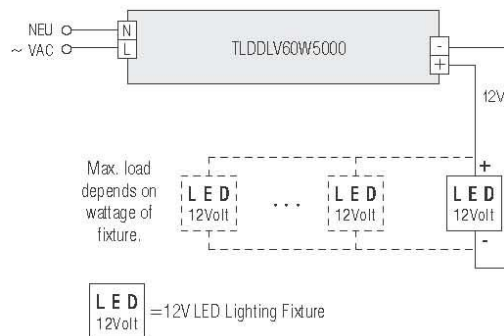
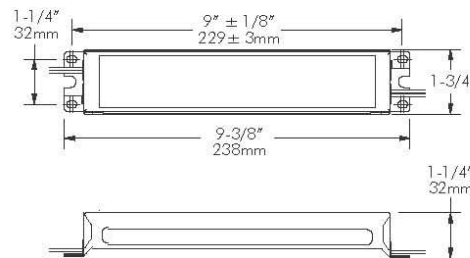
*All dimensions are subject to change without prior notice.

Construction: All STAINLESS STEEL construction. Magnetic transformer completely encased in waterproof potting compound.
Finishes: Transformers come in brushed stainless only. Custom "wet" paint finishes are available (contact factory for more information).
Features: "TMI" series transformers have a secondary output of 12V (11.8V). Each 300VA circuit has an internal circuit breaker in case of overload (power to transformer must be cycled to reset circuit breaker). All housings feature two 3/4" "knock-outs" in end plate and one 1/2" "knock-out" on each side plate. Transformer includes two 3/4" liquid tight 90° conduit adapters, two straight 1/2" liquid tight conduit adapters, six silicone filled waterproof wirenuts, and a tube of silicone for the cover.
General: It is recommended that these transformers are only loaded to 85% of their maximum capacity (i.e. 300VA = 255W max. load). It is also recommended that the minimum load should be greater than 40% of the total capacity of transformer (i.e. 300VA = 120W min. load). These recommendations will allow the transformer to function at its optimum level. All "TMI" series transformers are suitable for direct in-ground burial when properly installed. Also approved for above ground use within 1' above ground.

TMI	SERIES
	TMI - Magnetic Ingrade Transformer
	WATTAGE
	300 - 300VA Ingrade
	600 - 2 x 300VA Ingrade
	VOLTAGE
	120V - 120 Volt Primary
	277V - 120 Volt Primary



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11-2009



High Power Constant Voltage LED Driver

TLDDL60W5000

SPEC SHEET

Features:

- UL Class 2, limited output and current with isolation for safe operation.
- Multiple voltage from 120 to 277 volts.
- Tight regulated output (1% line, 5% load) to maximize LED performance.

AC Input Voltage:	120 ~ 277V, 50/60Hz
DC Output Voltage:	12V Constant
DC Output Current:	0.1 ... 5.00A Max
Output Wattage:	60W Max
Power Factor:	90% Min
Typical Efficiency:	90%
Short Circuit Protection:	Yes
Overload Protection:	Yes
Over-voltage Protection:	Yes
Dimming Function:	With TLC010i Dimming Controller (sold separately)
Operating Temperature:	-40 ~ 60°C (-40 ~ 140°F)
Maximum Case Temperature:	90°C (194°F)
Total Harmonic Distortion:	20% Max
Case Material:	Steel
Weight:	635g (1.40 lbs)
Approval:	IP66 outdoor rated. Approved to UL by CSA/CUS UL Listed



Note: Consult factory for wiring length and details.

ORDER CODE

TLDDL60W5000

[M] MPLIGHTING

t 604.708.1184 f 604.708.1185 www.mplighting.com
16 West 4th Avenue, Vancouver BC V5Y 1G3, Canada

[Project]

[Quantity]

[Notes]

Electrical



OCCUPANCY SENSORS

Power Packs

BZ-100 Dual Voltage Power Pack

Fully self-contained transformer and relay

Zero crossing for reliability and increased product life



Hold ON and Hold OFF inputs

Overcurrent protection (low voltage)

Dual 120/277 VAC

Plenum rated

PROJECT
LOCATION/TYPE

Product Overview

Description

The BZ-100 is a full-featured power pack, providing 24 VDC operating voltage to Watt Stopper's low voltage occupancy sensors. In addition, the BZ enables special hold-ON, hold-OFF and load shed applications when used with lighting control panels or building management systems.

Operation

The BZ consists of a transformer and a high-current relay. The transformer has a primary high voltage input of 120 or 277 VAC. The secondary output, which provides the operating power for Watt Stopper occupancy sensors, is 24 VDC, 150 mA. This 150 mA output is available with the power pack's relay connected. The power packs receive input from occupancy sensors or light level sensors and switch lighting on and off. For example, when an occupancy sensor detects motion, it electrically closes an internal circuit which sends 24 VDC to the power pack. This closes the power pack relay and turns the lights on.

Plenum Rated

The BZ is UL 2043 plenum rated with teflon coated low voltage leads and plenum rated plastic. This means that the power packs do not need to be installed in the junction box, but can be installed in the plenum. They are housed in ABS, UL-rated 94V-0 plastic enclosures.

Applications

BZ power packs can control lighting circuits, self-contained air conditioners, pumps, fans, motors, VAV systems, motorized damper controls and setback thermostats. The hold-OFF input can be used to perform load shedding. During a power alert or during peak demand, a signal from a BMS or utility meter triggers the BZ to shed non-critical lighting loads. The hold-OFF function also works with a security system to hold some lights off during a security walk-through. The hold-ON input is ideal for retail and commercial facilities that want to hold certain lighting ON during normal business hours. After-hours, a time clock signals the BZ to no longer hold lights ON, allowing occupancy sensors to resume control.

Features

- Self-contained transformer relay system
- Primary high voltage input of 120 or 277 VAC
- LED indicates status of relay or if there is a low voltage overcurrent
- Hold-ON and hold-OFF inputs integrate with lighting control panels, BMS and other building systems
- Hold-OFF input can provide load shedding function
- Hold-ON input enables method to override occupancy sensor and hold lighting ON
- Zero crossing circuitry for reliability and increased product life
- UL 2043 plenum rated
- Can be installed directly in plenum for cost-effective installation
- 1/2 inch snap-in nipple attaches to standard electrical enclosures through 1/2 inch knockouts

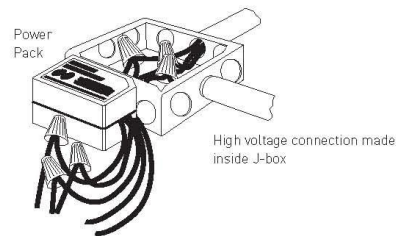
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Specifications

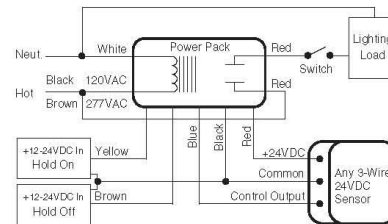
- 120/277 VAC voltage input
- Secondary voltage of 24 VDC
- Secondary output of 150 mA (with relay connected)
- Low voltage leads are rated for 300 volts
- Hold-ON and hold-OFF inputs for integration with lighting control panels, BMS, and other building systems 12-24 VDC
- UL-rated 94 V-0 plastic enclosure; units are grey
- UL 2043 plenum rated
- Dimensions: 1.6" x 2.75" x 1.6" (40.6mm x 69.9mm x 40.6mm) with a 1/2 inch snap-in nipple
- UL and CUL listed; Five year warranty

System Layout & Wiring

Installation Diagram

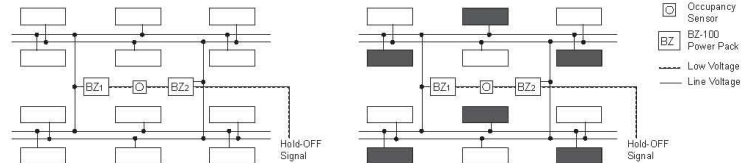


Wiring with Occupancy Sensor



Hold-OFF & Hold-ON Applications

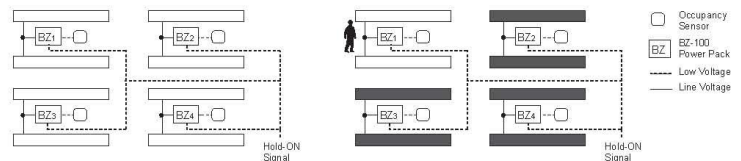
Load Shed (Hold-OFF) Application for Open Office Spaces



The occupancy sensor, connected to each BZ, keeps all lights on when the space is occupied.

When the load shed command is given (by utility meter, BMS, etc.), lights connected to the BZ2 are held off. Remaining lights, (BZ1) are controlled by occupancy sensor.

Hold-ON Retail Application



During store hours, a signal from a time clock to the BZ holds lights on, regardless of occupancy.

After hours, the clock schedule cancels the hold on and occupancy sensor control takes over.

Ordering Information

Installation Notes

Pub. No. 14406

Catalog No.	Input Voltage	Load Ratings			Output
		Ballast [A]	Incan [A]	Motor [HP]	
BZ-100	120/277 VAC; 60 Hz	20	20	1*	24 VDC; 150 mA**

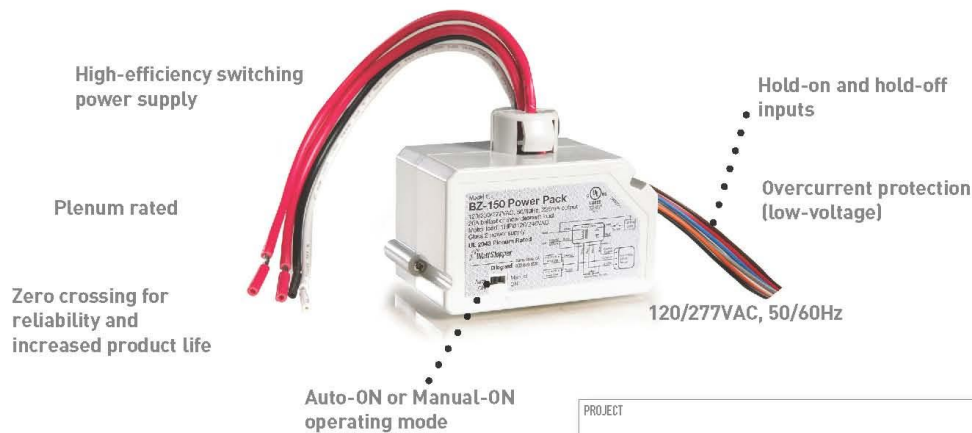
* 1 Hp rated at 120/250 VAC. ** Output is 150 mA with relay connected.

1. All Watt Stopper power packs should be installed in accordance with state, local, and national electrical codes and requirements.
2. Power packs are designed to attach to existing or new electrical enclosures with .5" [25.40mm] knockouts. [Check electrical codes in your area.]
3. Most applications require UL listed, 18-22 AWG, 3-conductor, Class 2 cable for low voltage wiring. For plenum return ceilings use UL listed plenum-approved cables.

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BZ-150 Universal Voltage Power Pack



PROJECT
LOCATION/TYPE

Product Overview

Description

The BZ-150 Universal Voltage Power Pack is full featured and can provide 24 VDC operating voltage to WattStopper's low-voltage occupancy sensors. In addition, the BZ-150 enables manual-on, hold-on, hold-off and load shed applications when used with lighting control panels or building management systems. This device is constructed with environmentally friendly materials and is RoHS-compliant.

Operation

The BZ-150 consists of a high-efficiency switching power supply and a high-current relay. It has an input of 120/277 VAC, 50/60Hz, and an output of 24VDC, 225mA. It turns the connected load on and off automatically based on occupancy sensor input, or manually with a low-voltage momentary switch. The dip switch setting allows the user to select Auto ON or Manual ON as the operating mode. Additional low-voltage inputs provide hold-on and hold-off features for broader applications.

Manual On and Bi-level Switching

Energy codes require automatic off. Some codes and EAct require bi-level switching. The BZ-150 meets both of these requirements, while seamlessly integrating manual on for maximum energy savings. When used with a low-voltage wall switch, Auto ON and Manual ON can be selected while in the field by using the conveniently located dip switch on the front. Combining switches, power packs and sensors provides easy and cost-effective code-compliant solutions.

Applications

The BZ-150 can control lighting circuits, self-contained air conditioners, pumps, fans, motors, VAV systems, motorized damper controls and setback thermostats. By using two low-voltage switches, a ceiling sensor and two BZ-150s (one set to Auto ON and one set to Manual ON) bi-level switching with manual-on operation can be achieved. The hold-on input is ideal for retail and commercial facilities that want to override an occupancy sensor and force lighting on during normal business hours. After hours, a time clock signals the BZ-150 to cancel the hold-on lighting mode, allowing the sensor to resume control. The hold-off input can be used for load shedding or security systems.

Features

- Self-contained power supply relay system
- Efficient switching power supply providing optimized current output based on number of sensors
- LED indicates status of relay or if there is a low-voltage overcurrent
- Hold-on and hold-off inputs integrate with BMS, lighting control panels & other building systems
- Integrates with low-voltage momentary switch to control any 24VDC occupancy sensor
- RoHS-compliant
- Provides auto-on or manual-on field-selectable operating mode
- Zero crossing circuitry for reliability and increased product life
- UL 2043 plenum rated for cost-effective installation
- 1/2" snap-in nipple attaches to standard electrical enclosures through 1/2" knockouts
- 14 AWG wires on the relay for 20A operation
- Qualifies for ARRA-funded public works projects

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800.879.8585

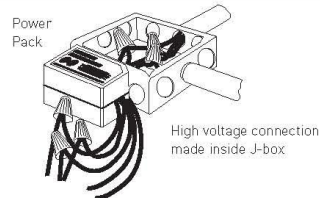
Specifications

- 120/277VAC, 50/60Hz voltage input
- Secondary voltage of 24 VDC
- Secondary output of 225 mA (with relay connected)
- Low-voltage leads are rated for 300 volts
- UL-rated 94 V-0 grey plastic enclosure

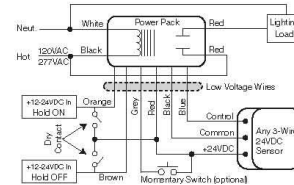
- Dimensions: 1.6" x 2.75" x 1.6" (40.6mm x 69.9mm x 40.6mm) H x W x D with a 1/2" (12.7mm) snap-in nipple
- UL and cUL listed
- Five year warranty

System Layout & Wiring

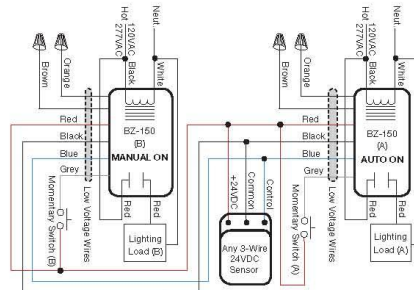
Installation Diagram



Wiring with Occupancy Sensor

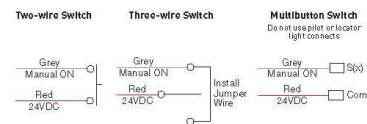


Manual-on & Bi-level Switching



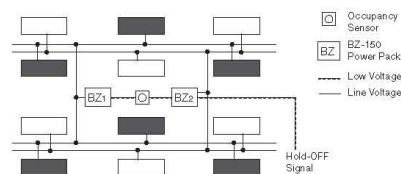
By using two low-voltage switches, a ceiling sensor and two BZ-150s (one set to Auto ON and one set to Manual ON) bi-level switching with manual-on operation can be achieved.

Low-voltage Momentary Switch Options



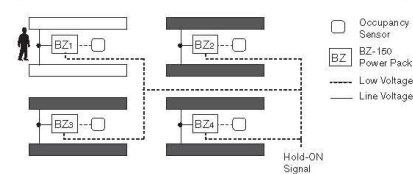
Hold-off & Hold-on Applications

Load Shed (Hold-off) Application for Open Office Spaces



The occupancy sensor connected to each BZ-150 keeps all lights on when the space is occupied. When the load shed command is given (by utility meter, BMS, etc.), lights connected to BZ₂ are held off. Remaining lights (connected to BZ₁) are still controlled by occupancy sensor.

Retail (Hold-on) Application



During store hours, a signal from a time clock to the BZ-150 holds lights on, regardless of occupancy. After hours, the clock schedule cancels the hold-on and occupancy sensor control takes over.

Ordering Information

Catalog No.	Input Voltage	Load Ratings			
		Ballast(A)	Incan(A)	Motor	Output
☐ BZ-150	120/277VAC, 50/60Hz	20	20	1 HP 120/250 VAC-rated	24 VDC
☐ BZ-150-U					225 mA w/relay connected
☐ BZ-150-FTA					

For a complete listing of Multibutton Low-voltage and Momentary Toggle Switches that will provide manual-on switching with the BZ-150, please refer to the product cut sheets in the section on Lighting Control Systems.

Installation Notes

Pub. No. 27404 rev. 11/2010

- 1) All WattStopper power packs should be installed in accordance with state, local, and national electrical codes and requirements.
- 2) Power packs are designed to attach to existing or new electrical enclosures with 5" 125.40mmJ knockout (check electrical codes in your area).
- 3) Most applications require UL-listed, 18-22 AWG, 3-conductor, Class 2 cables for low-voltage wiring. For plenum return ceilings use UL-listed plenum-approved cables.

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COMMERCIAL OCCUPANCY SENSORS & CONTROLS



DT-300 Series Dual Technology Ceiling Sensors



PROJECT
LOCATION/TYPE

Product Overview

Description

The DT-300 Series Dual Technology Ceiling Sensors combine the benefits of passive infrared (PIR) and ultrasonic technologies to detect occupancy. Sensors have a flat, unobtrusive appearance and provide 360 degrees of coverage.

Operation

Low voltage DT-300 Series sensors utilize a WattStopper power pack to turn lights on when both PIR and ultrasonic technologies detect occupancy. They can also work with a low voltage switch for manual-on operation. PIR technology senses motion via a change in infrared energy within the controlled area, whereas ultrasonic uses 40KHz high frequency ultrasound. Once lights are on, detection by either technology holds them on. When no occupancy is detected for the length of the time delay, lights turn off. DT-300 Series Sensors can also be set to trigger lights on when either technology or both detect occupancy, or to require both technologies to hold lighting on.

Auto Set

The DT-300 requires no adjustment at installation. Auto set continuously monitors the controlled space to identify usage patterns. Based on these patterns, the unit automatically adjusts time delay and sensitivity settings for optimal performance and energy efficiency. Sensors assign short delays (as low as five minutes) for times when the space is usually vacant, and longer delays (up to 30 minutes) for busier times.

Application

DT-300 Series Dual Technology Sensors have the flexibility to work in a variety of applications, where one technology alone could cause false triggers. Ideal applications include classrooms, open office spaces, large offices and computer rooms. The DT-300 Series mounting system makes them easy to install in ceiling tiles or to junction boxes, providing the flexibility to be used in a wide range of spaces.

Features

- Advanced control logic based on RISC microcontroller provides:
- Detection Signature Processing eliminates false triggers and provides immunity to RFI and EMI
- Walk-through mode turns lights off three minutes after the area is initially occupied – ideal for brief visits such as mail delivery
- Available with built-in light level sensor featuring simple, one-step setup
- Sensors work with low-voltage momentary switches to provide manual control
- Patented ultrasonic diffusion technology spreads coverage to a wider area
- LEDs indicate occupancy detection
- Uses plug terminal wiring system for quick and easy installation
- Eight occupancy logic options provide the ability to customize control to meet application needs
- Available with isolated relay for integration with BAS or HVAC
- Qualifies for ARRA-funded public works projects

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800.879.8585



DW-100 Dual Technology Wall Switch Sensor



PROJECT

LOCATION/TYPE

Product Overview

Description

The DW-100 dual technology wall switch sensor combines the benefits of passive infrared (PIR) and ultrasonic technologies, and can turn lights OFF and ON based on occupancy. It is characterized by high sensitivity to small and large movements, appealing aesthetics, and a variety of features.

Operation

The DW-100 fits in a single gang junction box. Once the lights are ON, detection by either technology holds lights ON until occupancy is no longer detected and the time delay elapses. DIP switch settings allow for a variety of control options including Auto-ON operation, walk-through and test mode. By default, Auto-ON turns lighting on when both PIR and ultrasonic technologies detect occupancy. Additional DIP switch settings allow the user to choose which sensing technologies turn-ON and hold-ON the lighting.

Manual-on Control

Factory default operation is for Manual-ON, so that users turn lights on only when needed. This control strategy is proven to save more energy than Auto-ON, and will be required where the ASHRAE 90.1-2010 energy code is adopted. If desired, the DW-100 may be reconfigured to turn lights on automatically.

Applications

WattStopper's dual technology has the flexibility to work in a variety of applications where one technology alone may not be sufficient. Common applications include small and executive offices, small and medium conference rooms and lunch/break rooms. In addition, dual technology sensors are the perfect choice for ADA-compliant buildings due to lower mounting height requirements.

Features

- Detection Signature Processing eliminates false triggers and provides immunity to RFI and EMI
- Zero-crossing for long relay life
- Vandal resistant lens combines precise coverage with durability
- Choice of Manual-ON or Auto-ON operation
- Selectable walk-through mode turns lights off three minutes after the room is initially occupied if no motion is detected after the first 30 seconds
- Test mode allows quick and easy adjustments
- Selectable audible alert for impending shutoff
- In automatic mode, sensor returns automatically to Auto-ON after lights are turned off manually; ideal for presentations
- Four occupancy logic options give users the ability to customize control to meet application needs
- Optional light level sensing with simple setup
- Service mode allows sensor to operate as a service switch in the unlikely event of a failure
- Sensor coverage tested to NEMA Guide Publication WD 7-2000
- Compatible with decorator wall plates
- Qualifies for ARRA-funded public works projects

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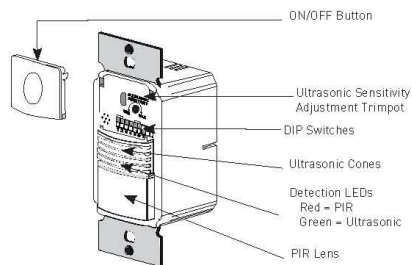
Specifications

- DW-100: 120/277 VAC; 50/60 Hz
@ 120 VAC, 0-800 W ballast or tungsten, 1/6 hp
@ 277 VAC, 0-1200 W ballast
- DW-100-347: 347 VAC; 50/60Hz, 0-1500 W ballast
- Time delays: 5, 15 or 30 minutes, walk-through, test-mode

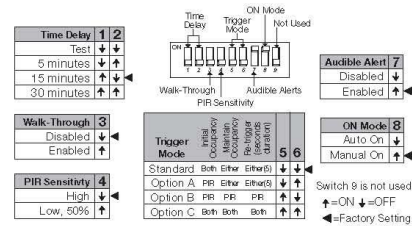
- Coverage:
Major motion, PIR 35' x 30', Ultrasonic 20' x 20'
Minor motion, PIR 20' x 15', Ultrasonic 15' x 15'
- Sensitivity adjustment: PIR (high/low), Ultrasonic (fully variable)
- Dimensions: 2.73" x 1.76" x 1.83"
(69.3mm x 44.7mm x 46.5mm) L x W x D
- UL and cUL listed
- Five year warranty

Controls & Settings

Product Controls

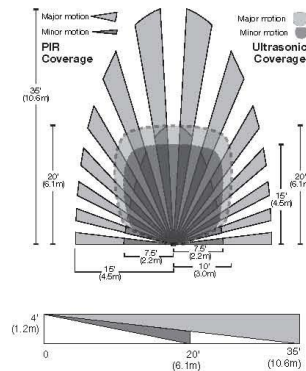


DIP Switch Settings

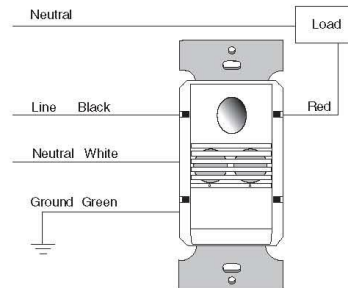


Coverage & Wiring

Coverage Pattern



Wiring Diagram



For best performance, WattStopper recommends using this sensor in spaces no larger than 18' x 15'.

Ordering Information

Catalog No.	Color	Voltage	Load Rating
☐ DW-100-W ☐ DW-100-W-U ☐ DW-100-W-FTA	White	120/277 VAC; 50/60 Hz	@ 120 VAC, 0-800 W ballast or tungsten, 1/6 hp @ 277 VAC, 0-1200 W ballast
☐ DW-100-LA ☐ DW-100-I ☐ DW-100-I-U ☐ DW-100-I-FTA	Lt. Almond Ivory		
☐ DW-100-G ☐ DW-100-B	Grey Black		
☐ DW-100-347-W ☐ DW-100-347-LA ☐ DW-100-347-I ☐ DW-100-347-G ☐ DW-100-347-B	White Lt. Almond Ivory Grey Black	347 VAC; 50/60 Hz	0-1500 W ballast

Order wall plate separately.

Pub. No. 22305 rev. 9/2010

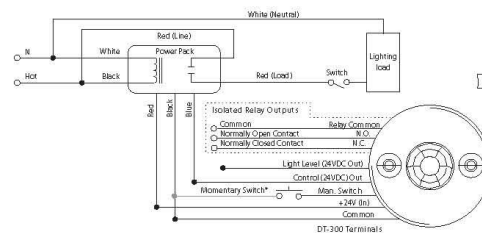
www.wattstopper.com | 8 0 0 . 8 7 9 . 8 5 8 5

Specifications

- 24 VDC/VAC
- Ultrasonic frequency: 40kHz
- Time delays: Auto set, fixed (5, 10, 15, 20, or 30 minutes), Walk-through/Test Modes
- Sensitivity adjustment: Auto set; reduced sensitivity (PIR); variable with trim pot (ultrasonic)
- Built-in light level sensor: 10 to 300 footcandles (107.6 to 3,229.2 lux)
- Low-voltage, momentary switch input for manual on or off operation

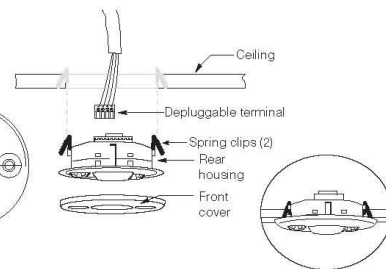
Wiring & Mounting

Wiring Diagram



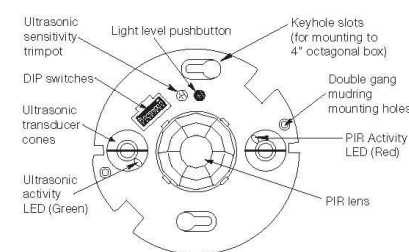
- DT-300 contains an isolated relay with N/O and N/C outputs; rated for 1 Amp @ 30 VDC/VAC
- Multi-level Fresnel lens provides 360° coverage
- Mounting options: ceiling tile; 4" octagonal J-box, 1.5" deep
- Max DT-300s per power pack: B=2, BZ=3
- Max DT-305s per power pack: B=3, BZ=4
- Dimensions: 4.50" diameter x 1.02" deep (114.3mm x 25.9mm)
- UL and cUL listed
- Five year warranty

Ceiling Mounting



Controls & Settings

Product Controls



DIP Switch Settings

Factory Setting
● = ON
— = OFF

Switch	1	2	3
Occupancy Logic	Standard	Option 1	Option 2
Time Delay	5 sec/SmartSet	5 minutes	10 min.
PIR Sensitivity	Minimum	Maximum	SmartSet

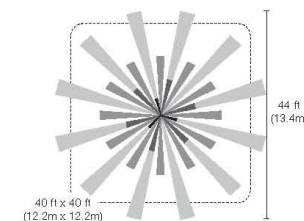
LEDs 7
Disabled
Enabled

PIR Sensitivity 8
Minimum
Maximum/SmartSet

↑ = walk-through mode

Coverage

Coverage Pattern



Coverage shown is maximum and represents half-step walking motion. Under ideal conditions, coverage for half-step walking motion can reach up to 1000 ft².

Ordering Information

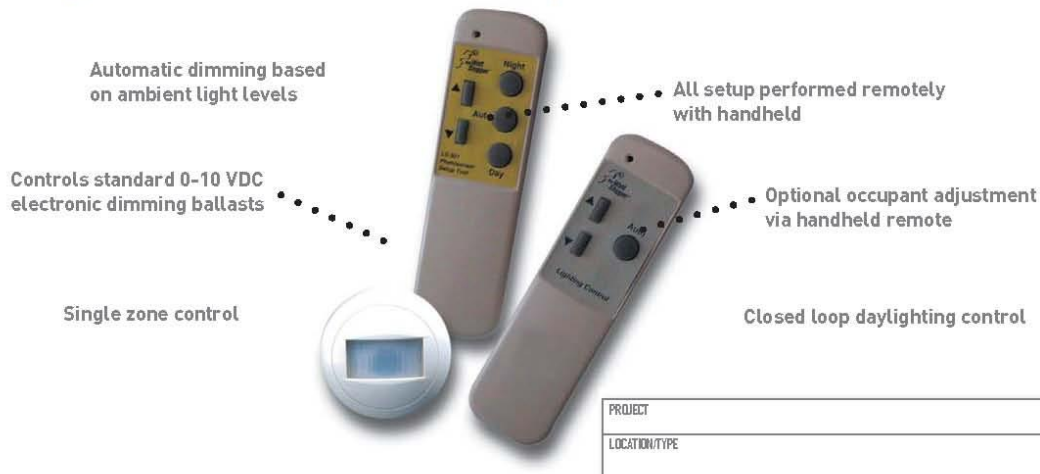
Catalog No.	Voltage	Current	Coverage	Features
☐ DT-300	24 VDC/VAC	43 mA	up to 1000 ft² (92.9 m²)	Isolated relay, light level
☐ DT-300-U	24 VDC/VAC	43 mA	up to 1000 ft² (92.9 m²)	
☐ DT-305	24 VDC/VAC	35 mA	up to 1000 ft² (92.9 m²)	
☐ DT-305-U	24 VDC/VAC	35 mA	up to 1000 ft² (92.9 m²)	

Sensors are white and use WattStopper power packs. Current consumption can be slightly higher when only one sensor per power pack is used.





LightSaver® LS-301 Dimming Photosensor



Product Overview

Description

The LightSaver LS-301 is a closed loop, ceiling mount, low voltage indoor photosensor that works with standard, 0-10 VDC electronic dimming ballasts to dim lighting as daylight increases.

Operation

The LS-301 mounts on a ceiling and utilizes a spectral filtering system to measure daylight and electric light levels. A closed loop daylighting system, the LS-301 measures the total light level from daylight and electric light in the controlled area to adjust electric lighting levels. As the daylight contribution increases, the lights dim down. The photosensor utilizes sliding setpoint control, which responds to the different spatial distribution qualities of electric light and daylight. The LS-301 calculates the required light level for current daylight contribution based on two setpoints. One represents the target level when no daylight is present (night setpoint) and the other when significant daylight is present (day setpoint).

Adjustment via Handheld Remote Control

All LS-301 adjustments are made with one of two handheld remotes. The FDR-301-S provides five buttons for initial set-up, which is easily completed by first raising or lowering electric light levels to desired levels, then programming this target level into the photosensor. The LSR-301-P provides three buttons for occupants to adjust light levels. With this optional tool, users can increase target light levels by up to 25% or reduce them to the lamp/ballast minimum level. Pressing the "Auto" button returns the control to programmed levels.

Applications

The LS-301 is designed to blend into its surroundings when installed in any environment. It provides one zone of daylighting control in a private office or classroom. In these applications, the LS-301 can be combined with an occupancy sensor. Often, it is possible for the LS-301 to share a single power pack with occupancy sensor(s).

Features

- Provides precise control of lighting to maintain desired light level
- Extremely linear photocell response with greater than 1% accuracy
- Designed to measure light as the human eye perceives it, eliminating "overreporting" illumination levels provided by daylight
- California Title 24-2008 compliant
- Separate handheld remote controls for setup and occupant adjustment to prevent tampering
- Boosts energy savings by reducing maximum lamp output, often resulting in a 20% reduction or more compared with lights at full output
- Achieves lumen maintenance by holding target light level as lamp output decreases over time
- Qualifies for use on ARRA-funded public works projects

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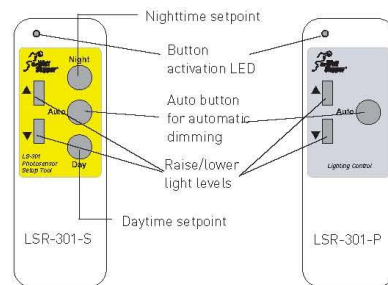


Specifications

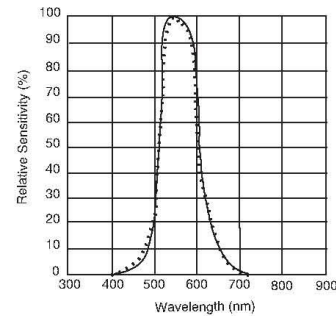
- Full range dimming: .2 VDC (minimum) to 10 VDC (100% lighting) output voltage
- Current consumption: 30 mA @ 24 VDC
- In typical applications, setpoints are adjustable from 20-60 footcandles (210-640 lux)
- Controls up to 50 standard dimming ballasts in one zone
- Sensor leads: gray and violet to ballast, red and black to 24 VDC
- Dimensions: 2.35" diameter, x 0.875" depth (60mm x 22mm), threaded piece extends 1.25" (31.8mm) from back, fits .5" knockout
- Five year warranty

Product Controls

Remote Controls



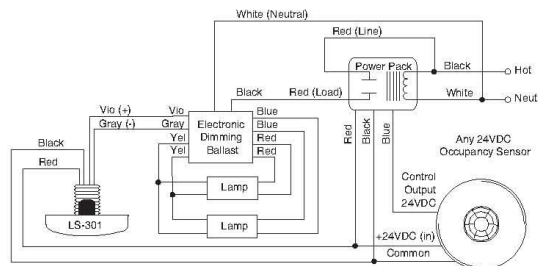
Spectral Response Curve



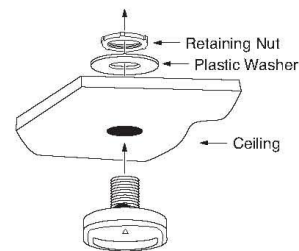
The spectral response of the LS-301 photocell closely matches the sensitivity of the human eye.

Wiring & Installation

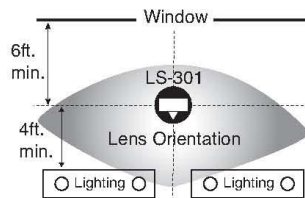
Wiring



Mounting and Installation



Coverage



Placement Guidelines

- Mount photocell between 6 and 12 feet (1.8m - 3.7m) from window.
- Do not mount directly above direct/indirect pendant fixtures. Mount at least 4 feet (1.2m) from pendant fixtures.

Ordering Information

Catalog No.	Description	Input Voltage
☐ LS-301	Dimming Photosensor	24 VDC
☐ LS-301-U	Dimming Photosensor, ARRA-compliant	24 VDC
☐ LS-301-FTA	Dimming Photosensor, ARRA-compliant (FTA exception)	24 VDC
☐ LSR-301-S	Setup Remote Control (2 AAA batteries included)	
☐ LSR-301-P	Occupant Remote Control (2 AAA batteries included)	

LS-301 works with WattStopper power packs



Cutler-Hammer

June 2006
Sheet 0821

Panelboards Pow-R-Line 1a

22.1-1

General Description — Pow-R-Line 1a

Pow-R-Line 1a



Pow-R-Line 1a

General Description

Panelboard Ratings

Voltage:

- 240 Vac maximum.

Main Lugs:

- 100 – 400 amperes.

Main Breakers:

- 100 – 400 amperes.

Branch Breakers:

- 15 – 100 amperes
(Bolt-on or plug-on chassis).

Short Circuit Current Ratings (Symmetrical)

- 240 Vac: 10 kA and 22 kA fully rated.
- 240 Vac: 22 – 200 kA series rated.

Service

- 3-phase, 4-wire 208Y/120 V and 240/120 V Delta.
- Single-phase, 3-wire 120/240 V.
- Single-phase, 2-wire 120 V.
- 3-phase, 3-wire 208 and 240 V.

Suitable for service entrance applications when specified.

Mains

For available mains, refer to **Table 22.1-1**.

Main breakers, 100 amperes, Types BAB and QBH are horizontally mounted, same as branch breakers. All other main breakers are vertically mounted.

Branch Circuits

For available branch devices, refer to **Table 22.1-2**.

Main Lugs Only

The short circuit rating of the MLO assembled panelboard will be fully rated based upon the lowest rated branch device or may be series rated with an approved upstream device.

Main lugs only ampere ratings: 100, 225 and 400.

Main Circuit Breakers

The short circuit rating shown is that of the main breaker only. The short circuit rating of the assembled panelboard is the rating of the lowest fully rated main or branch device or the rating of an approved series rated combination

Table 22.1-1. Main Circuit Breakers

Breaker Frame Amperes	Breaker Type	Interrupting Rating (kA Symmetrical) at 240 V
100	BAB	10
100	QBHW	22
100	EHD	18
150	FDB	18
225	FD	65
225	HFD	100
225	FDC	200
225	EDB	22
225	EDS	42
225	ED	65
225	EDH	100
225	EDC	200
250	JD	65
250	HJD	100
250	JDC	200
400	DK	65
400	KD	65
400	HKD	100
400	KDC	200

Table 22.1-2. Branch Circuit Breakers

Breaker Type	Ampere Rating	Number of Poles	Interrupting Rating (kA Symmetrical)		
			120 V	120/240 V	240 V
BAB, HQP	15 – 70	1	10	—	—
BAB, HQP	15 – 100	2	—	10	—
BAB, HQP	15 – 100	2,3	—	—	10
BAB-D ⊕, HQP-D ⊕	15 – 60	1,2	10	10	—
BAB-C ⊕, HQP-B ⊕	15 – 30	1,2	10	10	—
BABRP ⊕	15 – 30	1,2	10	10	—
BABRSP ⊕	15 – 30	1,2	10	10	—
QBGF, QBGFEP	15 – 50 ⊕	1,2	10	10	—
QPGF, QPGFEP	15 – 50 ⊕	1,2	10	10	—
QBAF ⊕, QBAG ⊕	15 – 20	1,2	10	10	—
QBHW	15 – 70	1	22	—	—
QBHW	15 – 100	2	—	22	—
QBHW	15 – 100	2,3	—	—	22
QBHGF, QBHGFEP	15 – 30	1,2	22	22	—
QPHGF, QPHGFEP	15 – 30	1,2	22	22	—
QBHAF ⊕, QBHAG ⊕	15 – 20	1,2	22	22	—

⊕ HID (High Intensity Discharge) rated breaker.

⊕ Switching Neutral breaker. 1-pole device requires 2-pole space, 2-pole device requires 3-pole space.

⊕ Solenoid operated breaker.

⊕ 50 ampere is 2-pole only.

⊕ Arc fault breaker.

⊕ Arc fault breaker with GFCI.

Series Rated Combinations

Refer to series rating tables beginning on **Page 22.0-11** for the approved series rated combinations available for the branch circuit breakers listed in **Table 22.1-2**.

22.1-2 Panelboards Pow-R-Line 1a

Technical Data — Pow-R-Line 1a

EATON | Cutler-Hammer

 June 2006
Sheet 0322

22

Pow-R-Line 1a Specifications

Bussing

100 – 400 amperes: Tin-plated aluminum is standard, copper is available as an option.

Boxes

Boxes are made from code-gauge galvanized steel.

Blank ends are supplied as standard, knockouts are available upon request.

EZ Trim

Trims are made from code-gauge steel and painted ANSI 61 gray.

All panelboards have door-in-door as standard with multi-point catch and lock, and concealed mounting hardware.

Modifications

Table 22.1-3. Sub-Feed Lugs (Main Lugs Only)

Amperes	Panel Height Addition
100	0 Inches (0 mm)
225	0 Inches (0 mm)

Table 22.1-4. Through-Feed Lugs

Amperes	Information
100	See Table 22.1-6
225	See Table 22.1-6
400	See Table 22.1-6

Table 22.1-5. Sub-Feed Breakers
(One Per Panel)

Ampere Rating	Breaker Type	Interrupting Rating (kA Symmetrical) at 240 V
150	FDB	18
225	FD	65
225	HFD	100
225	FDC	200
225	EDB	22
225	EDS	42
225	ED	65
225	EDH	100
225	EDC	200
250	JD	65
250	HJD	100
250	JDC	200
400	DK	65
400	KD	65
400	HKD	100
400	KDC	200

Shunt Trips

Shunt trips are available on breakers. BAB, HQP, QBHW and QPHW require one additional pole space for shunt trip, i.e., 1-pole is 2-pole size, 2-pole is 3-pole size and 3-pole is 4-pole size.

Ground Bar

Standard bolted in box. Aluminum is standard. Copper is available as an option.

Enclosures

Types 1, 12, 3R, 4 and 4X.

TVSS

Integrated onto panelboard chassis. For complete product description and available ratings, refer to **Section 36**.

Box Sizing and Selection

Box size for all Type 1 panelboards are available from **Table 22.1-6**.

Instructions

1. Select the rating and type of mains required.
2. Count total number of branch circuit poles (including spaces) required in the panelboard. Do not count main breaker poles. Convert 2- or 3-pole branch breakers to single-poles, i.e., 3-pole breaker, count as three poles.

Note: For horizontal mounted mains (BAB Type), use main lug table, include space in branch section for mains.

3. Using correct table, type of mains and ampere rating per Step 1, find total number of poles.

Note: Where total number of poles (Step 2) fall between number in table, use the next higher number.

4. Read box size across columns to the right.

Top and Bottom Gutters (minimum)

5-1/2 inches (139.7 mm).

Side Gutters

20-inch (508.0 mm) wide box:
6-1/2 inches (165.1 mm).

Table 22.1-6. Type 1 Panelboards — Dimensions in Inches (mm)

Ampere Rating of Mains	Main Breaker Type Mounting Position		Maximum Number of Branch Circuits Including Provisions	Box Dimensions ①②		
				Height	Width	Depth
100 Amperes						
100 A ③ Main Lugs or Main Breaker	EHD, FDB, FD, HFD, FDC Vertical	18	36 (914.4)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
100 A ③ Main Lugs or Main Breaker with 100 A Through-Feed Lugs or Sub-Feed Breaker	EHD, FDB, FD, HFD, FDC Vertical	18	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
225 Amperes						
225 A ④ Main Lugs or Main Breaker	EDB, EDS, ED, EDH, EDC, FD, HFD, FDC Vertical	18	36 (914.4)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
225 A ④ Main Lugs or Main Breaker with 225 A or 100 A Sub-Feed Lugs or Breaker	EHD, FDB, FD, HFD, FDC, EDB, EDS, ED, EDH, EDC Vertical	18	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
400 Amperes						
400 A Main Lugs or Main Breaker	DK, KD, HKD, KDC Vertical	18	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		30	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		42	72 (1828.8)	20 (508.0)	5.75 (146.1)	
		48	72 (1828.8)	20 (508.0)	5.75 (146.1)	
400 A Main Lugs or Main Breaker with 225 A or 100 A Sub-Feed Lugs or Breaker	DK, KD, HKD, KDC Vertical	18	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		30	72 (1828.8)	20 (508.0)	5.75 (146.1)	
		42	72 (1828.8)	20 (508.0)	5.75 (146.1)	
		48	90 (2286.0)	20 (508.0)	5.75 (146.1)	
	EHD, FDB, FD, HFD, FDC, EDB, EDS, ED, EDH, EDC Vertical	Sub-Feed Breakers				

① Smaller panelboard box sizes are available if required. Contact Eaton for application information.

② Add 8 inches (203.2 mm) for TVSS.

③ For horizontal mounted mains (BAB Type), use main lug table, include space in branch section for mains.

④ JD, HJD, JDC is same space requirement as 400 ampere DK, HKD, KDC.

General Description — Pow-R-Line 2a

Pow-R-Line 2a



Pow-R-Line 2a

General Description

Panelboard Ratings

Voltage:

- 240 Vac maximum.
- 480Y/277 Vac maximum.

Note: PRL2a panelboards are suitable for use on 3-phase, 3-wire applications when derived from a 3-phase, 4-wire 480Y/277 Vac service where the neutral is not brought to the panelboard. For 3-phase, 3-wire 480 Vac Delta services use a PRL3a panelboard.

- 250 Vdc maximum.

Main Lugs:

- 100 – 400 amperes.

Main Breakers:

- 100 – 400 amperes.

Branch Breakers:

- 15 – 100 amperes (bolt-on).

Short Circuit Current Ratings (Symmetrical)

- 240 Vac: 65 kA fully rated.
- 240 Vac: 100 – 200 kA series rated.
- 480Y/277 Vac: 14 kA fully rated.
- 480Y/277 Vac: 22 – 150 kA series rated.
- 250 Vdc: 10 kA and 14 kA fully rated.

Service

- 3-phase, 4-wire 208Y/120 V and 240/120 V Delta and 480Y/277 V.
- Single-phase, 3-wire 120/240 V.
- Single-phase, 2-wire 120 V.
- 3-phase, 3-wire 208 and 240 V.
- 2-wire 125 Vdc.
- 2-wire 250 Vdc.

Suitable for service entrance applications when specified.

Mains

For available mains, refer to **Table 22.2-1**.

The GHB main breaker is horizontally mounted, same as branch breakers. All other main breakers are vertically mounted.

Branch Circuits

For available branch devices, refer to **Table 22.2-2**.

Main Lugs Only

The short circuit rating of the MLO assembled panelboard will be fully rated based upon the lowest rated branch device or may be series rated with an approved upstream device.

Main lugs only ampere ratings: 100, 225 and 400.

Main Circuit Breakers

The short circuit rating shown is that of the main breaker only. The short circuit rating of the assembled panelboard is the rating of the lowest fully rated main or branch device or the rating of an approved series rated combination.

Table 22.2-1. Main Circuit Breakers

Breaker Frame (Amperes)	Breaker Type	Interrupting Rating (kA Symmetrical)		
		240 V	480Y/277 V	125/250 Vdc
100	GHB ①	65	14	14
100	EHD	18	14	10
150	FDB	18	14	10
225	FD	65	35	10
225	HFD	100	65	22
225	FDC	200	100	22
225	ED	65	—	—
250	EDH	100	—	—
250	EDC	200	—	—
250	JD	65	35	10
250	HJD	100	65	22
250	JDC	200	100	22
400	DK	65	—	10
400	KD	65	35	10
400	HKD	100	65	22
400	KDC	200	100	22

① At 480 V, use on 480Y/277 V systems only.

Table 22.2-2. Branch Circuit Breakers

Breaker Type	Ampere Rating	Number of Poles	Interrupting Rating (kA Symmetrical)				
			120 V	240 V	277 V	480Y/277 V	125/250 Vdc
GHB ①	15 – 100	1	65	—	14	—	14
GHB ①	15 – 100	2,3	—	65	—	14	14
GHQ	15 – 20	1	65	—	14	—	—
HGHB	15 – 30	1	65	—	25	—	—
GHQRSP ②③	15 – 20	1,2	65	65	14	14	—
GHBS ②	15 – 30	1,2	65	65	14	14	—
GHGFEP	15 – 60	1	—	—	14	—	—

① At 480 V, use on 480Y/277 Vac systems only.

② Solenoid operated breaker.

Series Rated Combinations

Refer to series rating tables beginning on **Page 22.0-11** for the approved series rated combinations available for the branch circuit breakers listed in **Table 22.2-2**.

22.2-2 Panelboards Pow-R-Line 2a

Technical Data — Pow-R-Line 2a

EATON | **Cutler-Hammer**

June 2006
Sheet 0324

22

Technical Data

Bussing

100 – 400 amperes: Tin-plated aluminum is standard, copper is available as an option.

Boxes

Boxes are made from code-gauge galvanized steel.

Blank ends are supplied as standard, knockouts are available upon request.

EZ Trim

Trims are made from code-gauge steel and painted ANSI 61 gray.

All panelboards have door-in-door as standard with multi-point catch and lock, and concealed mounting hardware.

Modifications

Table 22.2-3. Sub-Feed Lugs (Main Lugs Only)

Amperes	Panel Height Addition
100	0 Inches (0 mm)
225	0 Inches (0 mm)

Table 22.2-4. Through-Feed Lugs

Amperes	Information
100	See Table 22.2-6
225	See Table 22.2-6
400	See Table 22.2-6

Table 22.2-5. Sub-Feed Breakers
(One Per Panel)

Ampere Rating	Breaker Type	Interrupting Rating (kA Symmetrical)	
		240 V	480V/277 V
150	FDB	18	14
225	FD	65	35
225	HFD	100	65
225	FDC	200	100
225	ED	65	—
225	EDH	100	—
225	EDC	200	—
250	JD	65	35
250	HJD	100	65
250	JDC	200	100
400	KD	65	35
400	HKD	100	65
400	KDC	200	100

Shunt Trips

Shunt trips are available on breakers. GHB breakers with shunt trips require 3-pole frame.

Ground Bar

Standard bolted in box. Aluminum is standard. Copper is available as an option.

Enclosures

Types 1, 12, 3R, 4/4X.

TVSS

Integrated onto panelboard chassis. For complete product description and available ratings, refer to Section 36.

Box Sizing and Selection

Box size for all Type 1 panelboards are available from Table 22.2-6.

Instructions

- Using description on the required panelboard, select the rating and type of mains required.
- Count total number of branch circuit poles (including spaces) required in the panelboard. Do not count main breaker poles. Convert 2- or 3-pole branch breakers to single-poles. i.e., 3-pole breaker, count as three poles.

Note: For horizontal mounted mains (GHB Type), use main lug table, include space in branch section for mains.

Table 22.2-6. Type 1 Panelboards — Dimensions in Inches (mm)

Ampere Rating of Mains	Main Breaker Type Mounting Position	Maximum Number of Branch Circuits Including Provisions	Box Dimensions ☐☐			
			Height	Width	Depth	
100 A Panelboards						
100 A ☉ Main Lugs or Main Breaker	EHD, FDB, FD, HFD, FDC Vertical	18	36 (914.4)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
100 A ☉ Main Lugs or Main Breaker with 100 A Through-Feed Lugs or Sub-Feed Breaker	EHD, FDB, FD, HFD, FDC Vertical	18	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
225 A Panelboards						
225 A ☉ Main Lugs or Main Breaker	ED, EDH, EDC, FD, HFD, FDC Vertical	18	36 (914.4)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
225 A ☉ Main Lugs or Main Breaker with 225 A or 100 A Through-Feed Lugs or Sub-Feed Breaker	EHD, FDB, FD, HFD, FDC, ED, EDH, EDC Vertical	18	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		30	48 (1219.2)	20 (508.0)	5.75 (146.1)	
		42	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		48	60 (1524.0)	20 (508.0)	5.75 (146.1)	
400 A Panelboards						
400 A Main Lugs or Main Breaker	DK, KD, HKD, KDC Vertical	18	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		30	60 (1524.0)	20 (508.0)	5.75 (146.1)	
		42	72 (1828.8)	20 (508.0)	5.75 (146.1)	
		48	72 (1828.8)	20 (508.0)	5.75 (146.1)	
400 A Main Lugs or Main Breaker with 225 A or 100 A Through-Feed Lugs or Sub-Feed Breaker	DK, KD, HKD, KDC Vertical	Main	18	60 (1524.0)	20 (508.0)	5.75 (146.1)
			30	72 (1828.8)	20 (508.0)	5.75 (146.1)
			42	72 (1828.8)	20 (508.0)	5.75 (146.1)
			48	72 (1828.8)	20 (508.0)	5.75 (146.1)
	EHD, FDB, FD, HFD, FDC, ED, EDH, EDC Vertical	Sub-Feed Breaker	18	90 (2286.0)	20 (508.0)	5.75 (146.1)
			30			
			42			
			48			

① Smaller panelboard box sizes are available if required. Contact Eaton for application information.

② Add 8 inches (203.2 mm) for TVSS.

③ For horizontal mounted mains (GHB Type), use main lug table, include space in branch section for mains.

④ JD, HJD, JDC is same space requirement as 400 ampere DK, HKD, KDC.

For more information visit: www.EatonElectrical.com

CA08104001E

EATON**Cutler-Hammer**June 2006
Sheet 0829**Panelboards
Pow-R-Line 4****22.4-1****General Description — Pow-R-Line 4****Pow-R-Line 4****PRL4B
Circuit Breaker
Panelboard****PRL4F
Fusible
Panelboard****General Description****Panelboard Ratings****Voltage:**

- 240 V, 480 V or 600 Vac maximum.
- 250 Vdc maximum.

Main Lugs:

- 250 – 1200 amperes.

Main Breakers:

- 250 – 1200 amperes.

Main Switches:

- 200 – 1200 amperes.

Branches (Bolt-on):

- Breakers 15 – 1200 amperes.
- Fusible switches
30 – 1200 amperes.

Short Circuit Current Ratings (Symmetrical)

- 240 Vac: 10 – 200 kA fully rated.
- 240 Vac: 22 – 200 kA series rated.
- 480 Vac: 14 – 200 kA fully rated.
- 480 Vac: 22 – 150 kA series rated.
- 250 Vdc: 10 – 22 kA fully rated.

Service

- 3-phase, 4-wire 208Y/120 V,
240/120 V Delta and 480Y/277 V.
- Single-phase, 3-wire 120/240 V.
- Single-phase, 2-wire 120 V.
- 3-phase, 3-wire 120, 240,
480 and 600 V.
- 2-wire 125 Vdc.
- 2-wire 250 Vdc.

Suitable for service entrance
applications when specified.

Bussing

250 – 1200 amperes tin-plated
aluminum is standard, copper is
available as an option. Density rated
bus is also available as an option.

Main Lugs Only

The short circuit rating of the MLO
assembled panelboard will be fully
rated based upon the lowest rated
branch device or may be series rated
with an approved upstream device.

Main lugs only ampere ratings:
250, 400, 600, 800 and 1200.

Main Circuit Breakers

The short circuit rating shown is that
of the main breaker only. The short
circuit rating of the assembled panel-
board is the rating of the lowest fully
rated main or branch device, or the
rating of an approved series rated
combination.

22**Table 22.4-1. Main Circuit Breakers — Type PRL4B**

Breaker Frame Amperes	Breaker Type	Interrupting Rating (kA Symmetrical)			
		240 V	480 V	600 V	250 Vdc
250	JD	65	35	18	10
250	HJD	100	65	25	22
250	JDC	200	100	35	22
250	LCL	200	200	—	—
400	DK	65	—	—	10
400	KD ⓪	65	35	25	10
400	CKD ⓪⓪	65	35	25	10
400	HKD ⓪	100	65	35	22
400	CHKD ⓪⓪	100	65	35	22
400	KDC ⓪	200	100	65	22
400	LCL ⓪	200	200	—	—
400	LA-P	200	200	200	⓪
600	LGE	65	35	18	22
600	LGH	100	65	35	22
600	LD ⓪	65	35	25	22
600	CLD ⓪⓪	65	35	25	22
600	HLD ⓪	100	65	35	25
600	CHLD ⓪⓪	100	65	35	25
600	LDC ⓪	200	100	50	25
600	CLDC ⓪	200	100	50	25
800	MDL ⓪	65	50	25	22
800	CMDL ⓪⓪	65	50	25	22
800	HMDL ⓪	100	65	35	25
800	CHMDL ⓪⓪	100	65	35	25
800	ND ⓪	65	50	25	—
800	CND ⓪⓪	65	50	25	—
800	HND ⓪	100	65	35	—
800	CHND ⓪⓪	100	65	35	—
800	NDC ⓪	200	100	65	—
800	CNDC ⓪⓪	200	100	65	—
800	NB-P	200	200	200	⓪
1200	ND ⓪	65	50	25	—
1200	CND ⓪⓪	65	50	25	—
1200	HND ⓪	100	65	35	—
1200	CHND ⓪⓪	100	65	35	—
1200	NDC ⓪	200	100	65	—
1200	CNDC ⓪	200	100	65	—

⓪ Available with integral ground fault protection.

⓪ 100% rated circuit breaker.

⓪ 100,000 AIC based on NEMA test procedure.

Main Fusible Switches

The short circuit rating shown is that
of the main switch only. The short
circuit rating of the assembled panel-
boards is the rating of the lowest fully
rated main or branch device or the
rating of an approved series rated
combination. (Fuses are not included.)

400 and 600 ampere switches with
shunt trip will be rated 100 kA.

Note: Circuit breaker panelboards are
designated PRL4B. Fusible Switch panel-
boards are designated PRL4F.

Table 22.4-2. Main Fusible Switches

Switch Rating Amperes	Fuse Class	Interrupting Rating (kA Symmetrical)		
		240 V	600 V	250 Vdc
Switches Rated 240 Vac, 250 Vdc				
200	R, T	200	—	10
400	R, T	200	—	10
600	R, T	200	—	—
800	L	200	—	—
1200	L	200	—	—
Switches Rated 600 Vac				
200	R, J, T	200	200	—
400	R, J, T	200	200	—
600	R, J, T	200	200	—
800	L	200	200	—
1200	L	200	200	—

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For more information visit: www.EatonElectrical.com



Cutler-Hammer

June 2006
Sheet 0863

Lighting Control System Pow-R-Command Pow-R-Command 1000

23.2-1

General Description

Pow-R-Command 1000



Pow-R-Command 1000 Panel

General Description

Eaton's Cutler-Hammer Pow-R-Command 1000 is a microprocessor-based programmable lighting control system. The PRC1000 can be used as a stand-alone panelboard or networked as a system.

Components

- Intelligent power switching equipment.
- LCD programming display and keypad.
- Application Specific Controllers (ASCs).
- Software and support.
- Integration components.

Intelligent Power Switching Equipment

Pow-R-Command 1000 Panelboards

Pow-R-Command 1000 Panelboards are offered from 100 through 225 amperes in main lug and main breaker configurations. Available voltages are 120/240, 208Y/120 and 480Y/277, single-phase and 3-phase. The panelboard utilizes both branch mounted standard breakers through 100 amperes, and controllable thermal-magnetic breakers which are controlled by the Pow-R-Command 1000 System Controller. The Pow-R-Command 1000 controllers provide the ability to directly operate up to eight breaker control buses. Such a capability allows a single controller to directly operate up to 168 GHORSP and BABRSP controllable circuit breakers, with individual control and status feedback of each controllable breaker.

The System Controller also includes load override, holiday scheduling, one-shot or event schedules, off warning to tenants by blinking lights, memory loss protection, power failure/brown-out protection, hardware diagnostics, a real-time clock and 16 dry contact switch inputs.

Equipment within the Pow-R-Command 1000 System may be networked. Up to 120 panelboards may be networked over a shielded twisted pair network cable without the need for a personal computer in the system.

The Pow-R-Command 1000 Panelboard is listed UL® 67 for panelboards and UL 916 for energy management equipment.

23

23.2-2 Lighting Control System Pow-R-Command Pow-R-Command 1000

Operational Description

Pow-R-Command 1000



PRC1000 LCD Display

System Description

The PRC1000 system contains networkable intelligence and provides automated switching of branch circuit breakers.

Distributed Intelligence

The system is distributed intelligent and operates as a stand-alone device that can control its own circuits. A personal computer is not required for the system to operate.

Main Network

The Pow-R-Command System is capable of globally communicating over the main RS-485 network with up to 120 controllers over an end-to-end distance of 4,000 feet (1,219 m) using a shielded twisted pair network cable. It is also possible to place all controllers or clusters of controllers onto the facility's Ethernet network.

LCD Display and Keypad

The PRC1000 LCD display and keypad provides local programming, override and diagnostic functions.

Memory Loss Protection

Time schedules, time-of-day clock, day/date, and system configuration parameters are protected from memory loss if there is a power failure. The memory loss protection is rated for 10 years.

Power Failure/Brownout Recovery

When system input power drops below normal, the system will not lose its programmed information. Upon return of normal power, breaker positions scheduled during the power failure period are immediately updated. No operator interaction is required.

Astronomical Real-Time Clock

Time-of-day, day/date, automatic leap year and daylight savings time adjustments are provided as standard.

Control Software

It is possible to program the panel-board directly through its local RS-485 maintenance port with a hand-held programmer or with the lighting management software over a shielded twisted pair cable by way of a central operator's station.

Time Scheduling

Pow-R-Command 1000 supports 75 schedules as local control functions. Any of the 75 local time schedules in a controller can be designated as a back-up schedule to execute only if the master schedules fail or cease execution.

Holiday Scheduling

Pow-R-Command 1000 supports 16 system holidays through the Network Access Device and, additionally, each controller can execute 30 local holiday definitions.

Input to Output Switch Matrix

The input to output switch matrix feature allows any breaker connected to any panel to be controlled by any switch or any group of switches connected to any panel on the same network.

Messages/Alarms

The system will maintain an alarm log. The log will record where the alarm occurred, alarm reason, date and time of the alarm. The log is maintained in non-volatile memory. The alarm log can store up to 300 alarms.

Daylighting Optimization

Daylighting optimization is available using a combination of inputs on the PRC1000 controller or a Switch Override Controller and dimming cable.

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June 2006
Sheet 0864

Application Specific Controllers

Optional Application Specific Controllers expand the PRC1000 System through the network to customize the system to meet the needs of the tenant.

Switch Override Controller (SOC)



Switch Override Controller (SOC)

- Provides the ability to connect and monitor up to 48 additional 2-wire dry contact closures from wall switches, occupancy sensors, photocells, building automation system relay contacts or any remotely mounted device with a dry contact.
- Input connections to the controller are self-powered.
- It is possible to program any input to the switch override controller to control any breaker or group of breakers in the system.
- Inputs are capable of being individually time-schedule enabled for different days of the week.

Telephone Override Controller (TOC)

- Provides a voice prompted method for ON/OFF override control of lighting. It is possible to override an individual breaker or group of breakers ON or OFF during scheduled or nonscheduled hours using any touch-tone analog telephone.
- The Telephone Override Controller allows voice prompted control of lighting circuits for up to 1,000 individual users. It is possible to program any of the 1,000 users to control any breaker or group of breakers in the panelboard or system.



June 2006
Sheet 0865

Lighting Control System Pow-R-Command Pow-R-Command 1000

23.2-3

Technical Data

Technical Data

Panelboard Ratings

- Voltage:
 - 240 Vac
 - 480Y/277 Vac
- Main lugs:
 - 100 through 225 amperes
- Main breakers:
 - 100 through 225 amperes
- Branches:
 - 15 through 100 amperes
 - Controllable from 15 through 30 amperes

Interrupting Capacity (Symmetrical)

- 240 Vac: 65 kA maximum fully rated.
- 240 Vac: 100 kA maximum series rated.
- 480Y/277 Vac

Service

- 3-phase, 4-wire 208Y/120 V, 480Y/277 Vac and 240/120 V Delta.
- Single-phase, 3-wire, 120/240 V.

Mains

For available mains, refer to **Table 23.2-1**.

Branch Circuits

For available branch circuit devices, refer to **Table 23.2-2**.

Main Lugs Only

The short circuit rating of the MLO assembled panelboard will be fully rated based upon the lowest rated branch device or may be series rated with an approved upstream device.

- Main lugs only ampere ratings: 100 and 225.

Main Circuit Breakers

The short circuit rating shown is that of the main breaker only. The short circuit rating of the assembled panelboard is the rating of the lowest fully rated main or branch device or the rating of an approved series rating combination.

Branch Circuit Breakers

The type GHQRSP and BABRSP are the controllable circuit breakers. Controllable breakers are available in 1- and 2-pole styles, from 15 through 30 amperes. Non-controlled circuit breakers can be located within the panelboard chassis.

Table 23.2-2. Branch Circuit Breakers

Breaker Type	Ampere Rating	Number of Poles	Interrupting Rating (kA Symmetrical)				
			120 V	120/240 V	240 V	277 V	480 V
BAB	15 – 70	1	10	—	—	—	—
BAB	15 – 100	2	—	10	—	—	—
BAB	15 – 100	2, 3	—	—	10	—	—
BAB-D ①	15 – 60	1, 2	10	10	—	—	—
BAB-C ②	15 – 30	1, 2	10	10	—	—	—
BABRSP ③	15 – 30	1, 2	10	10	—	—	—
GHQRSP ④	15 – 20	1, 2	—	—	65	14	14
QBGFP ⑤, QBGFEP ⑥	15 – 50 ⑥	1, 2	10	10	—	—	—

① HID (High Intensity Discharge) rated breaker.

② Switching neutral breaker. 1-pole device requires 2-pole space; 2-pole device requires 3-pole space.

③ Controllable breaker.

④ GFCI for 5 mA personnel protection.

⑤ GFP for 30 mA equipment protection.

⑥ 50 ampere devices are available as 2-pole only.

Series Ratings

Eaton has tested the GHQRSP and BABRSP controllable circuit breakers for Series Rated Combinations up to 200 kAIC with breakers or fuses. For a complete listing of available series ratings, see **Section 22** (Panelboards) Series Ratings **Tables 22.0-6** through **22.0-16**.

Table 23.2-1. Main Circuit Breakers

Breaker Type	Frame Ampere Rating	Interrupting Rating (kA Symmetrical)	
		240 V	480Y/277 V
EHD	100	18	14
FDB	150	18	14
FD	225	65	35
HFD	225	100	65
FDC	225	200	100
ED	225	65	—
EDH	225	100	—
EDC	225	200	—
JD	250	65	35
HJD	250	100	65
JDC	250	200	100

23

23.2-4 Lighting Control System Pow-R-Command Pow-R-Command 1000

Layout

23

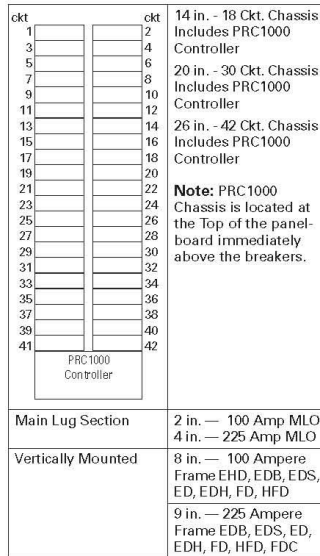


Figure 23.2-1. Pow-R-Command PRC1000 Layout

PRC1000 Panel Layout Instructions

1. Select PRC1000 Panelboard Chassis from **Figure 23.2-1**.
 - a. Determine required mains (lugs or breaker)
 - b. Select appropriate Main Lug
 - c. Select appropriate Main Device
 - d. Select appropriate branch breakers
2. Layout panel as shown in **Figure 23.2-1**. Total "in." determine box height shown in **Table 23.2-3**. (When total "in." units exceeds the number shown, use next size box size.)

Layout Example

1. Panel Description:
 - a. PRC1000, 3-phase 4-wire, 208Y/120 Vac, interrupting rating of 10,000 AIC symmetrical: 225 ampere main lugs only at bottom, surface mounted and the following branch breakers
 - b. 36 – 20 ampere, 1-pole BABRSP
 - c. 6 – 20 ampere, 1-pole BABRSP spaces
2. Layout information from **Figure 23.2-1**.
 - a. PRC1000 with 42-circuit Interior 26 in.
 - b. 225 ampere Main Lugs Section 4 in.
 - c. Total Panelboard Height 30 in.
3. From **Table 23.2-3**:
 - Panel Height: 30 in. 20 in. wide x 5.75 in. deep
 - Box Height: 48 in.
 - Box Catalog Number: YS2048 or EZB2048R
 - Trim Catalog Number: LT2048S or EZT2048S

Table 23.2-3. Box Selection — Dimensions in Inches (mm)

Maximum Panel Height	Box Height, Inches	Catalog Number			
		YS Box	LT Trim	EZ Box	EZ Trim
20-Inch Wide x 5.75-Inch Deep Boxes					
0 – 22.00	36.00	YS2036	LT2036S or F	EZB2036R	EZT2036S or F
23.00 – 28.00	42.00	YS2042	LT2042S or F	EZB2042R	EZT2042S or F
29.00 – 34.00	48.00	YS2048	LT2048S or F	EZB2048R	EZT2048S or F
35.00 – 46.00	60.00	YS2060	LT2060S or F	EZB2060R	EZT2060S or F
47.00 – 58.00	72.00	YS2072	LT2072S or F	EZB2072R	EZT2072S or F

Cabinets

Trims are code gauge steel, ANSI 61 light gray painted finish. Boxes are code gauge galvanized steel without knockout. Standard size is 20 in. wide x 5.75 in. deep.

Top and Bottom Gutters

6.38 in.

Minimum Side Gutters

4 in. (minimum) on 20 in. wide box size.

41.3-16 Uninterruptible Power Supplies — Powerware 3-Phase Units

Powerware 9390

Powerware 9390 Uninterruptible Power System



Powerware 9390

Description

The Powerware 9390 Uninterruptible Power System (UPS) is a double-conversion UPS that resolves all utility power problems and supplies clean, continuous, uninterruptible power to connected equipment. Whether you're selecting a UPS for a branch office, manufacturing floor, medical facility, or a large data center, there's a Powerware 9390 model that delivers just the right combination of performance and price for your needs.

Features and Benefits

- Provides unmatched power performance for efficiency, input current harmonic distortion (THD), and power factor.
- Scalable for capacity and redundancy to meet present and future power needs.
- Provides peace-of-mind that your batteries will be ready when you need them with innovative three-stage charging, battery health-checks, optional temperature-compensated charging, and remote monitoring.
- Lowers installation time and costs with small footprint and the flexibility to install against walls, using top- or bottom-entry cabling.
- Provides a one-year, limited factory warranty* on parts and labor, Start-up service, one year of remote monitoring, on-site preventive maintenance, and optional service plans.

Advanced Design Delivers Unequaled Power Performance

The innovative design of the Powerware 9390 delivers the industry's best performance combination of efficiency, input current distortion and power factor.

The Powerware 9390 operates at a high efficiency of up to 94 percent, reducing utility costs and extending battery run times. Higher system efficiency produces cooler operating conditions, which reduces facility air conditioning cost, extends the life of UPS components, and increases overall reliability, availability and performance.

A new input circuit design keeps input current THD low and input power factor near unity without compromising overall efficiency. As a result, the Powerware 9390 allows maximum transfer of power between power source and protected load and is exceptionally compatible with multiple power sources, especially auxiliary generators.

On the output side, the ultra-high speed switching Pulse Width Modulation (PWM) inverter enables the Powerware 9390 to provide its full rated power capability to the load whether the load power factor is 0.9 lagging, unity or 0.9 leading.

Double-Conversion Design Offers the Highest Protection Possible

Unlike some other commercially available UPS technologies, the double-conversion design completely isolates output power from all input power anomalies and delivers 100-percent conditioned, perfect sine-wave output — regulating both voltage and frequency.



Powerware 9390 View Panel

Even when presented with the most severe power problems, power output remains stable. Output voltage THD is held within two percent of nominal specification for linear loads, within five percent for non-linear loads — making the Powerware 9390 ideal for supporting equipment that is sensitive to a distorted voltage input as a result of harmonic loads. In the event of a utility power failure, there is no delay transferring to backup power.

UPS Control Innovations Optimize Battery Performance and Service Life

Eaton's ABM (Advanced Battery Management) technology uses a unique three-stage charging technique that significantly extends battery service life

Eaton | Cutler-Hammer

June 2006
Sheet 1738

and optimizes recharge time, compared to traditional trickle charging. An integrated battery management system tests and monitors battery health and remaining lifetime, and provides advance notification to guide preventive maintenance. The temperature-compensated charger monitors temperature changes and adjusts the charge rate accordingly to properly charge the battery and greatly extend battery life.

A variable battery bus accommodates 384 V to 480 V configurations, so the battery capacity can be matched to your exact run time requirements — either a specific run time, an extension to existing battery run time, or legacy battery installations.

With remote monitoring of the UPS and battery system, Eaton is there with you — able to respond to alarms and real-time battery data to avert potential battery problems.

Scalable Architecture Meets Your Current and Future Load Requirements

The Powerware 9390 UPS supports loads from 40 kVA to 160 kVA to deliver power protection for small branch offices to large corporate data centers and communication networks.

Up to four equivalent UPS modules can be paralleled for additional capacity or redundancy, without having to utilize a central paralleling cabinet. Up to eight UPS modules can be paralleled by utilizing a module tie cabinet. In all paralleling configurations, each UPS module operates independently yet is completely synchronized with the others. Parallel UPS modules can provide N+1, N+2, or greater redundancy.

Flexible Installation Options Expedite Deployment and Save Valuable Space

The Powerware 9390 UPS offers the smallest footprint of any UPS in its class — 35 to 50 percent smaller than competitive units. Cabling can enter the UPS from either the top or bottom of the cabinet to provide easier and flexible installation. The Powerware 9390 provides front panel access for all services and operation, increasing serviceability and reducing Mean Time to Repair (MTTR). And since the compact Powerware 9390 cabinet can be installed against back and side walls, you have more location options, installation is fast and easy, deployment cost is lower, and you save valuable data center space for future expansion.



Cutler-Hammer

June 2006
Sheet 1739

Uninterruptible Power Supplies — Powerware 3-Phase Units

41.3-17

Powerware 9390

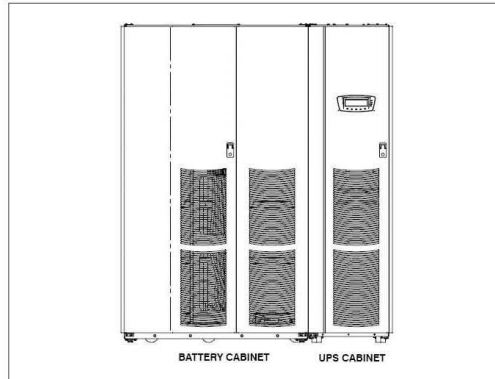


Figure 41.3-13. Powerware 9390 40/50/60/80 kVA UPS with Battery

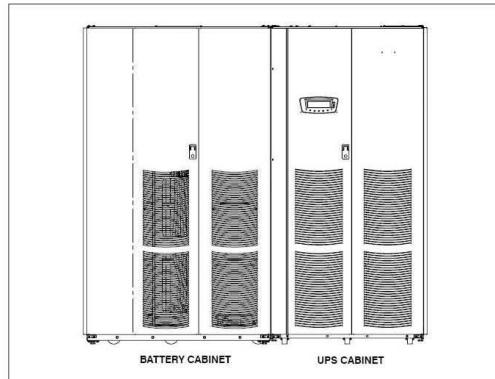


Figure 41.3-14. Powerware 9390 40/50/60/80 kVA UPS with Battery Cabinet

Table 41.3-16. Powerware 9390 (40 – 80 kVA) UPS Weights

Voltage		Weight — kg (lb.)		
Input	Output	Shipping	Installed	Point Loading
40/40				
208/220	208/220	263 (580)	241 (530)	4 at 60.3 (133)
480	480	231 (508)	208 (458)	4 at 52.2 (115)
80/40				
208/220	208/220	313 (690)	290 (640)	4 at 72.5 (160)
480	480	271 (618)	258 (568)	4 at 64.5 (142)
80/50				
208/220	208/220	313 (690)	290 (640)	4 at 72.5 (160)
480	480	271 (618)	258 (568)	4 at 64.5 (142)
80/60				
208/220	208/220	313 (690)	290 (640)	4 at 72.5 (160)
480	480	271 (618)	258 (568)	4 at 64.5 (142)
80/80				
208/220	208/220	313 (690)	290 (640)	4 at 72.5 (160)
480	480	271 (618)	258 (568)	4 at 64.5 (142)

Table 41.3-17. Powerware 9390 (100 – 160 kVA) UPS Cabinet Weights

Voltage		Weight— kg (lb.)		
Input	Output	Shipping	Installed	Point Loading
120/100				
208/220	208/220	531 (1170)	504 (1110)	6 at 84 (185)
480	480	467 (1030)	440 (970)	6 at 73 (162)
120/120				
208/220	208/220	531 (1170)	504 (1110)	6 at 84 (185)
480	480	467 (1030)	440 (970)	6 at 73 (162)
160/100				
208/220	208/220	581 (1280)	553 (1220)	6 at 92 (204)
480	480	517 (1140)	490 (1080)	6 at 82 (180)
160/120				
208/220	208/220	581 (1280)	553 (1220)	6 at 92 (204)
480	480	517 (1140)	490 (1080)	6 at 82 (180)
160/160				
208/220	208/220	581 (1280)	553 (1220)	6 at 92 (204)
480	480	517 (1140)	490 (1080)	6 at 82 (180)

Table 41.3-18. Powerware 9390 Air Conditioning or Ventilation Requirements During Full Load Operation

Ratings	Voltage		Heat Rejection BTU/hr ≠ 1000/hr (kg-cal/hr)
	Input	Output	
40 – 80 kVA ①			
40 kVA	208/220	208/220	11.8 (2.98)
	480	480	10.9 (2.76)
50 kVA	208/220	208/220	14.8 (3.73)
	480	480	13.7 (3.45)
60 kVA	208/220	208/220	17.7 (4.47)
	480	480	16.4 (4.14)
80 kVA	208/220	208/220	23.6 (5.96)
	480	480	21.9 (5.52)
100 – 160 kVA ②			
100 kVA	208/220	208/220	29.6 (7.45)
	480	480	27.4 (6.90)
120 kVA	208/220	208/220	35.5 (8.94)
	480	480	32.8 (8.28)
160 kVA	208/220	208/220	47.3 (11.9)
	480	480	43.8 (11.0)

① Ventilation required for cooling air exhaust: approximately 4.72 liter/sec (1000 cfm).

② Ventilation required for cooling air exhaust: approximately 9.44 liter/sec (2000 cfm).

41

41.3-18 Uninterruptible Power Supplies — Powerware 3-Phase Units

Powerware 9390

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June 2006
Sheet 1740

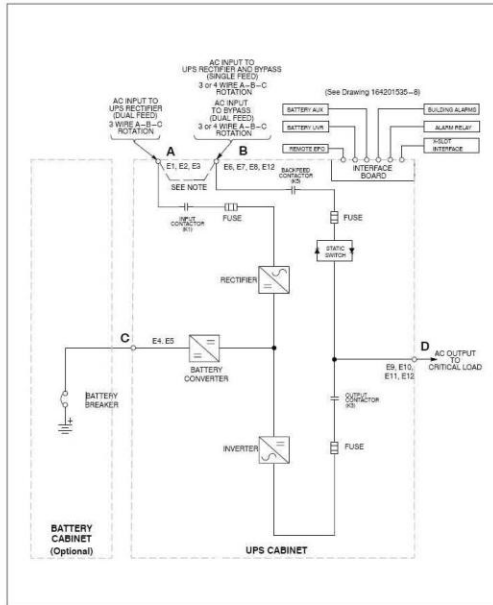


Figure 41.3-15. 9390 UPS with Battery — Single or Dual Feed

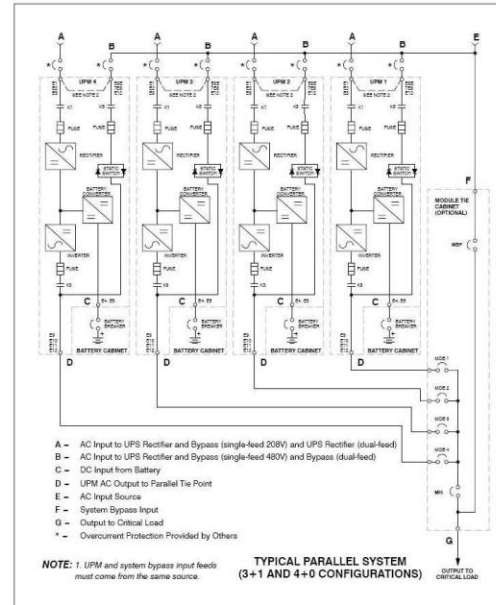


Figure 41.3-17. 9390 UPS Four-Module Parallel System with Remote Tie Cabinet

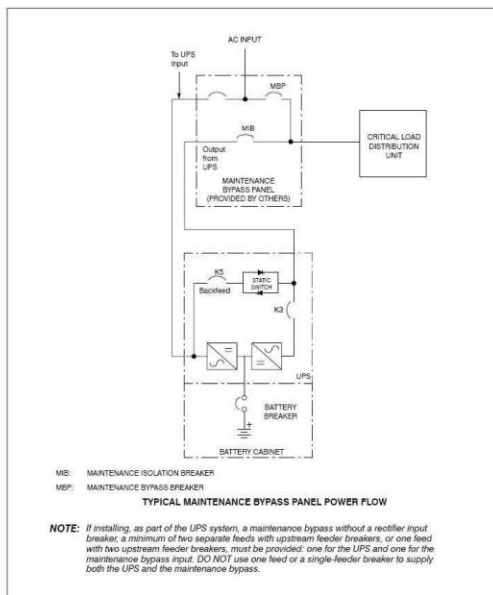


Figure 41.3-16. 9390 UPS with External Maintenance Bypass

41

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Uninterruptible Power Supplies — Powerware 3-Phase Units

41.3-19

Powerware 9390

Read and understand the following notes while planning and performing the installation:

1. Refer to national and local electrical codes for acceptable external wiring practices.
2. Material and labor for external wiring requirements are to be provided by designated personnel.
3. For external wiring, use 90° C copper wire. See the appropriate information in the tables. Wire sizes are based on using the specified breakers.
4. Wire ampacities are chosen from Table 310-16 of the NEC. Wire is 90°C specification.
5. If installing, as part of the UPS system, a maintenance bypass without a rectifier input breaker, a minimum of two separate feeds with upstream feeder breakers, or one feed with two upstream feeder breakers, must be provided: one for the UPS and one for the maintenance bypass input. DO NOT use one feed or a single feeder breaker to supply both the UPS and the maintenance bypass.
6. The bypass feed into this equipment uses three or four wires. The rectifier feed into this equipment uses three wires. The phases must be symmetrical about ground (from a Wye source) for proper equipment operation.
7. If the load requires a neutral, a bypass source neutral must be provided. If the load does not require a neutral and there is no neutral conductor connected at the bypass input, a neutral to ground bonding jumper must be installed. DO NOT install both a source neutral and a bonding jumper. See tables for neutral bonding jumper wire sizes. Bonding jumper must be copper wire.
8. The UPS cabinet is shipped with a debris shield covering the ventilation grill on top of the unit. Do not remove the debris shield until installation is complete. However, remove the shield before operating the UPS. Once the debris shield is removed, do not place objects on the ventilation grill.
9. Refer to the UPS manual for installation instructions.
10. Terminals are UL and CSA rated at 90°C. Refer to the tables for power cable terminations and conduit requirements.

Note: Callout letters A, B, C and D map to (9390-7).

Table 41.3-19. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-40/40 and 9390-80/40

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	40 36	40 36
Input and Bypass Input	Volts	208/220	480
Output	Volts	208/220	480

A — AC Input to UPS Rectifier (0.98 min. pF)

Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	125	55
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2/0 (1)	4 (1)

B — AC Input to UPS Bypass

Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	111/105	48
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2/0 (1)	4 (1)

C — DC Input from Battery to UPS

(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 101	432 – 480 101
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	1/0 (1)	1/0 (1)

D — AC Output to Critical Load

Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	111/105	48
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2/0 (1)	4 (1)

Neutral Bonding Jumper

Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4 (1)	6 (1)
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Table 41.3-20. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-80/50

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	50 45	50 45
Input and Bypass Input	Volts	208/220	480
Output	Volts	208/220	480

A — AC Input to UPS Rectifier (0.98 min. pF)

Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	155	67
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4/0 (1)	2 (1)

B — AC Input to UPS Bypass

Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	139/131	60
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4/0 (1)	2 (1)

C — DC Input from Battery to UPS

(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 126	432 – 480 126
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	1/0 (1)	1/0 (1)

D — AC Output to Critical Load

Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	139/131	60
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4/0 (1)	2 (1)

Neutral Bonding Jumper

Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2 (1)	6 (1)
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41

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41.3-20 Uninterruptible Power Supplies — Powerware 3-Phase Units

Powerware 9390

Eaton | Cutler-Hammer

June 2006
Sheet 1742

Table 41.3-21. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-80/60

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	60 54	60 54
Input and Bypass Input	Volts	208/220	480
Output	Volts	208/220	480
A — AC Input to UPS Rectifier (0.98 min. pF)			
Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	185	80
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	250 (1)	1 (1)
B — AC Input to UPS Bypass			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	167/158	72
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	250 (1)	1 (1)
C — DC Input from Battery to UPS			
(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 151	432 – 480 151
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	2/0 (1)	2/0 (1)
D — AC Output to Critical Load			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	167/158	72
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	250 (1)	1 (1)
Neutral Bonding Jumper			
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2 (1)	6 (1)

Table 41.3-22. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-80/80

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	80 72	80 72
Input and Bypass Input	Volts	208/220	480
Output	Volts	208/220	480
A — AC Input to UPS Rectifier (0.98 min. pF)			
Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	240	105
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2/0 (1)	1/0 (1)
B — AC Input to UPS Bypass			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	222/210	96
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2/0 (2)	1/0 (1)
C — DC Input from Battery to UPS			
(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 203	432 – 480 203
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	3/0 (2)	3/0 (1)
D — AC Output to Critical Load			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	222/210	96
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	2/0 (2)	1/0 (1)
Neutral Bonding Jumper			
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	1/0 (1)	6 (1)

Table 41.3-23. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-120/100 and 9390-160/100

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	100 90	100 90
Input and Bypass Input	Volts	208/220	480
Output	Volts	208/220	480
A — AC Input to UPS Rectifier (0.98 min. pF)			
Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	300	130
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	3/0 (2)	4/0 (1)
B — AC Input to UPS Bypass			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	278/262	120
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	3/0 (2)	4/0 (1)
C — DC Input from Battery to UPS			
(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 252	432 – 480 252
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	2/0 (2)	2/0 (2)
D — AC Output to Critical Load			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	278/262	120
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	3/0 (2)	4/0 (1)
Neutral Bonding Jumper			
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	1/0 (1)	2 (1)

Table 41.3-24. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-120/120 and 9390-160/120

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	120 108	120 108
Input and Bypass Input	Volts	208/220	480
Output	Volts	208/220	480
A — AC Input to UPS Rectifier (0.98 min. pF)			
Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	360	160
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4/0 (2)	4/0 (1)
B — AC Input to UPS Bypass			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	333/315	120
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4/0 (2)	4/0 (1)
C — DC Input from Battery to UPS			
(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 302	432 – 480 302
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	3/0 (2)	3/0 (2)
D — AC Output to Critical Load			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	333/315	120
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	4/0 (2)	4/0 (1)
Neutral Bonding Jumper			
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	1/0 (1)	2 (1)

41

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CA08104001E



Cutler-Hammer

June 2006
Sheet 1743

Uninterruptible Power Supplies — Powerware 3-Phase Units

41.3-21

Powerware 9390

Table 41.3-25. Input/Output Ratings and External Wiring Requirements for the Powerware 9390-160/160

Description	Units	Rating 50/60 Hz	
Basic Unit Rating at 0.9 lagging pF load	kVA kW	160 144	160 144
Input and Bypass Input Output	Volts	208/220 208/220	480 480
A — AC Input to UPS Rectifier (0.98 min. pF)			
Full Load Current plus Battery Recharge Current (3) Phases, (1) Ground	Amps	480	210
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	400 (2)	1/0 (2)
B — AC Input to UPS Bypass			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	444/420	192
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	400 (2)	1/0 (2)
C — DC Input from Battery to UPS			
(1) Positive, (1) Negative	Vdc Amps at (2.0 V/cell)	384 – 480 403	432 – 480 403
Minimum Conductor Size Number per Pole	AWG or kcmil (each)	250 (2)	250 (2)
D — AC Output to Critical Load			
Full Load Current — (3) Phases, (1) Neutral-if required, (1) Ground	Amps	444/420	192
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	400 (2)	1/0 (2)
Neutral Bonding Jumper			
Minimum Conductor Size Number per Phase	AWG or kcmil (each)	1/0 (2)	2 (2)

Table 41.3-26. UPS Cabinet Power Cable Terminations for the Powerware 9390-40/40, 9390-80/40, 9390-80/50, 9390-80/60, and 9390-80/80 (208 V/220 V Input and 208 V/220 V Output)

Terminal	Function	Size of Pressure Termination	Tightening Torque Nm (lb. in)	Screw Type
AC Input to UPS Rectifier and Bypass (Single Input)				
E6	Phase A	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E7	Phase B	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E8	Phase C	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
AC Input to UPS Rectifier (Dual Input)				
E1	Phase A	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E2	Phase B	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E3	Phase C	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
AC Input to Bypass (Dual Input)				
E6	Phase A	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E7	Phase B	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E8	Phase C	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
Single-Feed Jumper from Rectifier Input Terminals to Bypass Input Terminals				
—	Phase A	N/A	22.6 (200)	M10 Hex Bolt
—	Phase B	N/A	22.6 (200)	M10 Hex Bolt
—	Phase C	N/A	22.6 (200)	M10 Hex Bolt
AC Output to Critical Load				
E9	Phase A	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E10	Phase B	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
E11	Phase C	2 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
DC Input from Battery to UPS				
E4	Positive	1 - #6-350 kcmil	31.1 (275)	5/16 in. Hex
E5	Negative	1 - #6-350 kcmil	31.1 (275)	5/16 in. Hex
Input and Output Neutral				
E12	Neutral	8 - #6-250 kcmil	42.4 (375)	5/16 in. Hex
Customer Ground				
Ground	Ground	8 - #14-1/0	5.6 (50)	Slotted

41.3-22 Uninterruptible Power Supplies — Powerware 3-Phase Units

Powerware 9390

Eaton | Cutler-Hammer

June 2006
Sheet 1744

Table 41.3-27. UPS Cabinet Power Cable Terminations for the Powerware 9390-120/100, 9390-120/120, 9390-160/100, 9390-160/120 and 9390-160/160 (208 V/220 V Input and 208 V/220 V Output)

Terminal	Function	Size of Pressure Termination	Tightening Torque Nm (lb. in)	Screw Type
AC Input to UPS Rectifier and Bypass (Single Input)				
E1	Phase A	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
E2	Phase B	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
E3	Phase C	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
AC Input to UPS Rectifier (Dual Input)				
E1	Phase A	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
E2	Phase B	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
E3	Phase C	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
AC Input to Bypass (Dual Input)				
E6	Phase A	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
E7	Phase B	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
E8	Phase C	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
Single-Feed to Dual-Feed Wire Transfer from Rectifier Input Terminals to Bypass Input Terminals				
Rectifier	Phase A	N/A	12.5 (110)	M8 Hex Bolt
Bypass	Phase A	N/A	12.5 (110)	M8 Hex Bolt
Rectifier	Phase B	N/A	12.5 (110)	M8 Hex Bolt
Bypass	Phase B	N/A	12.5 (110)	M8 Hex Bolt
Rectifier	Phase C	N/A	12.5 (110)	M8 Hex Bolt
Bypass	Phase C	N/A	12.5 (110)	M8 Hex Bolt
AC Output to Critical Load				
E9	Phase A	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
E10	Phase B	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
E11	Phase C	2 - 2/0-500 kcmil	31.1 (275)	4 mm Hex
DC Input from Battery to UPS				
E4	Positive	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
E5	Negative	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
Input and Output Neutral				
E12	Neutral	8 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
Customer Ground				
Ground	Ground	8 - #14-1/0	5.6 (50)	Slotted

Table 41.3-28. UPS Cabinet Power Cable Terminations for the Powerware 9390-40/40, 9390-80/40, 9390-80/50, 9390-80/60, and 9390-80/80 (480 V Input and 480 V Output)

Terminal	Function	Size of Pressure Termination	Tightening Torque Nm (lb. in)	Screw Type
AC Input to UPS Rectifier and Bypass (Single Input)				
E6	Phase A	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E7	Phase B	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E8	Phase C	1 - #14-2/0	13.5 (120)	3/16 in. Hex
AC Input to UPS Rectifier (Dual Input)				
E1	Phase A	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E2	Phase B	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E3	Phase C	1 - #14-2/0	13.5 (120)	3/16 in. Hex
AC Input to Bypass (Dual Input)				
E6	Phase A	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E7	Phase B	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E8	Phase C	1 - #14-2/0	13.5 (120)	3/16 in. Hex
Single-Feed to Dual-Feed Wire Transfer from Rectifier Input Terminals to Bypass Input Terminals				
—	Phase A	N/A	5.6 (50)	1/4-20 Hex Nut
—	Phase B	N/A	5.6 (50)	1/4-20 Hex Nut
—	Phase C	N/A	5.6 (50)	1/4-20 Hex Nut
AC Output to Critical Load				
E9	Phase A	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E10	Phase B	1 - #14-2/0	13.5 (120)	3/16 in. Hex
E11	Phase C	1 - #14-2/0	13.5 (120)	3/16 in. Hex
DC Input from Battery to UPS				
E4	Positive	1 - #6-350 kcmil	31.1 (275)	5/16 in. Hex
E5	Negative	1 - #6-350 kcmil	31.1 (275)	5/16 in. Hex
Input and Output Neutral				
E12	Neutral	4 - #14-1/0	5.6 (50)	Slotted
Customer Ground				
Ground	Ground	8 - #14-1/0	5.6 (50)	Slotted



Cutler-Hammer

June 2006
Sheet 1745

Uninterruptible Power Supplies — Powerware 3-Phase Units

41.3-23

Powerware 9390

**Table 41.3-29. UPS Cabinet Power Cable Terminations
for the Powerware 9390-120/100, 9390-120/120, 9390-160/100,
9390-160/120 and 9390-160/160 (480 V Input and 480 V Output)**

Terminal	Function	Size of Pressure Termination	Tightening Torque Nm (lb. in)	Screw Type
AC Input to UPS Rectifier and Bypass (Single Input)				
E6	Phase A	2 - #6-250	42.4 (375)	5/16 in. Hex
E7	Phase B	2 - #6-250	42.4 (375)	5/16 in. Hex
E8	Phase C	2 - #6-250	42.4 (375)	5/16 in. Hex
AC Input to UPS Rectifier (Dual Input)				
E1	Phase A	2 - #6-250	42.4 (375)	5/16 in. Hex
E2	Phase B	2 - #6-250	42.4 (375)	5/16 in. Hex
E3	Phase C	2 - #6-250	42.4 (375)	5/16 in. Hex
AC Input to Bypass (Dual Input)				
E6	Phase A	2 - #6-250	42.4 (375)	5/16 in. Hex
E7	Phase B	2 - #6-250	42.4 (375)	5/16 in. Hex
E8	Phase C	2 - #6-250	42.4 (375)	5/16 in. Hex
Single-Feed to Jumper Bus from Rectifier Input Terminals to Bypass Input Terminals				
Rectifier	Phase A	N/A	12.5 (110)	M8 Hex Bolt
Bypass	Phase A	N/A	22.6 (200)	M10 Hex Bolt
Rectifier	Phase B	N/A	12.5 (110)	M8 Hex Bolt
Bypass	Phase B	N/A	22.6 (200)	M10 Hex Bolt
Rectifier	Phase C	N/A	12.5 (110)	M8 Hex Bolt
Bypass	Phase C	N/A	22.6 (200)	M10 Hex Bolt
AC Output to Critical Load				
E9	Phase A	2 - #6-250	42.4 (375)	5/16 in. Hex
E10	Phase B	2 - #6-250	42.4 (375)	5/16 in. Hex
E11	Phase C	2 - #6-250	42.4 (375)	5/16 in. Hex
DC Input from Battery to UPS				
E4	Positive	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
E5	Negative	2 - #2-600 kcmil	56.5 (500)	1/2 in. Hex
Input and Output Neutral				
E12	Neutral	8 - #6-250 kcmil	42.4 (375)	1/2 in. Hex
Customer Ground				
Ground	Ground	8 - #14-1/0	5.6 (50)	Slotted

41.3-24 Uninterruptible Power Supplies — Powerware 3-Phase Units

Powerware 9390

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June 2006
Sheet 1746

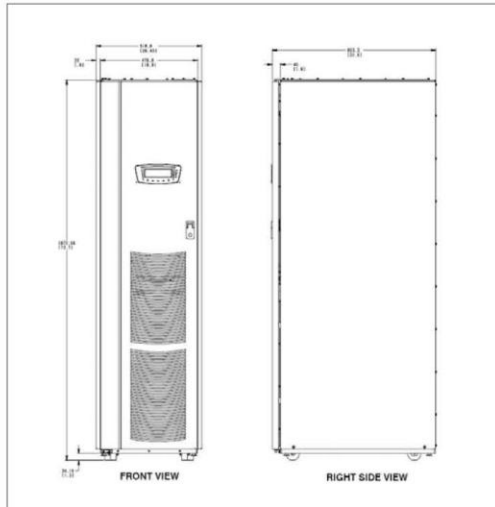


Figure 41.3-18. 9390 (40 to 80 kVA) UPS Dimensions

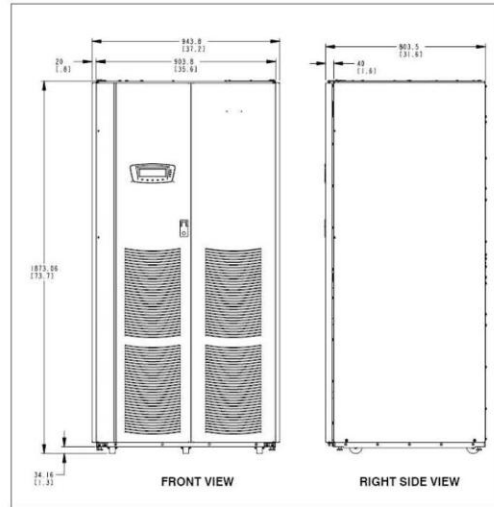


Figure 41.3-20. 9390 (100 to 160 kVA) UPS Dimensions

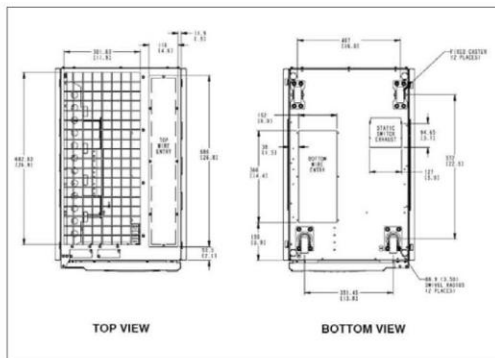


Figure 41.3-19. 9390 (40 to 80 kVA) UPS Dimensions

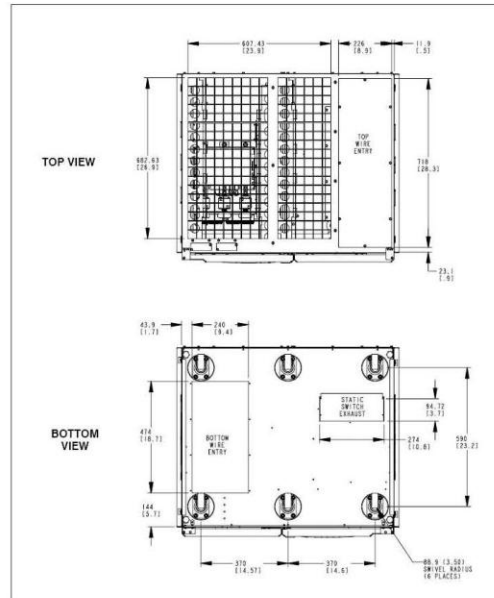


Figure 41.3-21. 9390 (100 to 160 kVA) UPS Dimensions

EATON
June 2006
Sheet 1747

Cutler-Hammer

**Uninterruptible Power Supplies — Powerware
3-Phase Units**

41.3-25

Powerware 9390

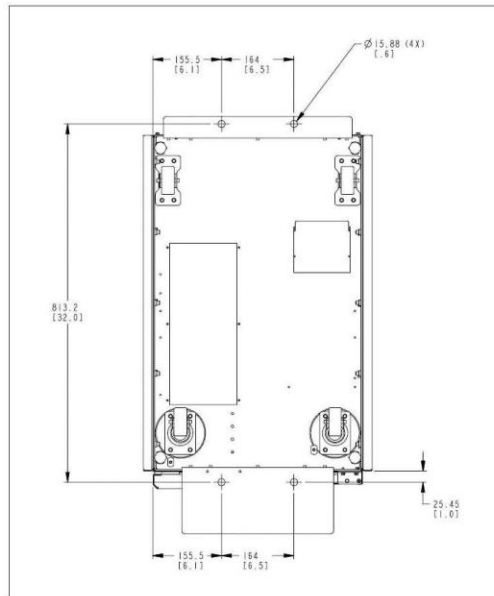


Figure 41.3-22. 9390 (40 to 80 kVA) UPS Floor Mounting Dimensions

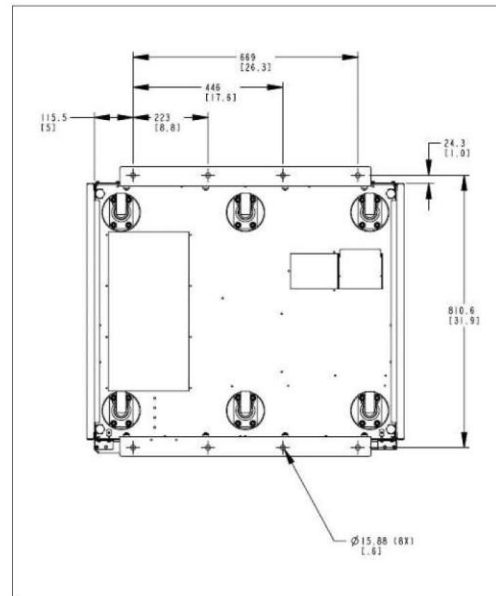


Figure 41.3-23. 9390 (100 to 160 kVA) UPS Floor Mounting Dimensions

36.1-18 Surge Protection (TVSS) & Power Conditioning Products Power Conditioning Products

SRT

EATON | Cutler-Hammer

June 2006
Sheet 1618

Sag Correction Using the Sag Ride Through



Sag Ride Through

The Cutler-Hammer Sag Ride Through (SRT) Power Conditioner prevents expensive, electrical downtime. It is a state-of-the-art solution to today's power conditioning challenges.

The Sag Ride Through (SRT) is a high performance, inverter-based voltage conditioning device developed to provide protection to sensitive loads against commonly occurring voltage sags.

The SRT monitors the incoming supply voltage and when it deviates from the nominal voltage level, the SRT achieves voltage conditioning by injecting the appropriate correction voltage in series with the power supply. The SRT provides an extremely fast reaction time and subcycle response to sag events that would otherwise cause loads to drop out.

The SRT is designed for low voltage systems (600 – 208, 3-phase) and is also offered in medium voltage applications from 25 kVA – 6 MVA. Installation is simple and the SRT provides customers with a new solution to improve productivity and reduce downtime for sag-related problems.

The SRT monitors the incoming supply voltage and when it deviates from the nominal voltage level, the SRT inserts an appropriate compensating voltage using the IGBT inverter and series injection transformer. Energy is sourced from the supply during this time. This regulates the load voltage to its nominal value, thus eliminating voltage disturbances from the utility supply affecting the load. See Figure 36.1-17.

Continuous SAG Regulation

The Sag Ride Through is an active voltage conditioner. This means it will constantly respond to voltage sags in the -10% range with a regulated output in the $\pm 1\%$ range. The SRT can be applied to the main service entrance, at branch locations or in front critical loads. The Cutler-Hammer SRT provides an outstanding return on investment. It delivers operation productivity

that is just not possible with traditional tap switching or ferroresonant technologies. The SRT consists of a voltage source inverter, bypass circuit and an injection transformer connected in series between the incoming utility supply and the load (see Figure 36.1-17). For the standard sag correcting SRT model, the injection transformer consists of a boost component.

Industries and Applications Affected by Sags

Key Industries

- Semi-conductor manufacturers.
- Communications.
- Steel mills.
- Petroleum and chemical processing.
- Health care.
- Paper mills.
- Automotives.
- Textile.
- Printing.
- Plastics.
- Other manufacturing.

Equipment or Processes

- Manufacturing process controllers.
- Variable speed drives.
- Robotics.
- Motor conductor.
- Telephone systems.
- HID lighting.
- HVAC controls.
- Medical equipment.
- Computers.

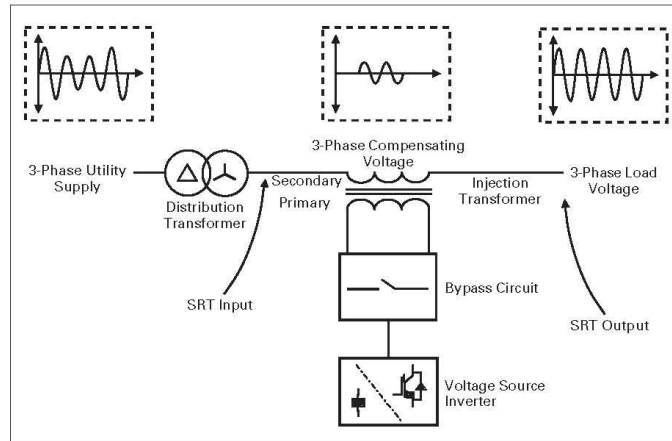


Figure 36.1-17. Block Diagram of the SRT Active Voltage Conditioner

Note: Fan cooling if it is in normal operating mode.

36



Cutler-Hammer

June 2006
Sheet 1619

Surge Protection (TVSS) & Power Conditioning Products 36.1-19 Power Conditioning Products

SRT

Table 36.1-13. SRT Features and Specifications

Features	Specifications
Load Capacity	
Capacity (kVA)	25 kVA – 6 MVA (as specified per model)
Displacement Power Factor of Connected Load	0 – 1, leading or lagging
Crest Factor for Rated kVA	1.63 at 100% of rated load for continuous operation (including up to 10% voltage correction)
Overload – 30 Seconds	150% with up to 10% of voltage correction
Input Supply	
Nominal Supply Voltage	208/480/600 V, 60 Hz 3-phase, 3-wire plus ground (higher system voltages supplied to requirement up to 36 kV)
Maximum Supply Voltage	110% of nominal supply voltage
Minimum 3-Phase Supply Voltage	
– Running	50% of nominal supply voltage
– Starting ①	75% of nominal supply voltage
Minimum Single-Phase-to-Ground Supply Voltage ②	
– Running	25% of nominal supply voltage
– Starting ①	63% of nominal supply voltage
Efficiency of System	98 – 99%
Output Supply	
Nominal Voltage (V)	208/480/600 V, 60 Hz; 3-phase, 3-wire plus ground (higher system voltages supplied to requirement up to 36 kV)
3-Phase Balanced Correction	+30% for at least 30 sec. for 100% correction
Single-Phase-to-Ground Correction ②	+45% for at least 30 sec.; +10% continuous 3-phase correction (all models). Consult factory for specialist correction requirements.
Voltage Regulation	±1% up to 10% continuous 3-phase correction ±2.5% at 30% 3-phase correction
Response (to Sag Event)	Initial sag correction applied within 1 ms, remainder over the next cycle
Bypass	
Nominal Power	SRT rating (kVA)
Maximum Overload Capacity (in Bypass):	
– For 10 Minutes (%)	125
– For 1 Minute (%)	150
– For 600 Milliseconds (%)	700
– For 100 Milliseconds (%)	1000
Transfer Time ③	
– Inverter to Bypass (ms)	< 0.5
– Bypass to Inverter (ms)	< 40 – 750
Environmental	
Operating Temperature	0 – 40°C; 50°C maximum with 20% load derating
Cooling	Forced ventilation
Capacity Derating with Elevation	-1.2% every 100 m above 1000 m
Humidity	< 95%, non-condensing
Warranty	1 year

① If SRT has tripped (off-line) due to below threshold input voltages, it cannot be restarted until the system voltage is at least this % of the nominal.

② Single-phase-to-ground fault occurring on the utility side of a delta-wye distribution transformer.

③ The SRT provides continuous correction and only transitions to and from bypass when manually starting and stopping or under fault or overload conditions. The transition from bypass to inverter takes up to 750 ms. The autoresettable bypass mode of operation includes an additional 5-second delay, allowing time for the fault to clear.

36

CA08104001E

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36.1-20 Surge Protection (TVSS) & Power Conditioning Products

EATON

Cutler-Hammer

June 2006
Sheet 1620

SRT

Table 36.1-14. SRT Controller Cabinet Dimensions

Inverter Frame Size	Load Capacity (kVA)		Controller Cabinet Dimensions H x W x D Inches (mm)	Controller Weight Lbs. (kg)	Controller Dissipation (Worst Case)		Airflow m ³ /min
	380/400 V 50/60 Hz	208 ①/480/600 V 60 Hz			%	kW	
1S	20	25	35.43 x 23.62 x 27.56 (900 x 600 x 700)	551 (250)	1.8	0.5	2
2S	40	50	35.43 x 23.62 x 27.56 (900 x 600 x 700)	727 (330)	1.8	0.9	2
3S	60	75	35.43 x 23.62 x 27.56 (900 x 600 x 700)	881 (400)	1.8	1.4	2
2M	140	175	84.84 x 31.50 x 31.69 (2155 x 800 x 805)	1674 (760)	1.8	3.2	4
3M	200	250	84.84 x 31.50 x 31.69 (2155 x 800 x 805)	2070 (940)	1.8	4.5	6
1L	300	350	84.84 x 31.50 x 31.69 (2155 x 800 x 805)	1542 (700)	0.8	2.8	6
2K	400	500	84.84 x 55.12 x 31.69 (2155 x 1400 x 805)	1982 (900)	0.8	4.0	12
2L	500	650	84.84 x 55.12 x 31.69 (2155 x 1400 x 805)	2093 (950)	0.8	5.2	12
3L	750	1000	84.84 x 63.00 x 31.69 (2155 x 1600 x 805)	2423 (1100)	0.8	8.0	18
4L	1000	1250	84.84 x 78.74 x 31.69 (2155 x 2000 x 805)	2753 (1250)	0.8	10.0	24
5L	1250	1500	84.84 x 78.74 x 31.69 (2155 x 2000 x 805)	3084 (1400)	0.8	12.0	30
6L	1500	2000	84.84 x 94.49 x 31.69 (2155 x 2400 x 805)	3634 (1650)	0.8	16.0	36

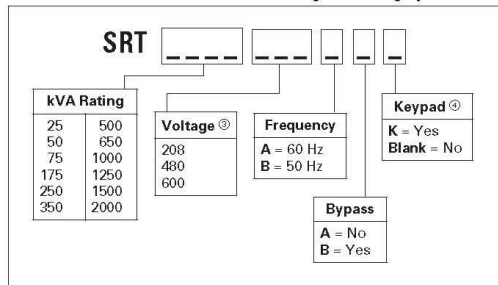
① 208 V models are available in 25 – 250 kVA only.

Table 36.1-15. SRT Transformer Cabinet Dimensions

Inverter Frame Size	Transformer ② Cabinet Dimensions H x W x D Inches (mm)	Transformer Weight ② Lbs. (kg)	Transformer Dissipation (Worst Case)	
			%	kW
1S	In Controller Cabinet	—	—	—
2S	In Controller Cabinet	—	—	—
3S	In Controller Cabinet	—	—	—
2M	In Controller Cabinet	—	—	—
3M	In Controller Cabinet	—	—	—
1L	35.43 x 32.48 x 27.95 (900 x 825 x 710)	1211 (550)	<1.0	3.0
2K	39.37 x 35.43 x 35.43 (1000 x 900 x 900)	1762 (800)	<1.0	4.0
2L	39.37 x 39.37 x 37.40 (1000 x 1000 x 950)	1982 (900)	<1.0	5.0
3L	43.30 x 39.37 x 37.40 (1100 x 1000 x 950)	2423 (1100)	<1.0	6.0
4L	51.18 x 55.12 x 47.24 (1300 x 1400 x 1200)	3084 (1400)	<1.0	7.0
5L	51.18 x 55.12 x 47.24 (1300 x 1400 x 1200)	3744 (1700)	<1.0	8.0
6L	55.12 x 59.06 x 47.24 (1400 x 1500 x 1200)	4405 (2000)	<1.0	9.0

② Nominal dimensions and weights. Consult factory for precise values.

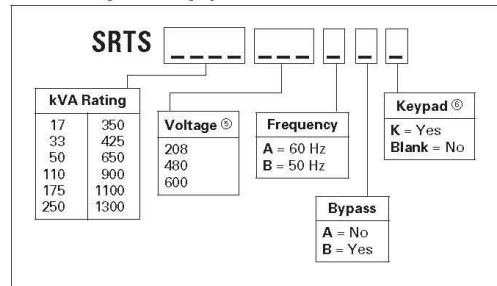
Table 36.1-16. 30% Correction Model Catalog Numbering System



③ 3-phase, 3-wire.

④ Keypad is standard on 175 kVA and larger.

Table 36.1-17. SRTS — SEMI F47 Compliant Version 40% Correction Model Catalog Numbering System

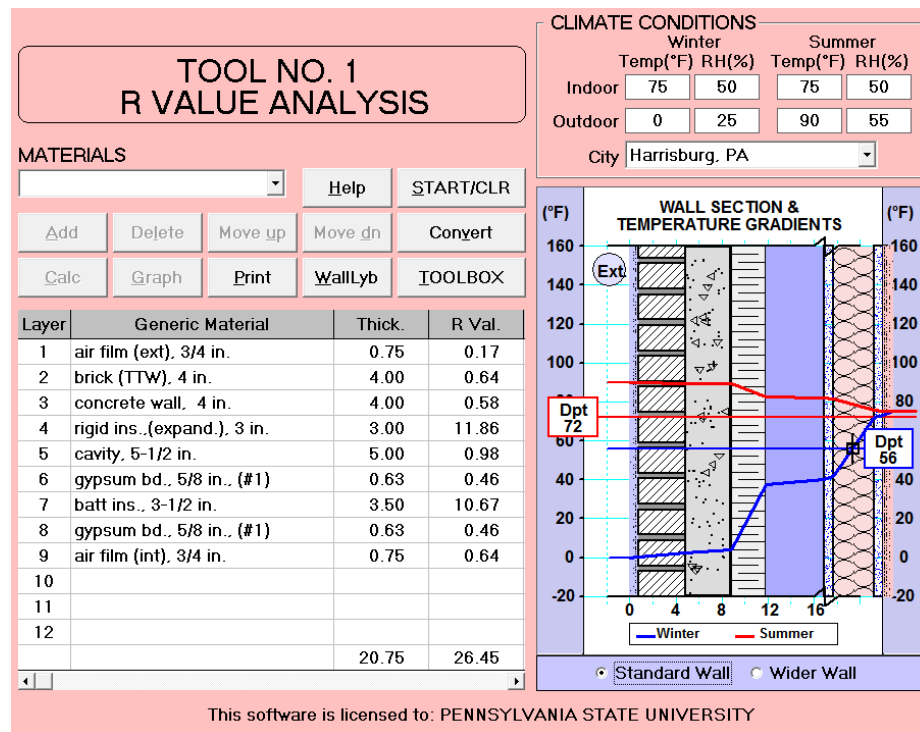


③ 3-phase, 3-wire.

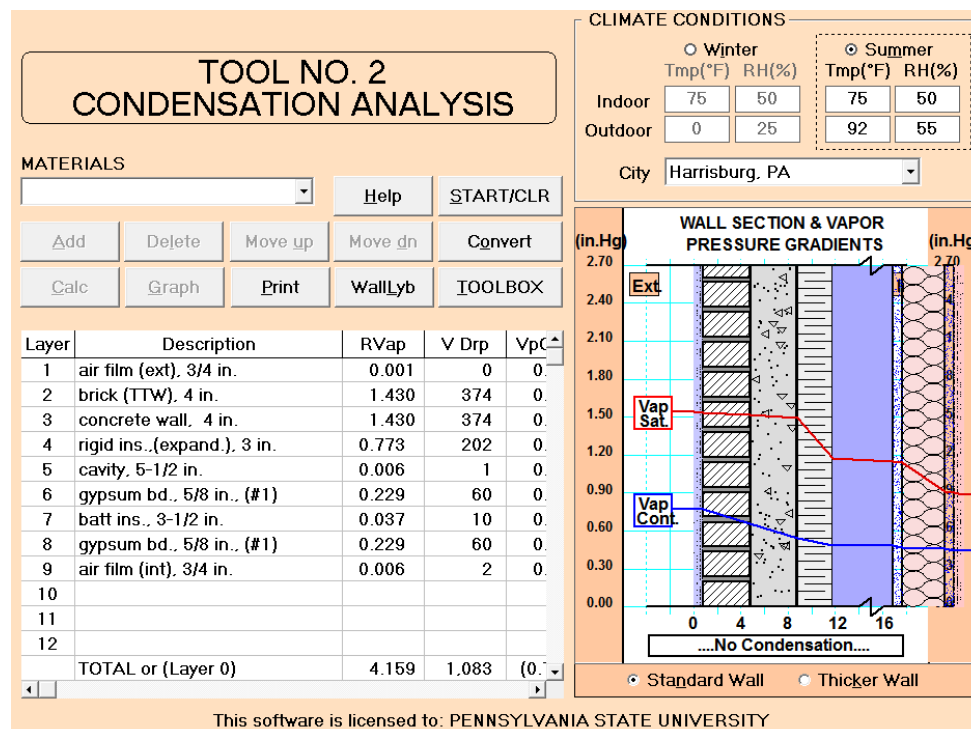
④ Keypad is standard on 110 kVA and larger.

APPENDIX F: Mechanical

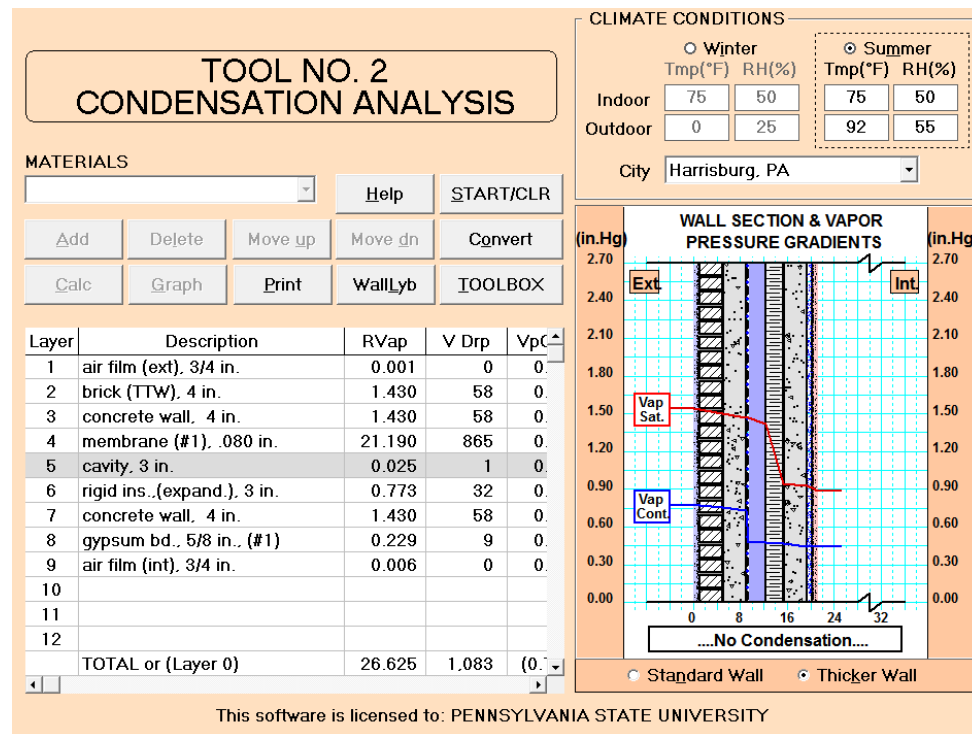
Thermal and Moisture Performance



HAM R Value Analysis of Existing Wall Condition



H.A.M. Condensation Analysis of Existing Façade Composition – Summer Conditions



H.A.M. Condensation Analysis of Alternate PCM Façade Composition – Summer Conditions

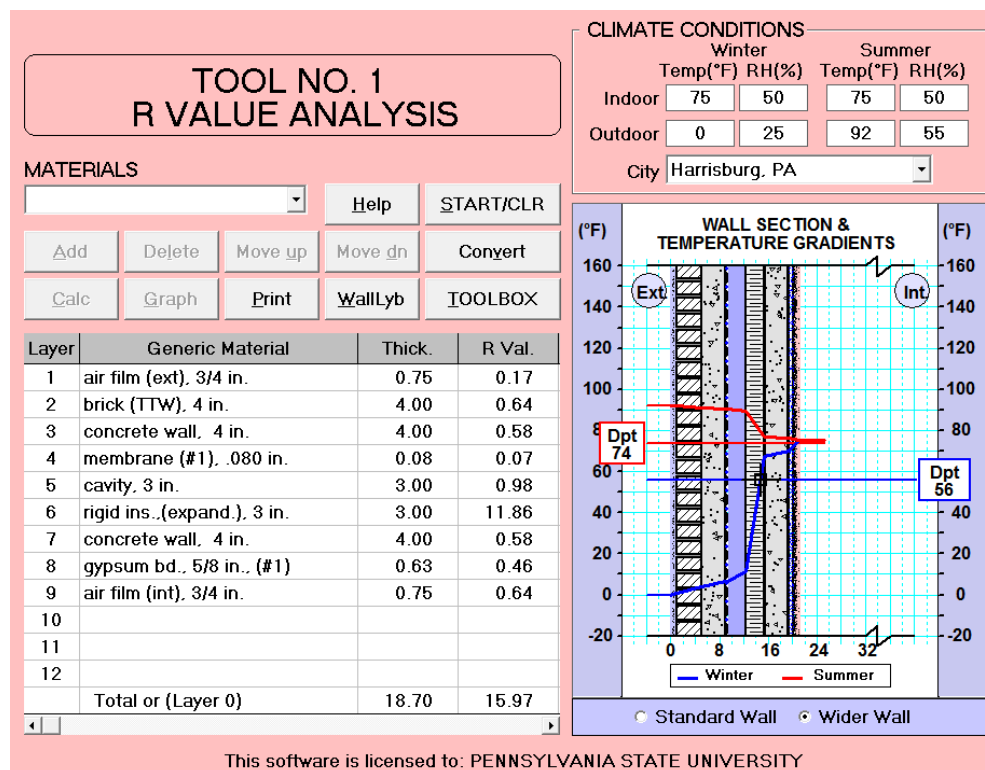


Figure 150: Temperature Analysis of Redesigned Wall Assembly

260

B. Zalba et al. / *Applied Thermal Engineering* 23 (2003) 251–283

Table 4
Organic substances with potential use as PCM

Compound	Melting temperature (°C)	Heat of fusion (kJ/kg)	Thermal conductivity (W/m K)	Density (kg/m ³)
Paraffin C ₁₄	4.5 [1]	165 [1]	n.a.	n.a.
Paraffin C ₁₅ –C ₁₆	8 [1]	153 [1]	n.a.	n.a.
Polyglycol E400	8 [4,11]	99.6 [4,11]	0.187 (liquid, 38.6 °C) [4,11] 0.185 (liquid, 69.9 °C) [11]	1125 (liquid, 25 °C) [4,11] 1228 (solid, 3 °C) [4,11]
Dimethyl-sulfoxide (DMS)	16.5 [28]	85.7 [28]	n.a.	1009 (solid and liquid) [28]
Paraffin C ₁₆ –C ₁₈	20–22 [29]	152 [29]	n.a.	n.a.
Polyglycol E600	22 [4,11]	127.2 [4,11]	0.189 (liquid, 38.6 °C) [4,11] 0.187 (liquid, 67.0 °C) [11]	1126 (liquid, 25 °C) [4,11] 1232 (solid, 4 °C) [4,11]
Paraffin C ₁₃ –C ₂₄	22–24 [1]	189 [1]	0.21 (solid) [1]	0.760 (liquid, 70 °C) [1] 0.900 (solid, 20 °C) [1]
1-Dodecanol	26 [9]	200 [9]	n.a.	n.a.
Paraffin C ₁₈	28 [1] 27.5 [30]	244 [1] 243.5 [30]	0.148 (liquid, 40 °C) [30] 0.15 (solid) [1] 0.358 (solid, 25 °C) [30]	0.774 (liquid, 70 °C) [1] 0.814 (solid, 20 °C) [1]
1-Tetradecanol	38 [9]	205 [9]		
Paraffin C ₁₆ –C ₂₈	42–44 [1]	189 [1]	0.21 (solid) [1]	0.765 (liquid, 70 °C) [1] 0.910 (solid, 20 °C) [1]
Paraffin C ₂₀ –C ₃₃	48–50 [1]	189 [1]	0.21 (solid) [1]	0.769 (liquid, 70 °C) [1] 0.912 (solid, 20 °C) [1]
Paraffin C ₂₂ –C ₄₅	58–60 [1]	189 [1]	0.21 (solid) [1]	0.795 (liquid, 70 °C) [1] 0.920 (solid, 20 °C) [1]
Paraffin wax	64 [4,11]	173.6 [4,11] 266 [6]	0.167 (liquid, 63.5 °C) [4,11] 0.346 (solid, 33.6 °C) [4,11] 0.339 (solid, 45.7 °C) [11]	790 (liquid, 65 °C) [4,11] 916 (solid, 24 °C) [4,11]
Polyglycol E6000	66 [4,11]	190.0 [4,11]	n.a.	1085 (liquid, 70 °C) [4,11] 1212 (solid, 25 °C) [4,11]
Paraffin C ₂₁ –C ₃₀	66–68 [1]	189 [1]	0.21 (solid) [1]	0.830 (liquid, 70 °C) [1] 0.930 (solid, 20 °C) [1]
Biphenyl	71 [4,11]	119.2 [4,11]	n.a.	991 (liquid, 73 °C) [4,11] 1166 (solid, 24 °C) [11]
Propionamide	79 [11]	168.2 [11]	n.a.	n.a.
Naphthalene	80 [4,11]	147.7 [4,11]	0.132 (liquid, 83.8 °C) [4,11] 0.341 (solid, 49.9 °C) [4,11] 0.310 (solid, 66.6 °C) [11]	976 (liquid, 84 °C) [4,11] 1145 (solid, 20 °C) [4,11]
Erythritol	118.0 [31]	339.8 [31]	0.326 (liquid, 140 °C) [31] 0.733 (solid, 20 °C) [31]	1300 (liquid, 140 °C) [31] 1480 (solid, 20 °C) [31]
HDPE	100–150 [32]	200 [32]	n.a.	n.a.
Trans-1,4-polybutadiene (TPB)	145 [33]	144 [33]	n.a.	n.a.

n.a.: not available.

Thermal Properties of organic PCM materials from Zalba, see Appendix C: Citations

Energy Analysis of Alternative Façade Compositions

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Total

Alternative: 2 Existing

Electric On-Pk Cons. (kWh) 45,559 40,279 50,543 49,075 52,075 52,063 53,895 56,438 52,321 51,455 49,736 45,744 598,888
On-Pk Demand (kW) 160 158 178 178 221 229 238 234 239 213 196 181 238

Purchased Steam On-Pk Cons. (therms) 2,992 2,780 2,062 1,510 1,142 1,003 1,060 1,064 1,127 1,558 1,819 2,637 20,763
On-Pk Demand (therms/hr) 7 7 5 4 3 2 3 3 3 4 5 6 7

Purchased Chilled Water On-Pk Cons. (therms) 456 381 851 1,340 2,962 4,416 5,963 4,748 3,343 1,610 1,077 486 27,612
On-Pk Demand (therms/hr) 6 6 7 8 13 15 17 16 14 10 8 6 17

Energy Consumption

Building Source 155,480 Btu/(ft2-year)
249,683 Btu/(ft2-year)

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2 2,451,930 lbm/year
SO2 18,955 gm/year
NOX 3,810 gm/year

Trane Trace Monthly Energy Report– Existing Façade

TRACE® 700 v6.2.6.5 calculated at 02:53 PM on 03/18/2011
Alternative - 2 Monthly Energy Consumption report Page 1 of 3

Project Name: Millennium Science Complex
Dataset Name: PSU MSC-wall comp analysis.TRC

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	
----- Monthly Energy Consumption -----														
Alternative: 4 PCM Panel														
Electric	On-Pk Cons. (kWh)	45,027	39,748	50,123	47,607	52,723	52,304	53,399	55,899	51,837	51,089	49,362	45,634	594,032
	On-Pk Demand (kW)	149	150	172	174	215	228	238	228	232	208	199	151	238
Purchased Steam	On-Pk Cons. (therms)	2,689	2,781	2,036	1,471	1,073	942	1,004	994	1,059	1,507	1,782	2,636	20,274
	On-Pk Demand (therms/hr)	7	7	5	3	3	2	2	3	3	3	5	6	7
Purchased Chilled Water	On-Pk Cons. (therms)	404	323	788	1,281	2,889	4,331	5,871	4,850	3,256	1,528	1,007	439	26,769
	On-Pk Demand (therms/hr)	5	5	7	8	12	14	16	15	13	10	8	5	18
Energy Consumption														
Building	162,133	BTU/(ft2-year)												
Source	246,087	BTU/(ft2-year)												
Environmental Impact Analysis														
	CO2	2,398,851 lbm/year												
	SO2	18,546 gm/year												
	NOX	3,728 gm/year												

Trane Trace Monthly Energy Report– Alternate PCM Facade

TRACEm 700 v6.2.6.5 calculated at 02:53 PM on 03/19/2011
Alternative - 4 Monthly Energy Consumption report Page 3 of 3

Project Name: Millennium Science Complex
Dataset Name: PSU MSC-wall comp analysis.TRC

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
----- Monthly Energy Consumption -----													
Alternative: 3	3 Pane Glass												
Electric													
On-Pk Cons. (kWh)	45,461	40,718	50,635	48,024	53,518	53,548	54,848	57,357	52,581	51,515	48,569	46,489	603,262
On-Pk Demand (kW)	181	161	181	185	225	234	242	241	230	212	194	162	242
Purchased Steam													
On-Pk Cons. (therms)	2,680	2,508	1,794	1,250	970	887	955	911	949	1,287	1,546	2,365	18,082
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	410	336	688	1,067	2,559	3,933	5,401	4,198	2,868	1,304	868	444	24,076
On-Pk Demand (therms/hr)	5	4	6	7	11	13	15	14	12	9	7	5	15
USE													
Environmental Impact Analysis													
Building	CO2												
Source	141,806 Btu/(ft2-year)												
	236,947 Btu/(ft2-year)												
	SO2												
	17,287 gm/year												
	NOX												
	3,475 gm/year												
Floor Area	44,249 ft2												

Trane Trace Monthly Energy Report – Alternate Triple Pane Facade

Project Name: Millennium Science Complex
Dataset Name: PSU MSC-wall comp analysis.TRC

TRACE® 700 v6.2.6.5 calculated at 03:03 PM on 03/19/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

MONTHLY ENERGY CONSUMPTION

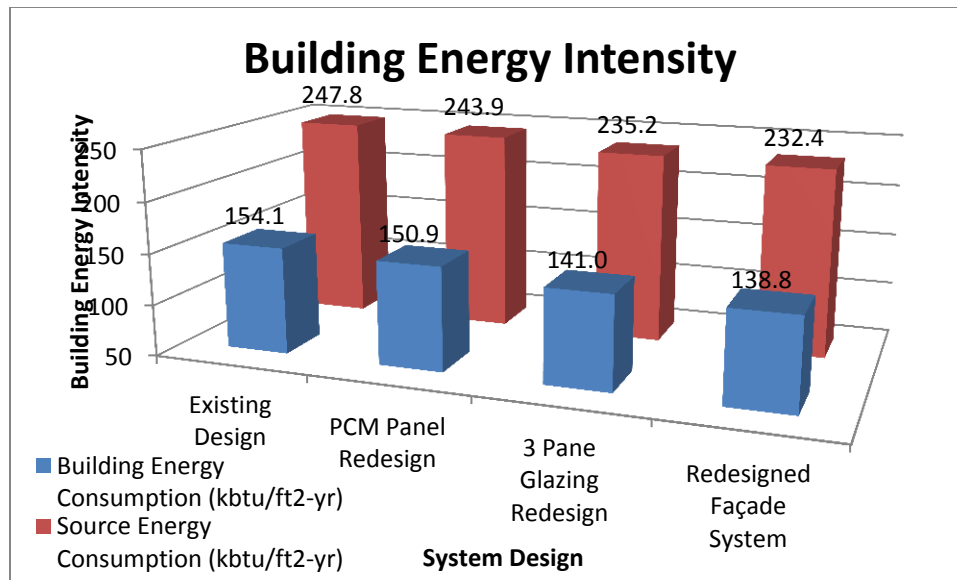
By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	
----- Monthly Energy Consumption -----														
Alternative: 3 3 Pane Glass and PCM Panel														
Electric	On-Pk Cons. (kWh)	45,075	40,183	50,302	47,843	53,219	53,228	54,479	50,803	52,132	51,199	48,283	45,805	598,600
	On-Pk Demand (kW)	146	153	172	179	216	231	243	238	224	202	185	158	243
Purchased Steam	On-Pk Cons. (therms)	2,690	2,527	1,777	1,216	921	829	921	866	899	1,254	1,527	2,374	17,800
	On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water	On-Pk Cons. (therms)	372	313	645	1,028	2,502	3,876	6,339	4,120	2,802	1,260	822	411	23,478
	On-Pk Demand (therms/hr)	4	4	6	7	11	13	15	14	12	8	7	4	15
Energy Consumption														
Building Source	139,448 Btu/(ft2-year)													
	232,653 Btu/(ft2-year)													
Environmental Impact Analysis														
CO2	2,198,834 lbm/year													
SO2	17,000 gm/year													
NOX	3,417 gm/year													

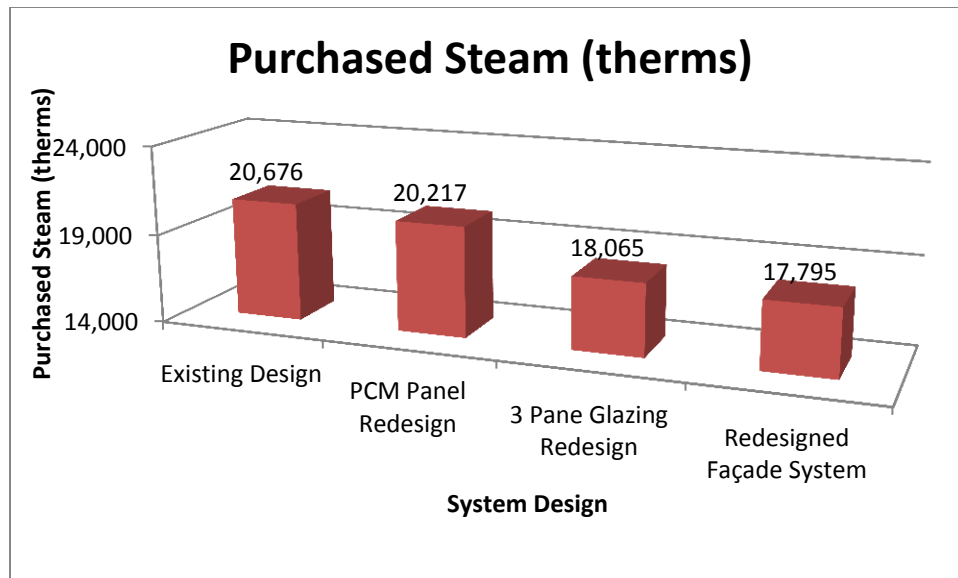
TRACE® 700 v6 2.6.5 calculated at 02:53 PM on 03/18/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

Project Name: Millennium Science Complex
Dataset Name: PSU MSC-wall comp analysis TRC

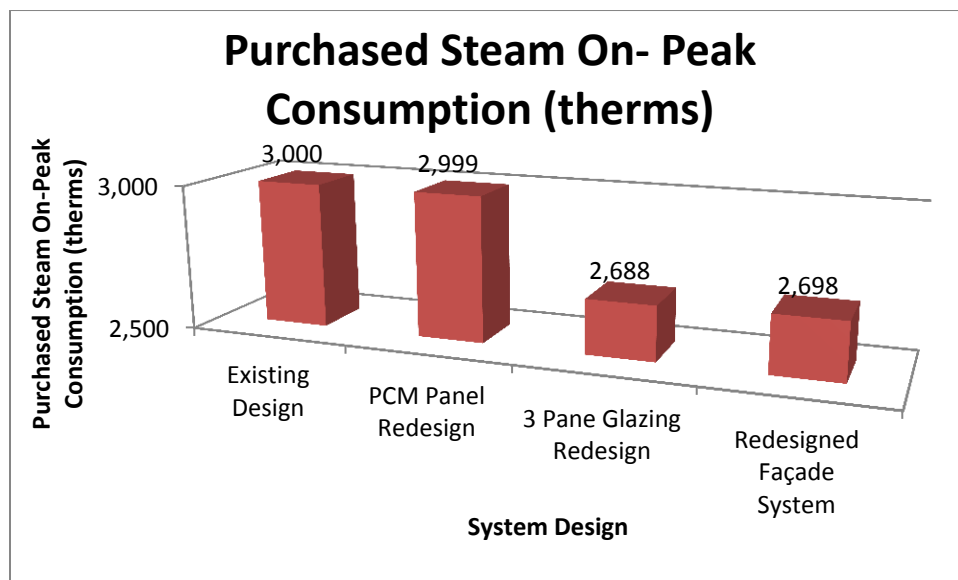
Trane Trace Monthly Energy Report– Alternate Triple Pane and PCM Facade



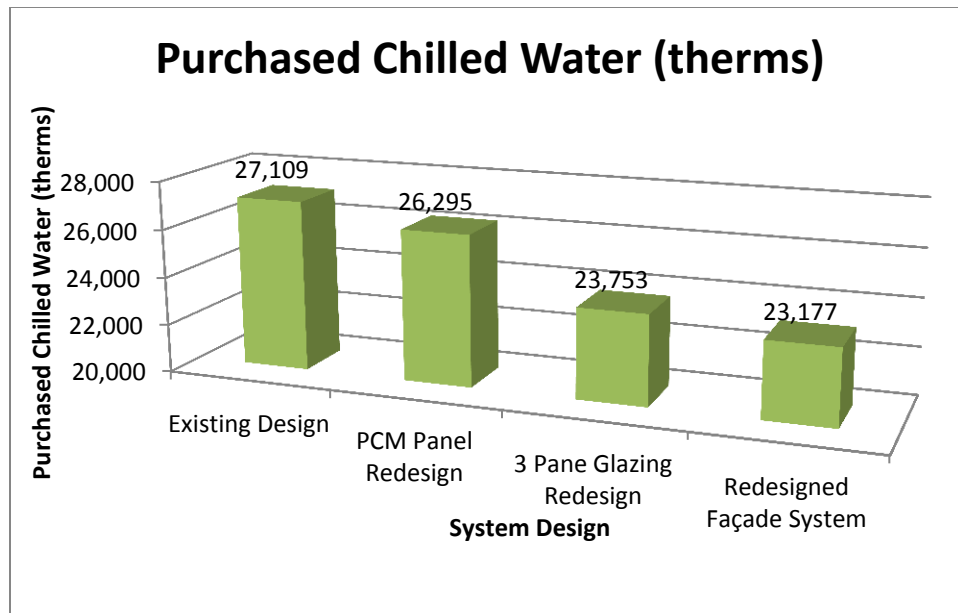
Graph of Total Building Energy Intensity of All Façade Design Options



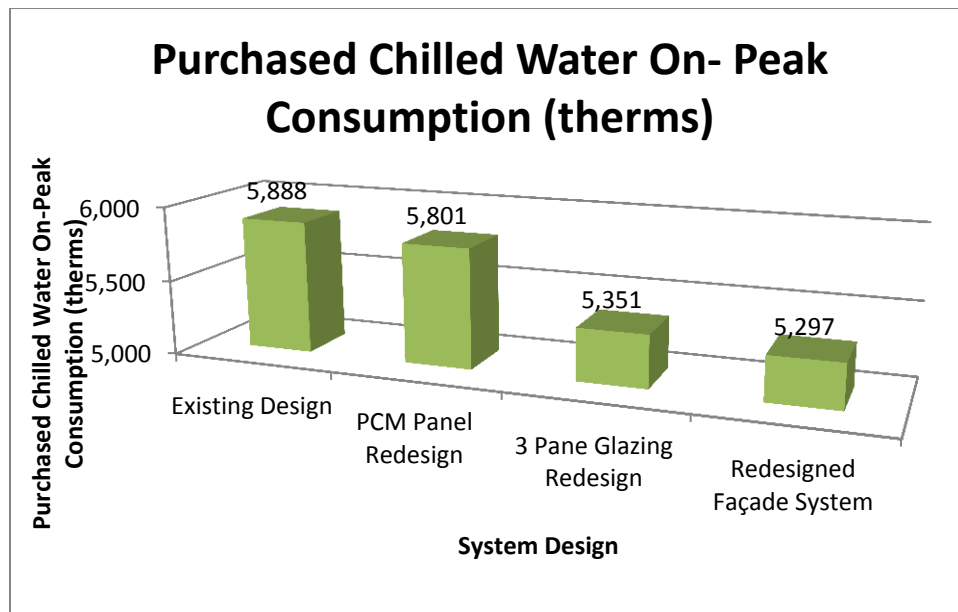
Graph of Purchased Steam of All Façade Design Options



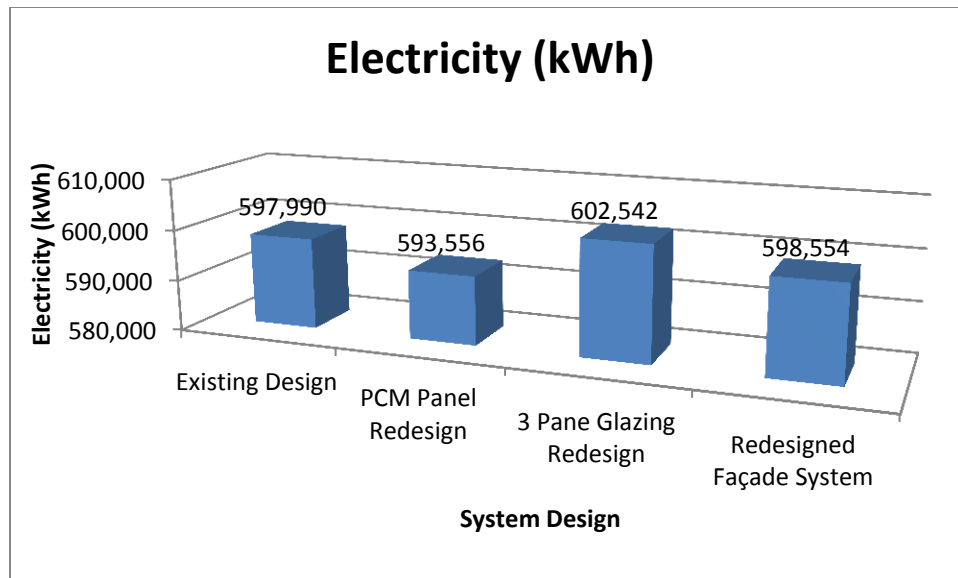
Graph of Peak Purchased Steam of All Façade Design Options



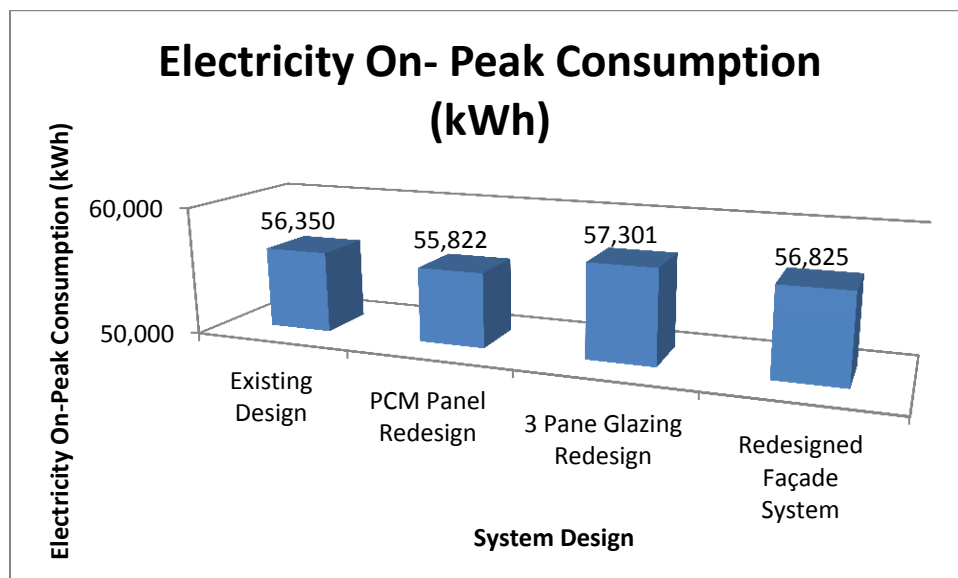
Graph of Purchased Chilled Water of All Façade Design Options



Graph of Peak Purchased Chilled Water of All Façade Design Options



Graph of Electricity of All Façade Design Options



Graph of Peak Electricity of All Façade Design Options

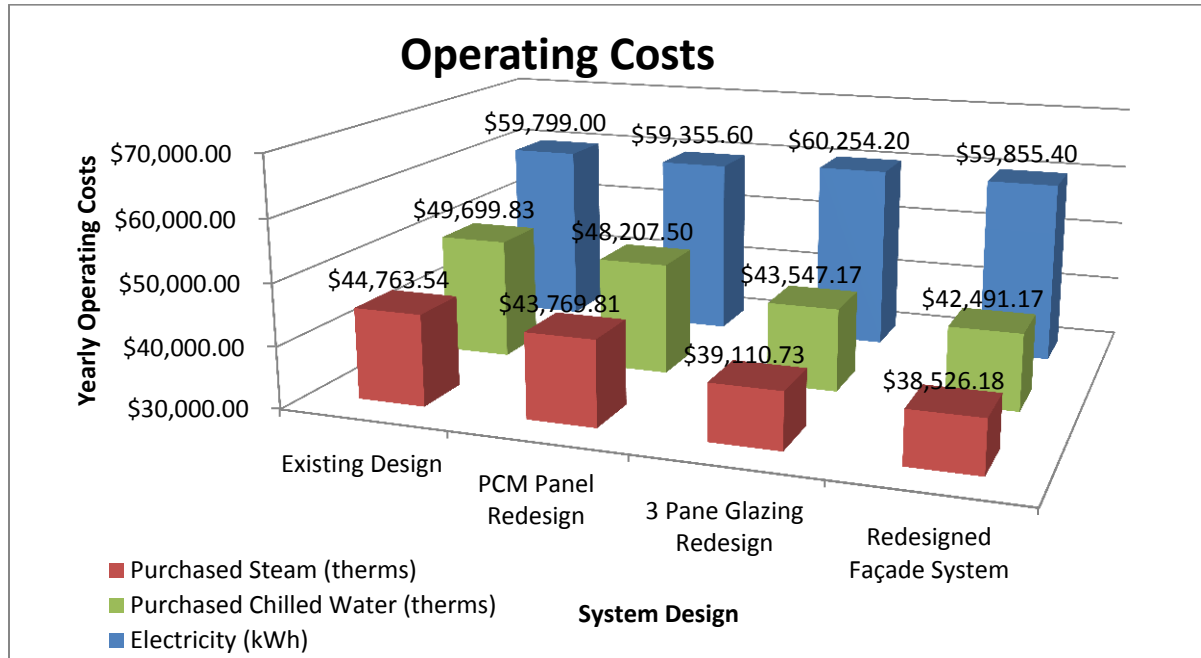
Operating and Life Cycle Cost Analysis

Utility Charge Rates

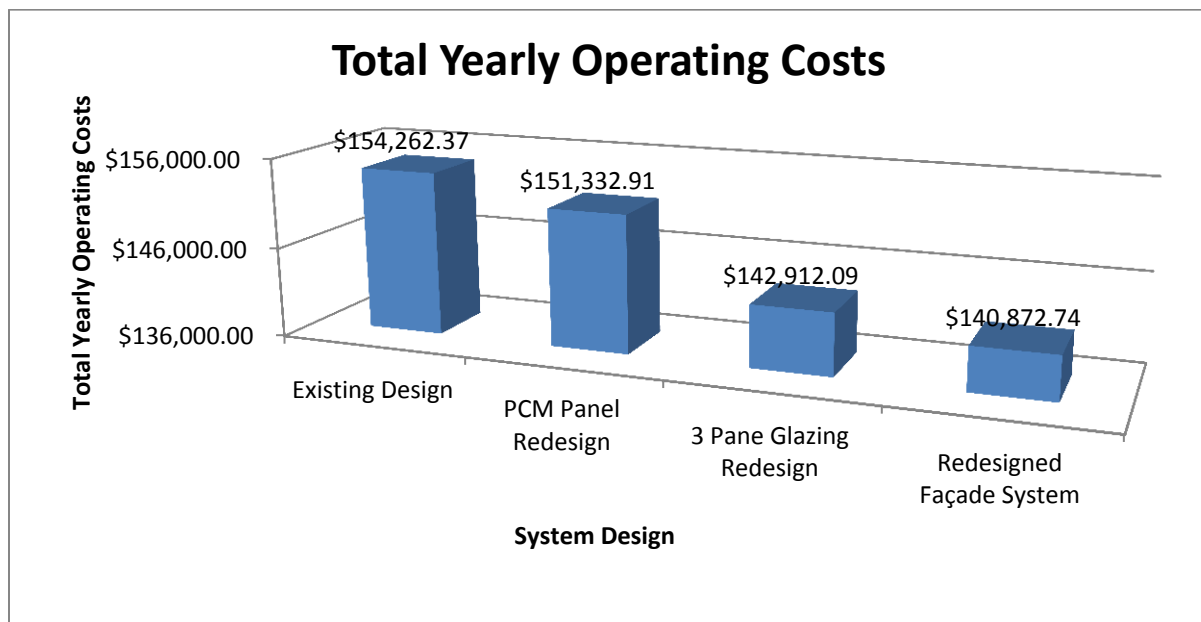
Some Departments pay the cost of their utility usage to OPP. These are Departments such as Housing and Food Service and Athletics. The following chart shows the billable rates charged as well as our avoidable costs that are used for Energy Savings Projects for FY 09-10:

Utility	Avoided Costs	Billable Rate	Units	Comments
Electricity	\$1.09	\$1.09	KW	5 sub-stations only, 1 st half
	\$0.07781	\$0.09648	KWH	5 sub-stations only, 1 st half
Electricity	\$1.09	\$1.09	KW	5 sub-stations only, 2 nd half
	\$0.07517	\$0.09481	KWH	5 sub-stations only, 2 nd half
Natural Gas	\$8.66	\$9.83	MCF	Blended Rate
Steam	\$9.85	\$21.65	1000 pounds	
Water & Wastewater	\$3.32	\$8.39	1000 gallons	
Chilled Water	\$0.22	\$0.22	Ton-Hour	Estimated Cost

Utility Cost Data from “Utility Fact Sheet University Park”, see Appendix C: Citations



Utility Operation Costs of All Building Design Options



Total Yearly Operating Costs of All Building Design Options

Table 2.8b Summary of Energy Costs for Seattle

	Annual Electricity Cost (\$/sf)	Annual Gas Cost (\$/sf)	Annual Energy Cost (\$/sf)	% Reduction in Energy Costs	% Reduction per LEED
Base Case	\$3.90	\$2.60	\$6.50		
Flow Setback (CFM21)	\$3.80	\$2.60	\$6.40	2%	2%
VAV	\$3.60	\$2.00	\$5.60	14%	22%
Supply Static Pressure of 4 in. w.g. (SP4)	\$3.60	\$2.70	\$6.30	3%	4%
Supply Static Pressure of 3 in. w.g. (SP3)	\$3.40	\$2.70	\$6.10	5%	8%
Enthalpy Wheel (Wheel)	\$4.00	\$1.30	\$5.30	18%	28%
Enthalpy Wheel w/ VAV (VWheel)	\$3.70	\$1.00	\$4.70	28%	44%
Heat Pipe (HtPipe)	\$4.10	\$1.50	\$5.60	13%	21%
Run-Around Loop (Loop)	\$4.10	\$1.50	\$5.60	13%	21%
Chiller Energy Recovery (CWER)	\$3.90	\$2.50	\$6.40	1%	2%
Direct Evap. Cooling (Evap)	\$3.80	\$2.60	\$6.40	1%	2%
Water-side Economizer (Econ)	\$3.80	\$2.60	\$6.40	1%	1%
Humidity Controls: Max 60%RH, Min 20%RH (RH26)	\$3.90	\$2.40	\$6.20	4%	6%
Humidity Controls: Max 50%RH, Min 40%RH (RH45)	\$4.00	\$3.30	\$7.30	-12%	-20%
Humidity Controls: Max 50%RH, Min 40%RH w/ Enthalpy Wheel (RH45 Wheel)	\$4.10	\$1.90	\$5.90	8%	13%
Lab Plug Loads 8 W/sf (EPD8)	\$3.20	\$2.60	\$5.80	11%	
Lab Plug Loads 4 W/sf (EPD4)	\$2.50	\$2.70	\$5.20	19%	
Advanced w/Run-Around Loop (ALoop)	\$3.50	\$1.10	\$4.70	28%	44%
Advanced w/Enthalpy Wheel (AWheel)	\$3.50	\$1.00	\$4.50	31%	48%

Case Study of Design Option Energy Costs from “Energy Analysis”, see Appendix C: Citations

Table A-1. SPV factors for finding the present value of future single costs (non-fuel)

Number of years from base date	Single Present Value (SPV) Factors		
	DOE	OMB Discount Rates ^a	
	Discount rate 3.0 %	Short term ^b 1.9 %	Long Term ^c 2.7 %
0.25	0.993	0.995	0.993
0.50	0.985	0.991	0.987
0.75	0.978	0.986	0.980
1	0.971	0.981	0.974
2	0.943	0.963	0.948
3	0.915	0.945	0.923
4	0.888	0.927	0.899
5	0.863	0.910	0.875
6	0.837	0.893	0.852
7	0.813	0.877	0.830
8	0.789	0.860	0.808
9	0.766	0.844	0.787
10	0.744	0.828	0.766
11	0.722		0.746
12	0.701		0.726
13	0.681		0.707
14	0.661		0.689
15	0.642		0.671
16	0.623		0.653
17	0.605		0.636
18	0.587		0.619
19	0.570		0.603
20	0.554		0.587
21	0.538		0.572
22	0.522		0.556
23	0.507		0.542
24	0.492		0.528
25	0.478		0.514
26	0.464		0.500
27	0.450		0.487
28	0.437		0.474
29	0.424		0.462
30	0.412		0.450

^aOMB discount rates as of February 2010.

^bShort-term discount rate based on OMB discount rate for 7-year study period.

^cLong-term discount rate based on OMB discount rate for 30-year study period.

OMB Long Term Discount Rates from “Energy Price Indices...”, see Appendix C: Citations

Table Ca-1. Projected fuel price indices (excluding general inflation), by end-use sector and fuel type.

Census Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont)															
Projected April 1 Fuel Price Indices (April 1, 2010 = 1.00)															
Sector and Fuel	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Residential															
Electricity	0.94	0.98	1.01	1.01	1.01	1.02	1.03	1.03	1.03	1.04	1.05	1.05	1.06	1.06	1.05
Distillate Oil	1.00	1.05	1.11	1.15	1.18	1.23	1.27	1.31	1.34	1.36	1.37	1.38	1.39	1.41	1.42
LPG	0.99	1.02	1.06	1.10	1.13	1.15	1.17	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26
Natural Gas	1.05	1.07	1.06	1.04	1.04	1.05	1.05	1.05	1.05	1.06	1.07	1.08	1.09	1.09	1.10
Commercial															
Electricity	0.90	0.92	0.94	0.93	0.92	0.93	0.95	0.95	0.96	0.97	0.98	0.99	1.00	1.01	1.01
Distillate Oil	1.01	1.07	1.14	1.19	1.23	1.29	1.33	1.37	1.40	1.43	1.44	1.46	1.48	1.49	1.50
Residual Oil	1.00	1.10	1.23	1.32	1.37	1.43	1.49	1.54	1.60	1.64	1.66	1.68	1.71	1.73	1.75
Natural Gas	1.07	1.13	1.13	1.11	1.11	1.12	1.12	1.12	1.12	1.13	1.14	1.16	1.17	1.17	1.18
Coal	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.95	0.94	0.95	0.95	0.95	0.95
Industrial															
Electricity	0.85	0.88	0.90	0.87	0.87	0.88	0.90	0.91	0.91	0.92	0.93	0.94	0.96	0.97	0.97
Distillate Oil	1.03	1.10	1.16	1.22	1.26	1.32	1.36	1.41	1.44	1.47	1.48	1.50	1.52	1.53	1.54
Residual Oil	1.01	1.10	1.22	1.31	1.36	1.41	1.46	1.51	1.57	1.60	1.62	1.64	1.66	1.69	1.71
Natural Gas	1.16	1.27	1.28	1.26	1.26	1.26	1.26	1.26	1.26	1.27	1.29	1.31	1.33	1.33	1.34
Coal	0.99	0.99	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95	0.95	0.95	0.95	0.95	0.95
Transportation															
Motor Gasoline	1.04	1.09	1.17	1.23	1.25	1.28	1.31	1.33	1.35	1.37	1.38	1.40	1.41	1.42	1.43

Fuel Price Indices page one from “Energy Price Indices...”, see Appendix C: Citations

Table Ca-1, continued. Projected fuel price indices (excluding general inflation), by end-use sector and fuel type.

Census Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont)															
Projected April 1 Fuel Price Indices (April 1, 2010 = 1.00)															
Sector and Fuel	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Residential															
Electricity	1.06	1.06	1.07	1.09	1.10	1.11	1.12	1.12	1.13	1.13	1.14	1.15	1.15	1.16	1.17
Distillate Oil	1.44	1.45	1.46	1.49	1.50	1.52	1.54	1.56	1.59	1.61	1.63	1.65	1.66	1.68	1.70
LPG	1.26	1.27	1.28	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.40	1.41	1.43
Natural Gas	1.11	1.12	1.14	1.16	1.19	1.21	1.23	1.24	1.25	1.26	1.27	1.29	1.30	1.31	1.32
Commercial															
Electricity	1.01	1.02	1.03	1.05	1.06	1.08	1.10	1.12	1.13	1.14	1.15	1.15	1.16	1.17	1.17
Distillate Oil	1.52	1.54	1.56	1.58	1.59	1.62	1.64	1.67	1.69	1.72	1.74	1.76	1.79	1.81	1.83
Residual Oil	1.77	1.78	1.81	1.83	1.86	1.89	1.92	1.94	1.98	2.00	2.03	2.06	2.10	2.14	2.17
Natural Gas	1.19	1.20	1.22	1.25	1.28	1.31	1.33	1.33	1.35	1.36	1.38	1.39	1.41	1.43	1.44
Coal	0.95	0.95	0.95	0.96	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.99
Industrial															
Electricity	0.97	0.98	1.00	1.02	1.04	1.06	1.09	1.10	1.11	1.13	1.13	1.14	1.15	1.15	1.16
Distillate Oil	1.56	1.58	1.60	1.62	1.64	1.66	1.69	1.71	1.74	1.77	1.79	1.81	1.83	1.85	1.87
Residual Oil	1.72	1.73	1.76	1.78	1.80	1.84	1.86	1.88	1.91	1.93	1.96	1.99	2.03	2.06	2.10
Natural Gas	1.36	1.38	1.41	1.45	1.48	1.53	1.56	1.58	1.60	1.62	1.64	1.66	1.69	1.72	1.75
Coal	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98
Transportation															
Motor Gasoline	1.45	1.46	1.48	1.50	1.51	1.52	1.54	1.56	1.58	1.60	1.62	1.63	1.65	1.66	1.68

Fuel Price Indices page two from “Energy Price Indices...”, see Appendix C: Citations

Area (ft2)	44,250	Electricity Consumption (KWh/ft2)	Electricity cost	Natural Gas Escalation Factor	Overhaul Cost	Maintenance Cost	Upfront Costs
Electricity Consumption (KWh/ft2)	13.514		59799.00		0		
Cost of Electricity (\$/KWh)	0.10		0				
KWh of Electricity Consumed	597,990		2.7			5	
			Discount Rate				
			Discount Rates				
			1.00000				
0			0.97371	1.07	65417.89		
1	2010		0.94811	1.13	67269.90		
2	2011		0.92318	1.13	65501.36		
3	2012		0.89891	1.11	62650.48		
4	2013		0.87528	1.11	61003.39		
5	2014		0.85227	1.12	59934.73		
6	2015		0.82986	1.12	58359.04		
7	2016		0.80805	1.12	56824.77		
8	2017		0.78680	1.12	55330.84		
9	2018		0.76612	1.13	54357.22		
10	2019		0.74598	1.14	53396.55		
11	2020		0.72636	1.16	52904.90		
12	2021		0.70727	1.17	51958.11		
13	2022		0.68867	1.17	50592.12		
14	2023		0.67057	1.18	49683.09		
15	2024		0.65294	1.19	48786.88		
16	2025		0.63577	1.2	47903.46		
17	2026		0.61906	1.22	47421.48		
18	2027		0.60278	1.25	47310.20		
19	2028		0.58694	1.28	47172.00		
20	2029		0.57151	1.31	47008.37		
21	2030		0.55648	1.33	46471.33		
22	2031		0.54185	1.33	45249.59		
23	2032		0.52761	1.35	44722.53		
24	2033		0.51373	1.36	43869.33		
25	2034		0.50023	1.38	43344.18		
26	2035		0.48708	1.39	42510.48		
27	2036		0.47427	1.41	41988.46		
28	2037		0.46180	1.43	41464.50		
29	2038		0.44966	1.44	40656.73		
30	2039			Total:	\$1,541,063.92	\$0.00	\$0.00
							Total Present Value \$1,541,063.92

Example of Electricity Life Cycle Cost – Existing Façade Design

Area (ft ²)	44,250	Chilled Water Consumption (ton-h/ft ²)	5.105	Chilled Water Cost	49699.83	Overhaul Cost	0	Maintenance Cost	0	Upfront Costs
Cost of Chilled Water (\$/ton-h)	0.22			Maintenance Cost	0					
Terms of Chilled Water Consumed	27,109			Discount Rate	2.7	Fuel Cost Increase Percentage	5			
				Discount Rates		Energy Cost				
0			1.00000	Natural Gas Escalation Factor						
1	2010		0.97371		1.07	54369.78				
2	2011		0.94811		1.13	55909.01				
3	2012		0.92318		1.13	54439.15				
4	2013		0.89891		1.11	52069.74				
5	2014		0.87528		1.11	50700.82				
6	2015		0.85227		1.12	49812.64				
7	2016		0.82986		1.12	48503.06				
8	2017		0.80805		1.12	47227.91				
9	2018		0.78680		1.12	45986.28				
10	2019		0.76612		1.13	45177.09				
11	2020		0.74598		1.14	44378.66				
12	2021		0.72636		1.16	43970.04				
13	2022		0.70727		1.17	43183.15				
14	2023		0.68867		1.17	42047.86				
15	2024		0.67057		1.18	41292.35				
16	2025		0.65294		1.19	40547.50				
17	2026		0.63577		1.2	39813.28				
18	2027		0.61906		1.22	39412.69				
19	2028		0.60278		1.25	39320.21				
20	2029		0.58694		1.28	39205.35				
21	2030		0.57151		1.31	39069.35				
22	2031		0.55648		1.33	38623.01				
23	2032		0.54185		1.33	37607.60				
24	2033		0.52761		1.35	37169.55				
25	2034		0.51373		1.36	36460.45				
26	2035		0.50023		1.38	36023.99				
27	2036		0.48708		1.39	35331.09				
28	2037		0.47427		1.41	34897.23				
29	2038		0.46180		1.43	34461.76				
30	2039		0.44966		1.44	33790.41				
					Total:	\$1,280,801.01	\$0.00	\$0.00	\$0.00	Total Present Value \$1,280,801.01

Example of Chilled Water Life Cycle Cost – Existing Façade Design

Area (ft ²)	44,250	Steam cost	44763.54	Overhaul Cost				
Steam Consumption (1000 lb/ft ²)	0.047	Maintenance Cost	0	0				
Cost of Steam (\$/1000 lb)	21.65	Discount Rate	2.7	Fuel Cost Increase Percentage	5			
Terms of Steam Consumed	20,676							
		Discount Rates	Natural Gas Escalation Factor	Energy Cost	Maintenance Cost	Overhaul Cost	Upfront Costs	
0		1.00000						
1	2010	0.97371	1.07	48969.66				
2	2011	0.94811	1.13	50356.01				
3	2012	0.92318	1.13	49032.14				
4	2013	0.89891	1.11	46898.07				
5	2014	0.87528	1.11	45665.11				
6	2015	0.85227	1.12	44865.15				
7	2016	0.82986	1.12	43685.63				
8	2017	0.80805	1.12	42537.13				
9	2018	0.78680	1.12	41418.82				
10	2019	0.76612	1.13	40690.00				
11	2020	0.74598	1.14	39970.88				
12	2021	0.72636	1.16	39602.85				
13	2022	0.70727	1.17	38894.11				
14	2023	0.68867	1.17	37871.58				
15	2024	0.67057	1.18	37191.10				
16	2025	0.65294	1.19	36520.24				
17	2026	0.63577	1.2	35858.94				
18	2027	0.61906	1.22	35498.14				
19	2028	0.60278	1.25	35414.84				
20	2029	0.58694	1.28	35311.39				
21	2030	0.57151	1.31	35188.90				
22	2031	0.55648	1.33	34786.89				
23	2032	0.54185	1.33	33872.34				
24	2033	0.52761	1.35	33477.79				
25	2034	0.51373	1.36	32839.12				
26	2035	0.50023	1.38	32446.01				
27	2036	0.48708	1.39	31821.93				
28	2037	0.47427	1.41	31431.16				
29	2038	0.46180	1.43	31038.94				
30	2039	0.44966	1.44	30434.27				
			Total:	\$1,153,589.13	\$0.00	\$0.00	\$0.00	\$1,153,589.13

Example of Steam Life Cycle Cost – Existing Façade Design

Electricity Cost/yr	\$59,799.00
Chilled Water Cost/yr	\$49,699.83
Steam/yr	\$44,763.54
Operating Costs/yr	\$154,262.37
Life Cycle Cost Assessment 30 yr	
Installation Cost	\$1,912,205
Electricity Cost	\$1,541,063.92
Chilled Water Cost	\$1,280,801.01
Steam Cost	\$1,153,589.13
Present Value	
Total Life Cycle Cost	\$5,887,659

Example of Combined Energy and Installation Life Cycle Cost – Existing Façade Design

Energy Analysis of Window to Wall Ratio Alternatives

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 4 Existing 50% 0306													
Electric													
On-Pk Cons. (kWh)	44,889	39,833	49,895	47,218	51,942	51,705	52,844	55,272	51,089	50,500	47,872	45,686	588,747
On-Pk Demand (kW)	150	155	171	171	213	225	234	230	221	203	187	155	234
Purchased Steam													
On-Pk Cons. (therms)	2,830	2,649	1,897	1,313	995	899	973	944	969	1,342	1,629	2,496	18,935
On-Pk Demand (therms/hr)	6	6	5	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	406	331	699	1,092	2,617	4,027	5,519	4,315	2,963	1,335	891	439	24,635
On-Pk Demand (therms/hr)	5	5	6	7	12	14	16	14	13	9	7	5	16
Energy Consumption													
Building	143,878 Btu/(ft2-year)												
Source	236,130 Btu/(ft2-year)												
Floor Area	44,249 ft2												
Environmental Impact Analysis													
	CO2 2,268,681 lbm/year												
	SO2 17,540 gm/year												
	NOX 3,526 gm/year												

Project Name: Millennium Science Complex
Dataset Name: MSC-existing-706050.TRC

TRACES 700 v6.2 6.5 calculated at 01:19 PM on 03/21/2011
Alternative - 4 Monthly Energy Consumption report Page 3 of 3

Trane Trace Monthly Energy Report from Trane Trace – Existing Façade 50% Glazing

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Total

Alternative: 3 Existing 60% 0367

Electric On-Pk Cons. (kWh) 45,101 40,068 50,094 47,507 52,276 51,982 53,133 55,617 51,501 50,821 48,164 45,554 591,818
On-Pk Demand (kW) 152 158 175 174 218 228 235 232 223 210 191 157 235

Purchased Steam

On-Pk Cons. (therms) 2,888 2,692 1,957 1,384 1,048 934 1,002 991 1,026 1,419 1,699 2,547 19,587
On-Pk Demand (therms/hr) 6 6 5 3 2 2 2 2 2 3 4 5 6

Purchased Chilled Water

On-Pk Cons. (therms) 421 337 752 1,180 2,750 4,179 5,689 4,480 3,110 1,435 959 453 25,746
On-Pk Demand (therms/hr) 5 5 7 8 12 14 16 15 13 9 8 6 16

Energy Consumption

Building 148,097 Btu/(ft2-year)
Source 240,735 Btu/(ft2-year)

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2 2,335,207 lbm/year
SO2 18,054 gbm/year
NOX 3,629 gbm/year

Trane Trace Monthly Energy Report from Trane Trace – Existing Façade 60% Glazing

Project Name: Millennium Science Complex
Dataset Name: MSC-existing-706060.TRC

TRACE® 700 v6.2.6.5 calculated at 01:19 PM on 03/21/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Total

Alternative: 2 Existing 70% 0428

Electric
On-Pk Cons. (kWh) 45,411 40,326 50,381 47,901 52,768 52,433 53,643 56,169 52,061 51,258 48,558 45,594 596,494
On-Pk Demand (kW) 157 168 177 177 221 229 237 233 227 213 193 161 237

Purchased Steam

On-Pk Cons. (therms) 2,956 2,749 2,026 1,467 1,111 978 1,040 1,036 1,092 1,510 1,777 2,602 20,342
On-Pk Demand (therms/hr) 7 7 5 3 3 2 2 3 3 4 4 6 7

Purchased Chilled Water

On-Pk Cons. (therms) 443 352 816 1,284 2,891 4,335 5,871 4,655 3,265 1,549 1,035 471 26,968
On-Pk Demand (therms/hr) 6 5 7 8 12 15 17 15 14 10 8 6 17

Energy Consumption

Building 152,925 Btu/(ft2-year)
Source 246,215 Btu/(ft2-year)

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2 2,411,341 lbm/year
SO2 18,643 gm/year
NOX 3,747 gm/year

Trane Trace Monthly Energy Report from Trane Trace – Existing Façade 70% Glazing

Project Name: Millennium Science Complex
Dataset Name: MSC-existing-706050.TRC

TRACE® 700 v6.2.6.5 calculated at 01:19 PM on 03/21/2011
Alternative - 2 Monthly Energy Consumption report Page 1 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
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Alternative: 2 Existing 75% 0458

Electric													
On-Pk Cons. (kWh)	45,559	40,279	50,548	48,075	52,975	52,663	53,895	56,438	52,321	51,455	48,736	45,744	598,688
On-Pk Demand (kW)	160	158	178	178	221	229	238	234	229	213	196	161	238

Purchased Steam

On-Pk Cons. (therms)	2,992	2,780	2,062	1,510	1,142	1,003	1,060	1,064	1,127	1,558	1,819	2,637	20,753
On-Pk Demand (therms/hr)	7	7	5	4	3	2	3	3	3	4	5	6	7

Purchased Chilled Water

On-Pk Cons. (therms)	456	361	851	1,340	2,962	4,416	5,963	4,748	3,343	1,610	1,077	486	27,612
On-Pk Demand (therms/hr)	6	6	7	8	13	15	17	16	14	10	8	6	17

Energy Consumption

Building	155,480	Btu/(ft2-year)
Source	249,083	Btu/(ft2-year)

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2	2,451,630	lbm/year
SO2	18,955	gm/year
NOX	3,810	gm/year

Trane Trace Monthly Energy Report from Trane Trace – Existing Façade 75% Glazing

Project Name: Millennium Science Complex
Dataset Name: MSC-existing-908075.TRC

TRACE® 700 v6.2.6.5 calculated at 01:49 PM on 03/21/2011
Alternative - 2 Monthly Energy Consumption report Page 1 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 3	Existing 80% 0489												
Electric													
On-Pk Cons. (kWh)	45,705	40,399	50,612	48,244	53,198	52,895	54,166	56,708	52,582	51,651	48,912	45,901	600,973
On-Pk Demand (kW)	162	158	178	180	222	230	238	236	232	214	200	160	238
Purchased Steam													
On-Pk Cons. (therms)	3,030	2,812	2,100	1,555	1,175	1,030	1,085	1,093	1,163	1,609	1,862	2,678	21,193
On-Pk Demand (therms/hr)	7	7	5	4	3	2	3	3	3	4	5	6	7
Purchased Chilled Water													
On-Pk Cons. (therms)	471	374	887	1,397	3,036	4,505	6,060	4,841	3,424	1,674	1,121	508	28,298
On-Pk Demand (therms/hr)	6	6	7	9	13	15	17	16	14	10	9	6	17
Energy Consumption													
Building	158,201 Btu/(ft2-year)												
Source	252,130 Btu/(ft2-year)												
Floor Area	44,249 ft2												

Environmental Impact Analysis

CO2	2,494,522 lbm/year
SO2	19,286 gm/year
NOX	3,877 gm/year

Trane Trace Monthly Energy Report from Trane Trace – Existing Façade 80% Glazing

Project Name: Millennium Science Complex
Dataset Name: MSC-existing-908075.TRC

TRACEm 700 v6.2.6.5 calculated at 01:49 PM on 03/21/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

MONTHLY ENERGY CONSUMPTION
By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
----- Monthly Energy Consumption -----													
Alternative: 4 Existing 90% 055													
Electric													
On-Pk Cons. (kWh)	45,987	40,745	50,762	48,586	53,639	53,362	54,709	57,236	53,092	52,023	49,262	46,174	605,576
On-Pk Demand (kW)	186	159	179	181	223	231	239	238	236	216	207	164	239
Purchased Steam													
On-Pk Cons. (therms)	3,117	2,878	2,186	1,645	1,243	1,086	1,136	1,156	1,233	1,711	1,957	2,769	22,115
On-Pk Demand (therms/hr)	7	7	5	4	3	3	3	3	3	4	5	6	7
Purchased Chilled Water													
On-Pk Cons. (therms)	512	400	969	1,515	3,185	4,681	6,259	5,026	3,588	1,801	1,215	561	29,713
On-Pk Demand (therms/hr)	7	6	8	9	13	15	17	16	15	11	9	7	17
Energy Consumption													
Building	163,838 Btu/(ft2-year)												
Source	258,434 Btu/(ft2-year)												
Floor Area	44,249 ft2												
Environmental Impact Analysis													
	CO2 2,583,413 lbm/year												
	SO2 19,973 gm/year												
	NOX 4,015 gm/year												

Trane Trace Monthly Energy Report from Trane Trace – Existing Façade 90% Glazing

Project Name: Millennium Science Complex
Dataset Name: MSC-existing-908075.TRC

TRACE® 700 v6.2.6.5 calculated at 01:49 PM on 03/21/2011
Alternative - 4 Monthly Energy Consumption report Page 3 of 3

By ACADEMIC

Environmental Impact Analysis

ONLY

Project Name: Millennium Science Complex
Dataset Name: MSC-4pcm-908075.TRC

Thomas Villacampa

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 3 3pane 80% 0489													
Electric													
On-Pk Cons. (kWh)	45,550	40,896	50,703	49,074	53,609	53,662	54,964	57,508	52,784	51,843	48,704	48,339	604,228
On-Pk Demand (kW)	183	182	181	184	226	236	245	243	233	214	196	164	245
Purchased Steam													
On-Pk Cons. (therms)	2,703	2,530	1,815	1,269	985	878	961	922	963	1,304	1,564	2,389	18,278
On-Pk Demand (therms/hr)	6	6	5	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	410	333	688	1,070	2,571	3,946	5,416	4,216	2,895	1,315	878	445	24,171
On-Pk Demand (therms/hr)	5	5	8	7	11	14	15	14	13	9	7	5	15
Energy Consumption													
Building	142,537 Btu/(ft2-year)												
Source	236,924 Btu/(ft2-year)												
Environmental Impact Analysis													
CO2	2,247,538 lbm/year												
SO2	17,377 gmi/year												
NOX	3,493 gmi/year												

ONLY

Trane Trace Monthly Energy Report from Trane Trace – Alternate Triple Pane Façade 80% Glazing

Project Name: Millennium Science Complex
Dataset Name: MSC-4pcm-908075.TRC

TRACER 700 v6.2.8.5 calculated at 03:11 PM on 02/14/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 2 3pane 75% 0458													
Electric	On-Pk Cons. (kWh)	45,442	40,834	50,544	47,919	63,404	53,476	54,782	57,301	52,834	51,489	48,531	602,542
	On-Pk Demand (kW)	161	181	180	184	228	238	245	242	231	212	195	245
Purchased Steam	On-Pk Cons. (therms)	2,688	2,519	1,798	1,248	982	860	950	904	940	1,280	1,543	18,085
	On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	6
Purchased Chilled Water	On-Pk Cons. (therms)	404	332	670	1,040	2,519	3,889	5,351	4,151	2,828	1,280	851	23,753
	On-Pk Demand (therms/hr)	5	4	6	7	11	13	15	14	12	8	7	15
Energy Consumption													
Building	140,980 Btu/(ft2-year)												
Source	235,165 Btu/(ft2-year)												
Floor Area	44,249 ft2												
Environmental Impact Analysis													
CO2	2,222,985 lbm/year												
SO2	17,187 gm/year												
NOX	3,455 gm/year												

TRACES 700 v6 2.6.6 calculated at 03:11 PM on 02/14/2011
Alternative - 2 Monthly Energy Consumption report Page 1 of 3

Project Name: Millennium Science Complex
Dataset Name: MSC-4pcm-008075.TPC

Trane Trace Monthly Energy Report from Trane Trace – Alternate Triple Pane Façade 75% Glazing

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Total

Alternative: 2 3pane 70% 0428

Electric On-Pk Cons. (kWh) 45,406 40,597 50,434 47,814 53,270 53,395 54,850 57,160 52,378 51,354 48,418 46,408 801,313
On-Pk Demand (kW) 158 180 178 183 228 235 244 242 231 210 194 180 244

Purchased Steam On-Pk Cons. (therms) 2,673 2,511 1,782 1,228 943 848 937 888 919 1,258 1,522 2,359 17,887
On-Pk Demand (therms/hr) 6 6 4 3 2 2 2 2 2 3 4 5 6

Purchased Chilled Water On-Pk Cons. (therms) 400 332 650 1,010 2,469 3,834 6,288 4,090 2,774 1,245 828 435 23,358
On-Pk Demand (therms/hr) 4 4 6 7 11 13 15 14 12 8 7 5 15

Energy Consumption

Building 139,541 Btu/(ft2-year)
Source 233,595 Btu/(ft2-year)

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2 2,200,303 lbm/year
SO2 17,011 gm/year
NOX 3,419 gm/year

TRACER 700 v8.2.8.5 calculated at 02:56 PM on 02/14/2011
Alternative - 2 Monthly Energy Consumption report Page 1 of 3

Project Name: Millennium Science Complex
Dataset Name: MSC-3pane70%glassncpm-700060.TRC

Trane Trace Monthly Energy Report from Trane Trace – Alternate Triple Pane Façade 70% Glazing

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Total

Alternative: 3 3pane 60% 0367

Electric	45,359	40,432	50,276	47,612	53,050	53,245	54,571	56,988	52,102	51,135	48,241	46,756	590,798
On-Pk Cons. (kWh)	156	157	175	181	225	235	243	241	231	204	191	159	243
On-Pk Demand (kW)													
Purchased Steam													
On-Pk Cons. (therms)	2,645	2,494	1,751	1,186	907	824	920	862	881	1,217	1,482	2,336	17,504
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	394	333	620	954	2,375	3,732	5,174	3,667	2,669	1,183	786	430	22,616
On-Pk Demand (therms/hr)	4	4	5	7	11	13	15	14	12	8	7	4	15

Energy Consumption

Building	136,933 Btu/(ft2-year)
Source	230,865 Btu/(ft2-year)
Floor Area	44,249 ft2

Environmental Impact Analysis

CO2	2,156,174 lbm/year
SO2	16,893 gm/year
NOX	3,355 gm/year

Project Name: Millennium Science Complex
Dataset Name: MSC-3pane60glassncpm-706050.TRC

TRACe® 700 v8.2.6.5 calculated at 02:56 PM on 02/14/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

Trane Trace Monthly Energy Report from Trane Trace – Alternate Triple Pane Façade 60% Glazing

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Total

Alternative: 4 3pane 50% 0306

Electric On-Pk Cons. (kWh) 45,357 40,338 50,144 47,428 63,002 63,377 64,710 67,141 51,004 50,955 48,082 46,627 690,164
On-Pk Demand (kW) 155 156 174 179 222 234 242 236 234 204 187 168 242

Purchased Steam On-Pk Cons. (therms) 2,622 2,474 1,728 1,164 881 811 915 848 853 1,177 1,450 2,312 17,223
On-Pk Demand (therms/hr) 6 6 4 3 2 2 2 2 2 3 4 5 6

Purchased Chilled Water On-Pk Cons. (therms) 394 335 595 901 2,264 3,641 6,084 3,875 2,576 1,123 750 426 21,964
On-Pk Demand (therms/hr) 4 4 5 6 11 13 14 13 12 8 6 4 14

Energy Consumption

Building Source 134,843 Btu/(ft2-year)
228,760 Btu/(ft2-year)

Floor Area 44,240 ft2

Environmental Impact Analysis

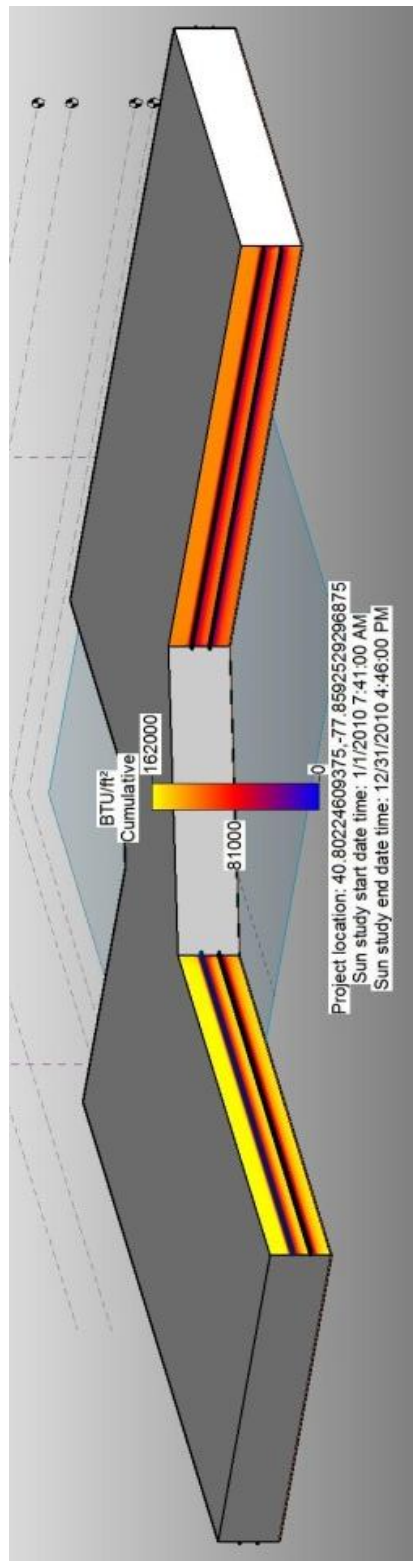
CO2 2,126,217 lbm/year
SO2 16,438 gm/year
NOX 3,304 gm/year

Project Name: Millennium Science Complex
Dataset Name: MSC-3pane50%0306-708060.TRC

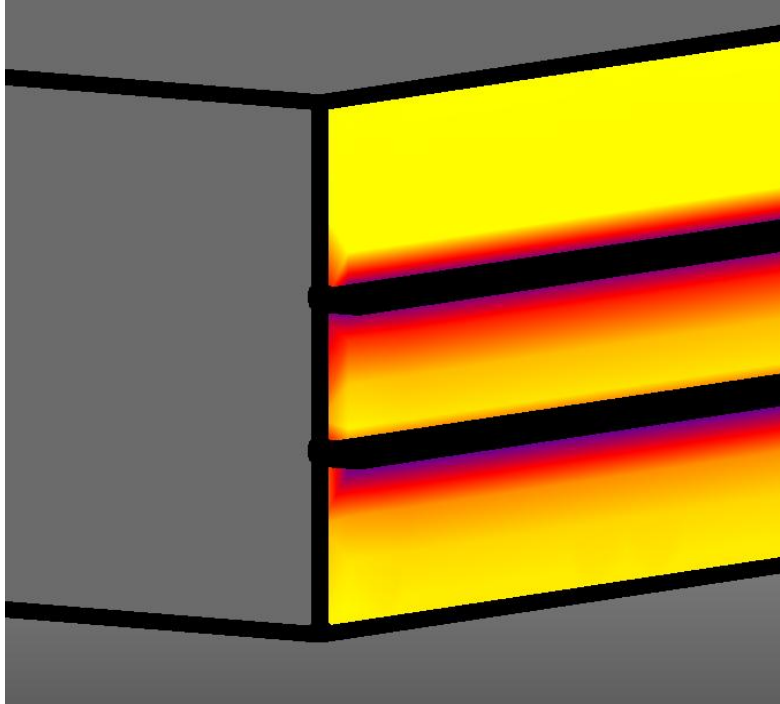
TRACE® 700 v8.2.6.5 calculated at 02:56 PM on 02/14/2011
Alternative - 4 Monthly Energy Consumption report Page 3 of 3

Trane Trace Monthly Energy Report from Trane Trace – Alternate Triple Pane Façade 50% Glazing

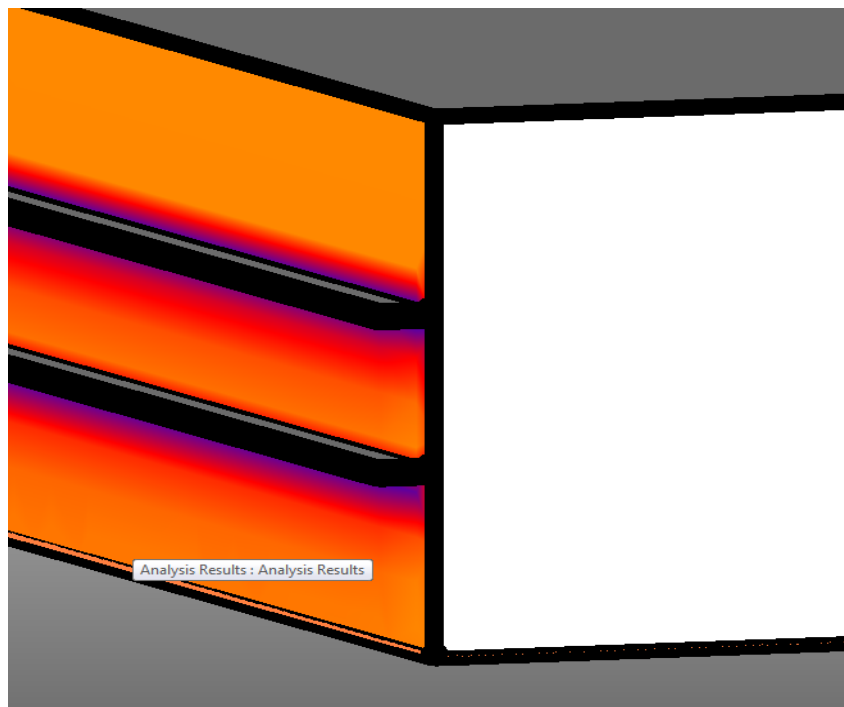
Project Vasari Shading Analysis



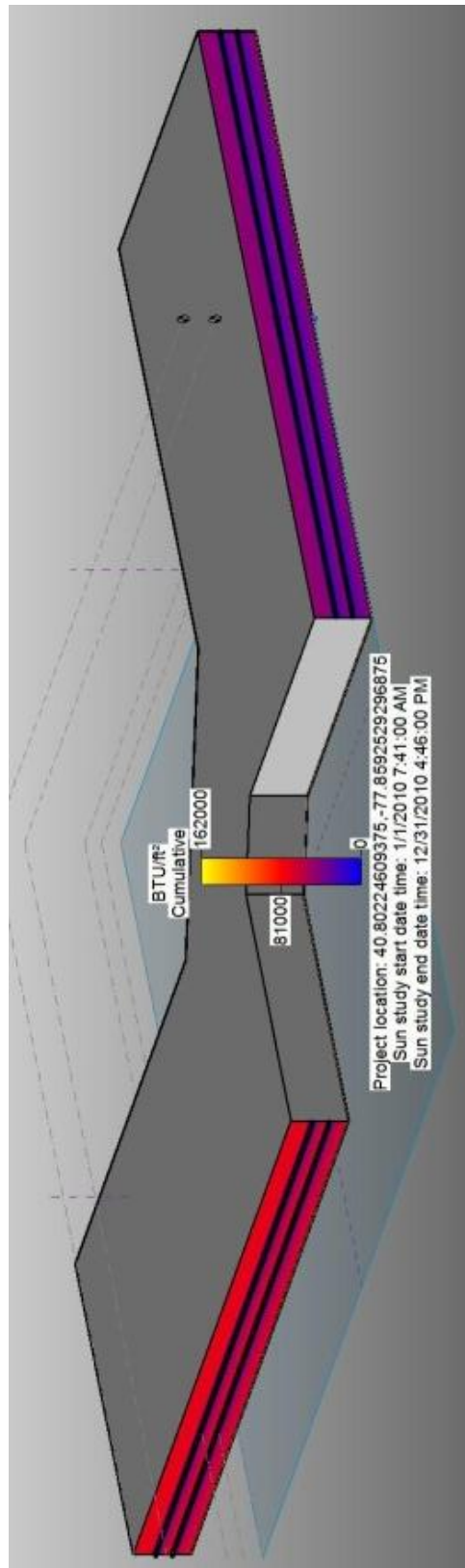
Project Vasari Total Cumulative Solar Radiation – South and East Facades



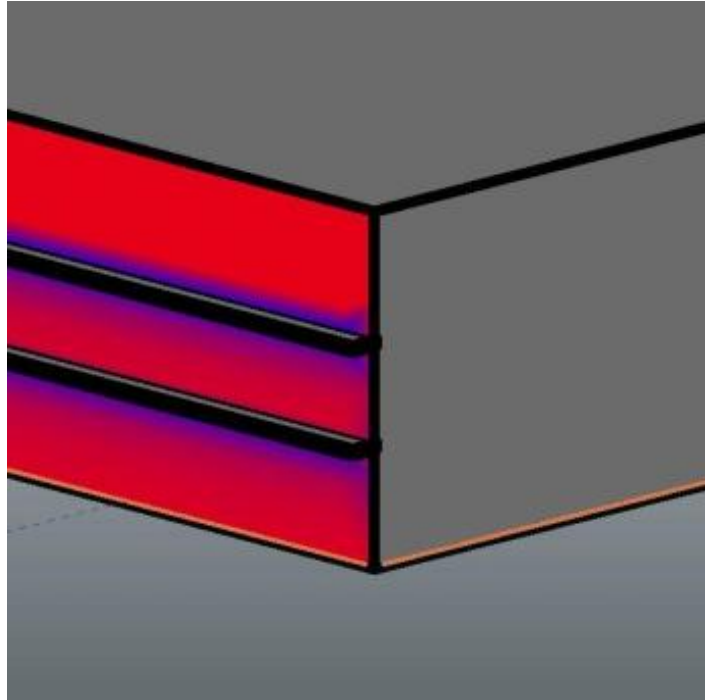
Project Vasari Total Cumulative Solar Radiation –East Facade



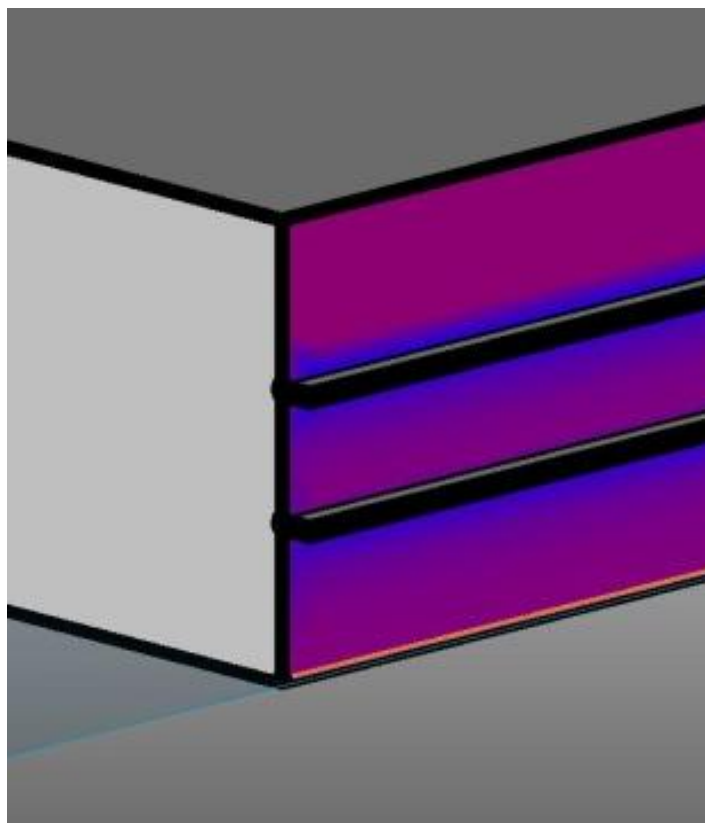
Project Vasari Total Cumulative Solar Radiation – South Facade



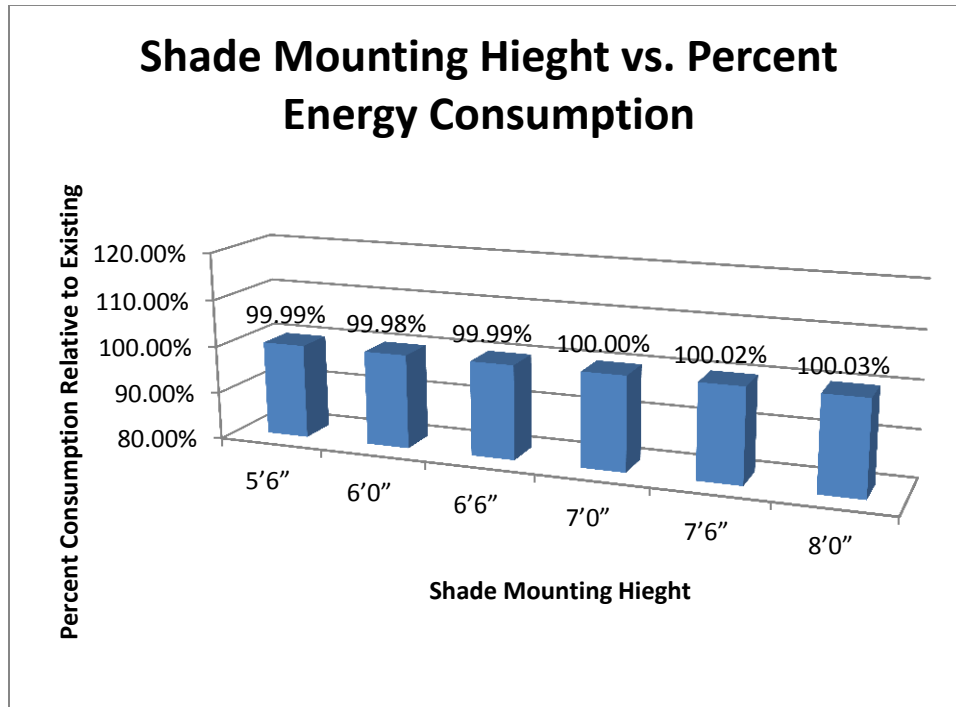
Project Vasari Total Cumulative Solar Radiation – North and West Facades



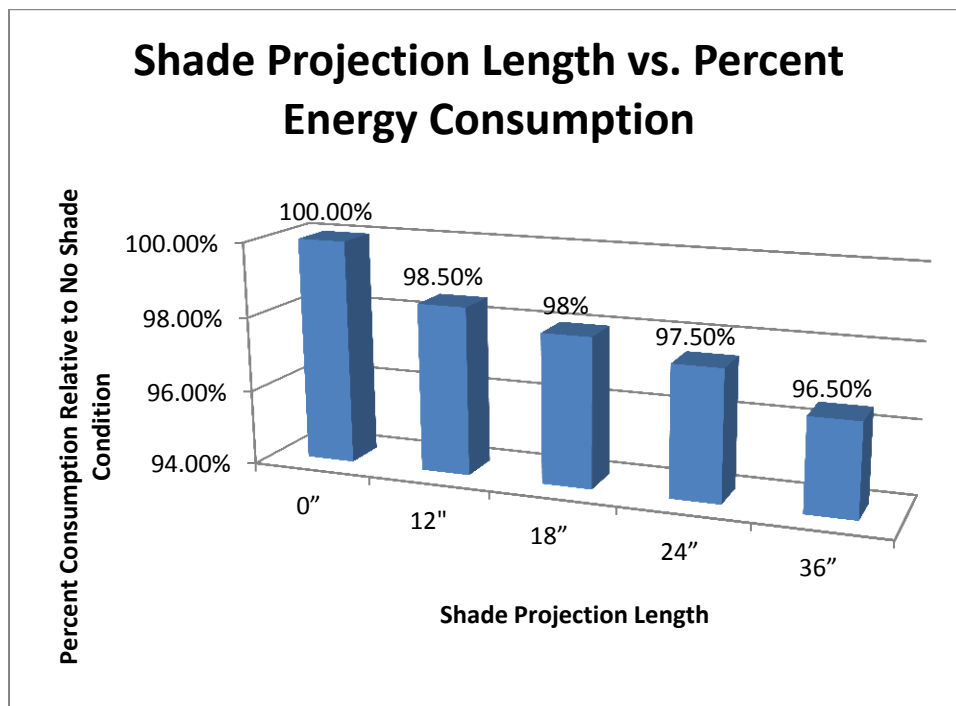
Project Vasari Total Cumulative Solar Radiation – North Facade



Project Vasari Total Cumulative Solar Radiation – East Facade



Graph of Project Vasari Shading Mounting Height Analysis



Graph of Project Vasari Shading Length Analysis

Energy Analysis of Lighting Redesigns

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 3 Lighting Redesign													
Electric	On-Pk Cons. (kWh)	43,984	39,148	48,753	46,218	51,464	52,837	55,152	50,564	49,801	46,802	45,303	581,353
	On-Pk Demand (kW)	152	153	171	176	219	237	233	220	200	186	155	237
Purchased Steam	On-Pk Cons. (therms)	2,683	2,528	1,762	1,209	916	825	868	893	1,241	1,511	2,372	17,759
	On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	3	4	5	6
Purchased Chilled Water	On-Pk Cons. (therms)	395	336	620	953	2,359	5,155	3,944	2,656	1,175	781	430	22,514
	On-Pk Demand (therms/hr)	4	4	5	7	11	13	13	12	8	6	4	15
Energy Consumption													
Building Source	135,853 Btu/(ft2-year)												
	227,185 Btu/(ft2-year)												
Floor Area	44,249 ft2												
Environmental Impact Analysis													
	CO2	2,142,151 lbm/year											
	SO2	16,562 gm/year											
	NOX	3,329 gm/year											

Trane Trace Monthly Energy Report – Lighting Redesign

TRACEm 700 v6.2.6.5 calculated at 03:42 PM on 03/21/2011
Alternative - 3 Monthly Energy Consumption report Page 1 of 1

Project Name: Millennium Science Complex
Dataset Name: MSC-day/lighting study, TRC

Energy Analysis of Alternative Duct Systems

Section	Component	Length (ft)	Airflow (cfm)	Width (in)	Height (in)	Hydraulic Diameter (in)	Round Diameter (in)	Max Diameter (in)	Area (in ²)	Velocity (fpm)	Absolute Roughness (ft)
1	Diffuser 90 Diverging Tee	4.00	600.00	1.00	1.00	1	12.00	12.00	113.10	763.9 763.9 763.9	0.0100
2	90 Rounded Elbow	5.00	600.00	14.00	10.00	11.66666667		11.67	106.90	808.2 808.2	0.0005
3	Transition	6.00	600.00	14.00	10.00	11.66666667		11.67	106.90	808.2 808.2	0.0005
4	90 Diverging Tee Fire Damper 90 Rounded Elbow	10.00	2000.00	18.00	14.00	15.75		15.75	194.83	1478.2 1478.2 1478.2	0.0005
5	Transition Diverge Heating Coil Transition Converge Supply Valve 90 Rounded Elbow	9.00	2000.00	18.00	14.00	15.75		15.75	194.83	1478.2 1478.2 1478.2 1478.2	0.0005
6	Fire Damper 90 Converging Tee	5.00	2000.00	18.00	14.00	15.75		15.75	194.83	1478.2 1478.2 1478.2	0.0005
7	Diverging Tap Diverging Tap Transition	40.00	6650.00	30.00	16.00	20.86956522		20.87	342.07	2799.4 2799.4 2799.4	0.0005
8	Diverging Tap Diverging Tap 45 Elbow	17.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2 3088.2	0.0005
9	45 Elbow	9.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2	0.0005
10	Fire Damper 90 Elbow	9.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2 3088.2	0.0005
11	90 Elbow	16.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2	0.0005
12	90 Elbow	8.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2	0.0005
13	90 Elbow	22.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2	0.0005
15	Bullhead Tee	9.00	8800.00	40.00	16.00	22.85714286		22.86	410.33	3088.2 3088.2	0.0005
16	Diverging Tap Diverging Tap 90 Elbow	75.00	14855.00	54.00	20.00	29.18918919		29.19	669.17	3196.7 3196.7 3196.7	0.0005
16	90 Elbow	6.00	5000.00	54.00	20.00	29.18918919		29.19	669.17	1076.0 1076.0	0.0005
17	Abrupt Opening	4.00	5000.00	54.00	20.00	29.18918919		29.19	669.17	1076.0 1076.0	0.0005

Example of Hand Static Pressure Loss Calculations Page One – Existing Design

Relative Roughness (e/D)	Kinematic Viscosity (ft ² /s)	Density (lb/ft ³)	Reynolds Number (Re)	Friction Factor (f)	Pressure Drop Per 100ft (in wg per 100ft)	Velocity Pressure (in wg)	Loss Coefficient (Co)	Pressure Drop (in wg)
0.010000	0.0001580	0.0750000	80584.84938	0.038929176	0.141595			0.0057
						0.036384669	1.12	0.4075
						0.036384669	1.58	0.0575
0.0005143	0.0001580	0.0750000	82887.27365	0.020990578	0.087896			0.0044
						0.040724546	0.19	0.0077
0.0005143	0.0001580	0.0750000	82887.27365	0.020990578	0.087896			0.0053
						0.040724546	0.49	0.0200
0.0003810	0.0001580	0.0750000	204659.9349	0.018233722	0.189194			0.0189
						0.136231856	1.12	0.1526
						0.136231856	0.19	0.0259
0.0003810	0.0001580	0.0750000	204659.9349	0.018233722	0.189194			0.0170
						0.136231856	1.52	0.2071
						0.136231856	0.12	0.3000
0.0003810	0.0001580	0.0750000	204659.9349	0.018233722	0.189194			0.0163
						0.136231856	0.19	0.3000
						0.136231856	0.19	0.0259
0.0003810	0.0001580	0.0750000	204659.9349	0.018233722	0.189194			0.0095
						0.136231856	0.19	0.0259
						0.136231856	0.35	0.0477
0.0002875	0.0001580	0.0750000	513560.5297	0.01624232	0.456141			0.1825
						0.488574279	0.07	0.0342
						0.488574279	0.07	0.0342
0.0002625	0.0001580	0.0750000	620503.3402	0.015826449	0.493872			0.0840
						0.594591215	0.07	0.0416
						0.594591215	0.07	0.0416
0.0002625	0.0001580	0.0750000	620503.3402	0.015826449	0.493872			0.0444
						0.594591215	0.07	0.0416
						0.594591215	0.07	0.0416
0.0002625	0.0001580	0.0750000	620503.3402	0.015826449	0.493872			0.0444
						0.594591215	0.19	0.1130
						0.594591215	0.33	0.1962
0.0002625	0.0001580	0.0750000	620503.3402	0.015826449	0.493872			0.0790
						0.594591215	0.11	0.0654
						0.594591215	0.11	0.0654
0.0002625	0.0001580	0.0750000	620503.3402	0.015826449	0.493872			0.0395
						0.594591215	0.11	0.0654
						0.594591215	0.11	0.0654
0.0002056	0.0001580	0.0750000	820226.9202	0.015006419	0.392905			0.2947
						0.637086058	0.31	0.1975
						0.637086058	0.31	0.1975
0.0002056	0.0001580	0.0750000	276077.7247	0.016507002	0.048964			0.0701
						0.072175998	0.11	0.0029
						0.072175998	0.11	0.0079
0.0002056	0.0001580	0.0750000	276077.7247	0.016507002	0.048964			0.0020
						0.072175998	1	0.0722
						0.072175998	1	4.81

Example of Hand Static Pressure Loss Calculations Page Two – Existing Design

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 2 Existing Static - 481													
Electric													
On-Pk Cons. (kWh)	45,487	40,469	50,384	47,729	53,159	53,284	54,585	56,988	52,149	51,193	48,293	46,816	600,535
On-Pk Demand (kW)	156	153	177	181	223	233	241	239	229	205	190	159	241
Purchased Steam													
On-Pk Cons. (therms)	2,636	2,481	1,745	1,187	914	826	919	865	889	1,222	1,484	2,328	17,496
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	409	346	652	999	2,440	3,800	5,242	4,040	2,733	1,226	817	447	23,153
On-Pk Demand (therms/hr)	4	4	6	7	11	13	15	14	12	8	7	4	15
Energy Consumption													
Building	138,184	Btu/(ft2-year)											
Source	231,943	Btu/(ft2-year)											
Floor Area	44,249	ft2											
Environmental Impact Analysis													
CO2	2,178,897	lbm/year											
SO2	16,846	gm/year											
NOX	3,386	gm/year											

Trane Trace Monthly Energy Report – Existing Design

Project Name: Millennium Science Complex
Dataset Name: MSC-Existing_2_2_TRC

TRACES® 700 v6.2.6.5 calculated at 11:17 AM on 03/09/2011
Alternative -2 Monthly Energy Consumption report Page 1 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
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Alternative: 3 Decrease 2 Inches - 660

Electric	On-Pk Cons. (kWh)	45,667	40,561	50,560	47,902	53,338	53,457	54,765	57,167	52,322	51,372	48,466	47,030	602,808
	On-Pk Demand (kW)	156	168	177	181	224	233	241	240	229	205	191	159	241

Purchased Steam

On-Pk Cons. (therms)	2,594	2,439	1,718	1,174	914	826	918	861	889	1,209	1,465	2,286	17,291
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6

Purchased Chilled Water

On-Pk Cons. (therms)	436	363	699	1,064	2,555	3,937	5,383	4,183	2,857	1,300	872	475	24,126
On-Pk Demand (therms/hr)	5	4	6	7	11	13	15	14	12	9	7	5	15

Energy Consumption

Building	140,081
Source	233,499

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2	2,208,817 lbm/year
SO2	17,077 gbm/year
NOX	3,433 gbm/year

Trane Trace Monthly Energy Report – Decrease Duct Size 2 Inches

Project Name: Millennium Science Complex
Dataset Name: MSC-Existing_2_TRC

TRACE® 700 v6.2.6.5 calculated at 11:17 AM on 03/09/2011
Alternative - 3 Monthly Energy Consumption report Page 2 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 4 Increase 2 Inches - 375													
Electric													
On-Pk Cons. (kWh)	45,354	40,415	50,280	47,627	53,054	53,182	54,480	55,883	52,047	51,088	48,191	46,668	599,267
On-Pk Demand (kW)	156	158	176	181	223	233	241	239	228	205	190	159	241
Purchased Steam													
On-Pk Cons. (therms)	2,661	2,506	1,763	1,195	914	828	923	866	889	1,230	1,496	2,352	17,625
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	396	336	625	960	2,372	3,736	5,211	3,978	2,660	1,183	786	431	22,675
On-Pk Demand (therms/hr)	4	4	5	7	11	13	15	14	12	8	7	4	15
Energy Consumption													
Building	137,298	Btu/(ft2-year)											
Source	231,209	Btu/(ft2-year)											
Floor Area	44,249	ft2											
Environmental Impact Analysis													
CO2	2,164,933	lbm/year											
SO2	16,738	gm/year											
NOX	3,364	gm/year											

Trane Trace Monthly Energy Report – Increase Duct Size 2 Inches

Project Name: Millennium Science Complex
Dataset Name: MSC-Existing_-2_TRC

TRACE® 700 v6.2.6.5 calculated at 11:17 AM on 03/09/2011
Alternative - 4 Monthly Energy Consumption report Page 3 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 2 Increase 4 Inches													
Electric													
On-Pk Cons. (kWh)	45,313	40,381	50,215	47,563	52,988	53,118	54,412	56,817	51,983	51,022	48,127	46,610	598,547
On-Pk Demand (kW)	156	158	176	181	223	233	241	239	228	205	190	159	241
Purchased Steam													
On-Pk Cons. (therms)	2,678	2,522	1,774	1,200	914	829	931	867	889	1,235	1,505	2,368	17,711
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	388	330	608	936	2,330	3,686	5,170	3,925	2,615	1,157	767	421	22,332
On-Pk Demand (therms/hr)	4	4	5	7	11	13	14	13	12	8	6	4	14
Energy Consumption													
Building	136,663 Btu/(ft2-year)												
Source	230,706 Btu/(ft2-year)												
Floor Area	44,249 ft2												
Environmental Impact Analysis													
	CO2 2,154,916 lbm/year												
	SO2 16,660 gm/year												
	NOX 3,349 gm/year												

Trane Trace Monthly Energy Report – Increase Duct Size 4 Inches

Project Name: Millennium Science Complex
Dataset Name: MSC-4_6_8.TRC

TRACE® 700 v6.2.6.5 calculated at 11:40 AM on 03/09/2011
Alternative - 2 Monthly Energy Consumption report Page 1 of 3

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 3 Increase 6 Inches													
Electric													
On-Pk Cons. (kWh)	45,286	40,359	50,171	47,520	52,944	53,076	54,368	56,773	51,940	50,978	48,085	46,518	598,016
On-Pk Demand (kW)	156	157	176	181	223	233	241	239	228	205	190	159	241
Purchased Steam													
On-Pk Cons. (therms)	2,689	2,532	1,781	1,204	914	830	932	867	889	1,238	1,510	2,378	17,766
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	381	326	597	921	2,302	3,653	5,135	3,891	2,585	1,139	755	415	22,099
On-Pk Demand (therms/hr)	4	4	5	7	11	13	14	13	12	8	6	4	14
Energy Consumption													
Building	136,219	Btu/(ft2-year)											
Source	230,342	Btu/(ft2-year)											
Floor Area	44,249	ft2											

Environmental Impact Analysis

CO2	2,147,907 lbm/year
SO2	16,606 gbm/year
NOX	3,338 gbm/year

Project Name: Millennium Science Complex
Dataset Name: MSC-4_6_8.TRC

Trane Trace Monthly Energy Report – Increase Duct Size 6 Inches

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 4 Increase 8 Inches													
Electric													
On-Pk Cons. (kWh)	45,266	40,343	50,140	47,490	52,912	53,045	54,309	56,743	51,910	50,947	48,054	46,437	597,596
On-Pk Demand (kW)	156	157	176	181	223	233	241	239	228	205	190	159	241
Purchased Steam													
On-Pk Cons. (therms)	2,697	2,540	1,786	1,207	914	831	933	869	889	1,241	1,514	2,386	17,806
On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water													
On-Pk Cons. (therms)	378	323	590	910	2,282	3,630	5,110	3,866	2,563	1,125	746	410	21,934
On-Pk Demand (therms/hr)	4	4	5	7	11	13	14	13	11	8	6	4	14
Energy Consumption													
Building	135,904 Btu/(ft2-year)												
Source	230,080 Btu/(ft2-year)												
Floor Area	44,249 ft2												
Environmental Impact Analysis													
	CO2 2,142,948 lbm/year												
	SO2 16,568 gm/year												
	NOX 3,330 gm/year												

Environmental Impact Analysis

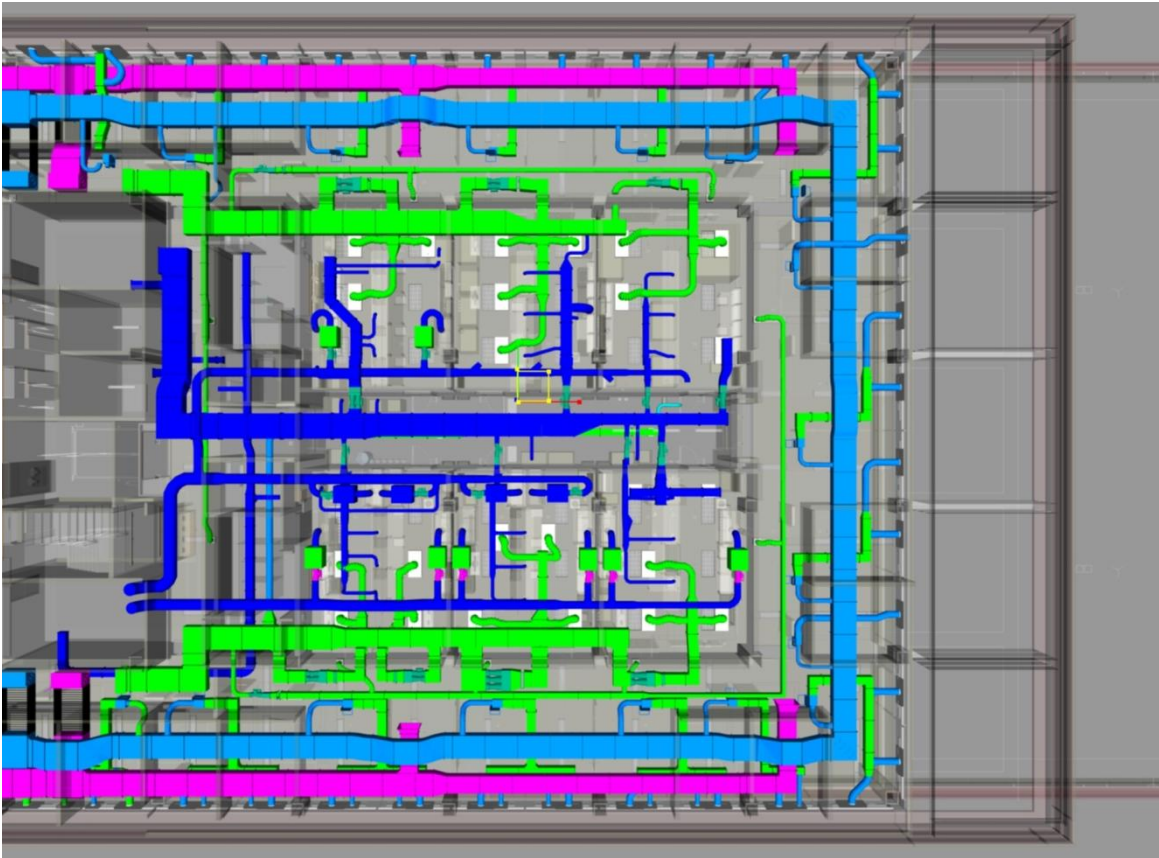
CO2	2,142,948	lbm/year
SO2	16,568	gm/year
NOX	3,330	gm/year

Project Name: Millennium Science Complex
Dataset Name: MSC-4_6_8_TRC

TRACE® 700 v6.2.6.5 calculated at 11:40 AM on 03/09/2011
Alternative - 4 Monthly Energy Consumption report Page 3 of 3

Trane Trace Monthly Energy Report – Increase Duct Size 8 Inches

Modeling of Duct Systems



Navisworks Model of Existing Duct Systems in Material Science Third Floor Wing

Complete Energy Analysis of All Design Alternatives

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

----- Monthly Energy Consumption -----

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
---------	-----	-----	-----	-----	-----	------	------	-----	------	-----	-----	-----	-------

Alternative: 3 Trip, 60%, LTG, and Duct Redesigns

Electric	On-Pk Cons. (kWh)	43,117	38,424	47,844	45,022	49,528	49,369	50,307	52,482	48,305	48,110	45,642	44,356	562,305
	On-Pk Demand (kW)	139	140	153	157	192	200	208	204	193	175	164	142	208
Purchased Steam	On-Pk Cons. (therms)	2,737	2,578	1,817	1,227	916	832	934	868	893	1,257	1,538	2,422	18,019
	On-Pk Demand (therms/hr)	6	6	4	3	2	2	2	2	2	3	4	5	6
Purchased Chilled Water	On-Pk Cons. (therms)	381	326	584	898	2,250	3,592	5,072	3,826	2,536	1,109	736	409	21,717
	On-Pk Demand (therms/hr)	4	4	5	6	10	12	14	13	11	8	6	4	14

Energy Consumption

Building	133,173 Btu/(ft2-year)
Source	222,177 Btu/(ft2-year)

Floor Area 44,249 ft2

Environmental Impact Analysis

CO2	2,069,890 lbm/year
SO2	16,235 gbm/year
NOX	3,263 gbm/year

Project Name: Millennium Science Complex

Dataset Name: Complete Energy Savings.trc

TRACEm 700 v6.2.6.5 calculated at 08:38 PM on 04/03/2011

Alternative - 3 Monthly Energy Consumption report Page 1 of 1

TRACER 700 v6.2.6.5 calculated at 08:38 PM on 04/03/2011
Alternative - 3 Monthly Energy Consumption report Page 1 of 1

Project Name: Millennium Science Complex
Dataset Name: Complete Energy Savings.trc

Trane Trace Monthly Energy Report Including All Design Alternatives – Triple Pan Glazing, 60% Glazing, Lighting Redesigns, and Duct Size Increase

APPENDIX G: Structural

Façade Redesigns

Existing Designs

Self Weight Calculation

	width(in)	thickness(in)	length(in)	Vol(cf)	pcf	Weight
Top Return	22.75	6	264	20.9	150	3.13
Bott Return	22.75	6	264	20.9	150	3.13
Front Panel	5	125.25	264	95.7	150	14.35
Side Returns	16.75	125.25	8	9.7	150	1.46
Brick	141.75	2	264	43.3	120	5.20
Totals				7.1	CY	27.26 K

Wind Load Calculations

Panel Dimensions/
Spans

length: 22 ft

width: 10.44 ft

length-to-width ratio ≥ 2

- assume one-way span between top and bottom flanges.

Minimum Thickness- One ft. strip

$$f'c = 5000 \text{ psi}$$

$$Fr = 7.5sq(f'c) = 530.33 \text{ psi}$$

Wind Pressures = w

windward: 18.45 psf

leeward 31.87 psf

w= 51.0 plf

Max Moment:

$$wl^2/8 = 694.4 \text{ lb-ft}$$

Max Stress at extreme fiber

$$1) f = MC/I \quad 2) f = Fr \quad 3) I = MC/Fr$$

$$4) C = t/2 \quad 3) I = bt^3/12$$

Allowable Thicknesses: Assuming Uncracked Section

Thickness (in)	I (in ⁴)	C (in)	Fr (psi)	$\emptyset M_{cap}$ (lb-ft)	Mu(SW)	Mu(wind)
2	8	1	530	318	858	694
3	27	1.5	530	716	1096	694
4	64	2	530	1273	1335	694
4.25	77	2.125	530	1437	1394	694
5	125	2.5	530	1989	1573	694
6	216	3	530	2864	1811	694

*Note: Moment due to wind and self-weight are separate cases

Minimum Reinforcing: ACI 318-08, 10.5.1

$$A_{s_{min}} = 0.0018 \cdot b \cdot d$$

Thickness (in)	$A_{s_{min}}$ (in ²)	Reinforcing
2	0.037	6x6 W2.1/2.1
3	0.056	6x6 W2.9/2.9
4	0.074	6x6 W4.0/4.0
5	0.108	6x6 W6.3/6.3
6	0.130	6x6 W7.4/7.4

Deflection Check

- assume simply supported one-foot section of panel

Thickness (in)	E (psi)	I (in ⁴)	$\Delta = 5wl^4/(384EI)$ (in)	$\Delta_{all} = l/360$	
2	4030508.7	8	2.64E-04	0.261	ok
3	4030508.7	27	7.82E-05	0.261	ok
4	4030508.7	64	3.30E-05	0.261	ok
5	4030508.7	125	1.69E-05	0.261	ok
6	4030508.7	216	9.78E-06	0.261	ok

Top/Bottom Return- Stress Check

- Lateral bending due to wing using entire c-section

W_u = 301.2 lb/ft

M_u = 18221 lb-ft

beff < 41.75
68.625
143

A_{top} = 131 in²

A_{bott} = 131 in²

A_{front} = 251 in² -within beff

N.A. = 5.87 in -from front of panel

I_{tot} = 12421 in⁴

f = Fr = 530.3 psi

c = 16.88 in

M_{cap} = 32526 lb-ft

Final Redesign- 60% Window to Wall Ratio

Self Weight Calculation- 60%

	width(in)	thickness(in)	length(in)	Vol(cf)	pcf	Weight
Top Return	14	6	264	12.8	150	1.93
Bott Return	14	5.5	264	11.8	150	1.76
Front Panel	6	141.25	264	129.5	150	19.42
Brick	157.25	2	264	48.0	120	5.77
Totals				7.5	CY	28.88
%increase				6.15%		

Allowable thicknesses: Concrete, no reinforcing

Thickness (in)	I (in ⁴)	C (in)	Fr (psi)	M _{cap} (lb-ft)	Mu(SW)	Mu(wind)
2	8	1	530.33	318.2	1091.101	883.1
3	27	1.5	530.33	715.9	1394.185	883.1
4	64	2	530.33	1272.8	1697.268	883.1
5	125	2.5	530.33	1988.7	2000.352	883.1
5.5	166.375	2.75	530.33	2406.4	2151.894	883.1
6	216	3	530.33	2863.8	2303.436	883.1

Window-to-Wall Ratio Results				
Ratio (%)	Minimum Thickness (in)	M _{cap} (lb-ft)	M _{sw} (lb-ft)	M _{wind} (lb-ft)
50	6	2864	2819	1081
60	5.5	2406	2152	883
70	4.5	1611	1477	706
80	4	1273	1058	550

Plenum Investigation

Waffle Slab Design

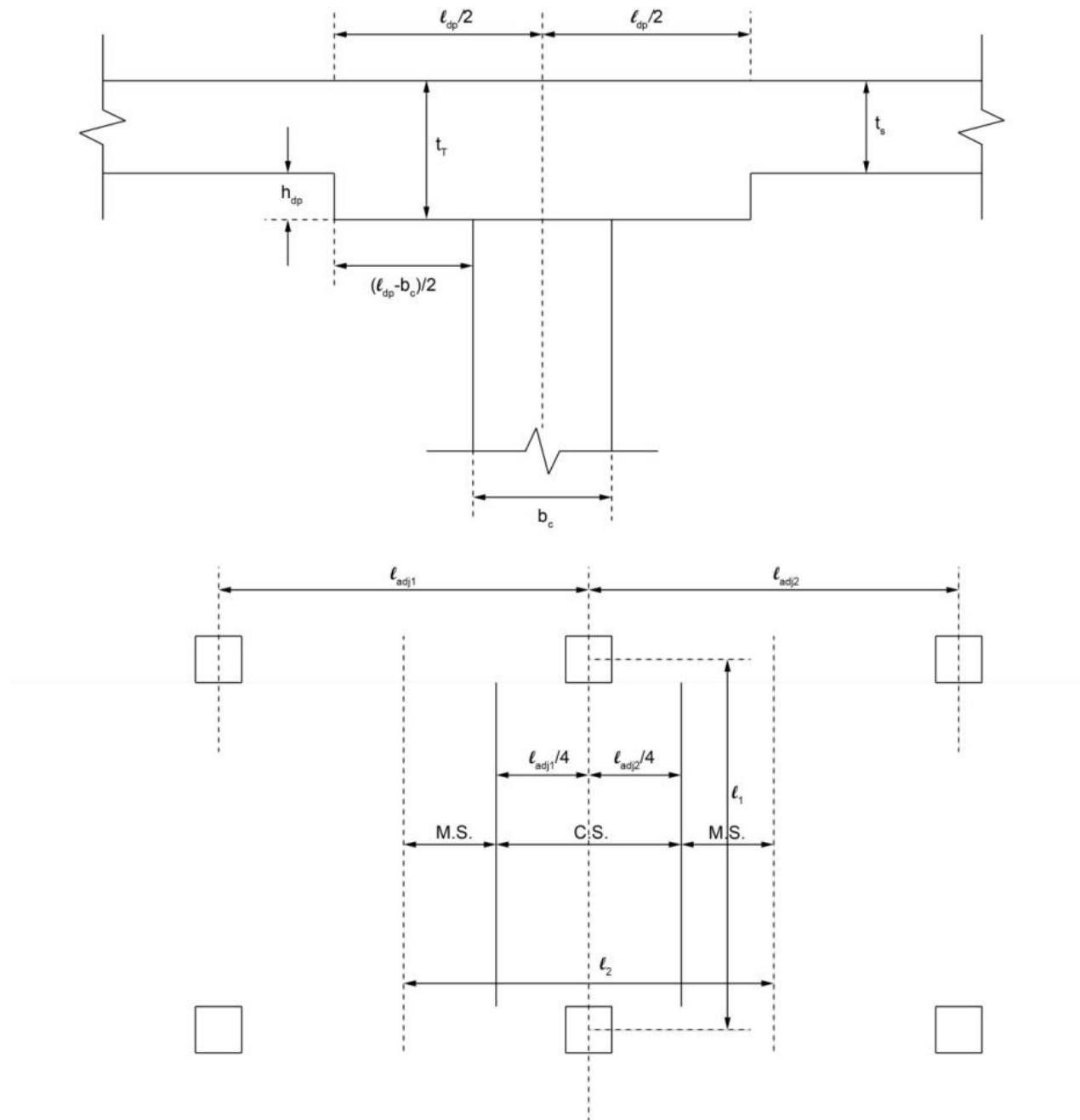
	Direct Design Requirements
OK	1) 3 or more continuous spans
OK	2) Panel Proportions of 2:1 long side to short side or less
OK	3) Regular Spacing; Adjacent spans do not differ by more than 1/3 the longer span
OK	4) Uniformly distributed gravity load LL/DL < 2 (unfactored)
OK	5) Maximum column offset: 10% of width of panel

$l_1 =$	22	ft.
$l_2 =$	22	ft.
$l_{adj} =$	22	ft.
No. Spans:	5	
Adjacent Span (ft.)	22	
Live Load	150	psf
Dead Load	148.8	psf
Column Offset (%)	0	

Self Weight

area	484	SF
slab depth	4.5	in
pan depth	8	in
concrete den	150	pcf
# pans	29	
pan size	30	in
rib width	6	in
joist spacing	36	in
total weight	118.8	psf

f'_c (psi)	4000
l_{adj1} (ft.)	22
l_{adj2} (ft.)	22
column strip (ft.)	11
middle strip (ft.)	11
l_{dp} (in.)	90
w_{dp} (in.)	90
t_s (in.)	4.5
h_{dp} (in.)	8
t_T (in.)	12.5
h_c (in.)	24
b_c (in.)	24
E_{cb} (psi)	0
E_{cbDP} (psi)	0
E_{cs} (psi)	4E+06
I_b (in.^4)	3840
I_s (in.^4)	1002.4
$A_{CS DP}$ (in.^2)	1314
$A_{CS slab}$ (in.^2)	594



ACI Table 9.5c - Minimum Thickness Without Interior Beams (ft)						
Fy (ksi)	Without Drop Panels			With Drop Panels		
	Exterior Panels		Interior Panels	Exterior Panels		Interior Panels
	Without Edge Beam	With Edge Beam		Without Edge Beam	With Edge Beam	
40	0.621	0.569	0.569	0.569	0.513	0.513
60	0.683	0.621	0.621	0.621	0.569	0.569
75	0.732	0.661	0.661	0.661	0.603	0.603

$M_0 =$	483.73	k*ft.
$\alpha_f =$	0.000	
$l_2/l_1 =$	1	
$\alpha_f * l_2/l_1 =$	0.000	

$C_{dp} =$	18423	$\beta_t =$	0.00
$C_{slabCS} =$	3923	$\beta_t =$	0.00
$C_{slabMS} =$	3923	$\beta_t =$	0.00

Interior Span

Negative Factored Moment: 314.42 k*ft.

Positive Factored Moment: 169.30 k*ft.

End Span

	1	2	3	4	5
(ft*k)	Exterior Edge Unrestrained	Beams Between all supports	Without Beams Between Int. Supports		Exterior Edge Fully Restrained
			Without Edge Beam	With Edge Beam	
Int. Negative Factored Mom.	362.80	338.61	338.61	338.61	314.42
Positive Factored Mom.	304.75	275.72	251.54	241.86	169.30
Ext. Negative Factored Mom.	0.00	77.40	125.77	145.12	314.42

Column Strip Moments(K-ft)

<u>Int. Negative</u>					
$l_2/l_1=$	0.5	1	1	0	2
$\alpha_f * l_2/l_1=0$	0.75	0.75	0.75	0.75	0.75
0.000	0.75	0.75	0.75	0.75	0.75
$\alpha_f * l_2/l_1 \geq 1$	0.9	0.75	0.75	1.05	0.45

<u>Ext. Negative</u>						
$l_2/l_1=$		0.5	1	1	0	2
$\alpha_f * l_2/l_1=0$	$\beta_t=0$	1	1.00	1	1.00	1
	0.00	1.00	1.00	1.00	1.00	1.00
	$\beta_t \geq 2.5$	0.75	0.75	0.75	0.75	0.75
0.000	$\beta_t=$	1.00	1.00	1.00	1.00	1.00
$\alpha_f * l_2/l_1 \geq 1$	$\beta_t=0$	1	1.00	1	1.00	1
	0.00	1.00	1.00	1.00	1.00	1.00
	$\beta_t \geq 2.5$	0.9	0.75	0.75	1.05	0.45

<u>Pos. Moment</u>					
$l_2/l_1=$	0.5	1	1	0	2
$\alpha_f * l_2/l_1=0$	0.6	0.60	0.6	0.60	0.6

Design Moment Summary

ft.*k	Moments:	Int. Negative	Ext. Negative	Positive
Interior Span	M.S.	78.61	-----	67.72
	C.S.	235.82	-----	101.58
Exterior Span	M.S.	84.65	0.00	100.62
	C.S.	253.96	125.8	150.92

Column Strip Reinforcement

Interior Span

Int. Negative

$$\begin{aligned} A_{s \min} &= 1.49 \text{ in.}^2 \\ b_{\text{eff}} &= 66 \text{ in.} \\ d &= 10.5 \text{ in.} \\ M_u/(4d) &= 5.61 \text{ in.}^2 \\ \text{try } A_s &= 6.32 \text{ in.}^2 \\ a &= 1.69 \text{ in.} \\ c &= 1.99 \text{ in.} \\ \rho &= 0.91 \text{ OK} \\ \epsilon_u &= 0.013 \text{ OK} \\ \phi M_n &= 274.59 \text{ ft.*k} \end{aligned}$$

8 #8

$$\begin{aligned} bw &= 90 \text{ in} \\ &162 \text{ in} \\ b_{\text{eff}} &\leq 336.00 \text{ in} \\ &66 \text{ in} \end{aligned}$$

h=	12.5	<- adjust for b_{eff}	
rebar #	8		
diamete			
r	1		in.
area	0.79		in. ²

Positive

$$\begin{aligned} A_{s \min} &= 0.68 \text{ in.}^2 \\ b_{\text{eff}} &= 30 \text{ in.} \\ d &= 10.50 \text{ in.} \\ M_u/(4d) &= 2.42 \text{ in.}^2 \\ \text{try } A_s &= 2.37 \text{ in.}^2 \\ a &= 1.39 \text{ in.} \\ c &= 1.64 \text{ in.} \\ \rho &= 0.75 \text{ OK} \\ \epsilon_u &= 0.016 \text{ OK} \\ \phi M_n &= 104.55 \text{ ft.*k} \end{aligned}$$

3 #8

h=	12.5	
rebar #	8	
diamete		
r	1	in.
area	0.79	in. ²

Middle Strip Reinforcement

Interior Span

Int. Negative

$A_{s \min} =$	0.54	in. ²				
$b_{\text{eff}} =$	24	in.	- 4*rib width			
$d =$	10.5625	in.				
$M_u/(4d) =$	1.86	in. ²				
try $A_s =$	1.76	in. ²	4 #7	$h =$	12.5	<- adjust for b_{eff}
$a =$	1.29	in.		rebar #	7	
$c =$	1.52	in.		diameter	0.875	in.
$\rho =$	0.69	OK		area	0.44	in. ²
$\epsilon_u =$	0.018	OK				
$\phi M_n =$	78.53	ft.*k	FAIL			

Positive

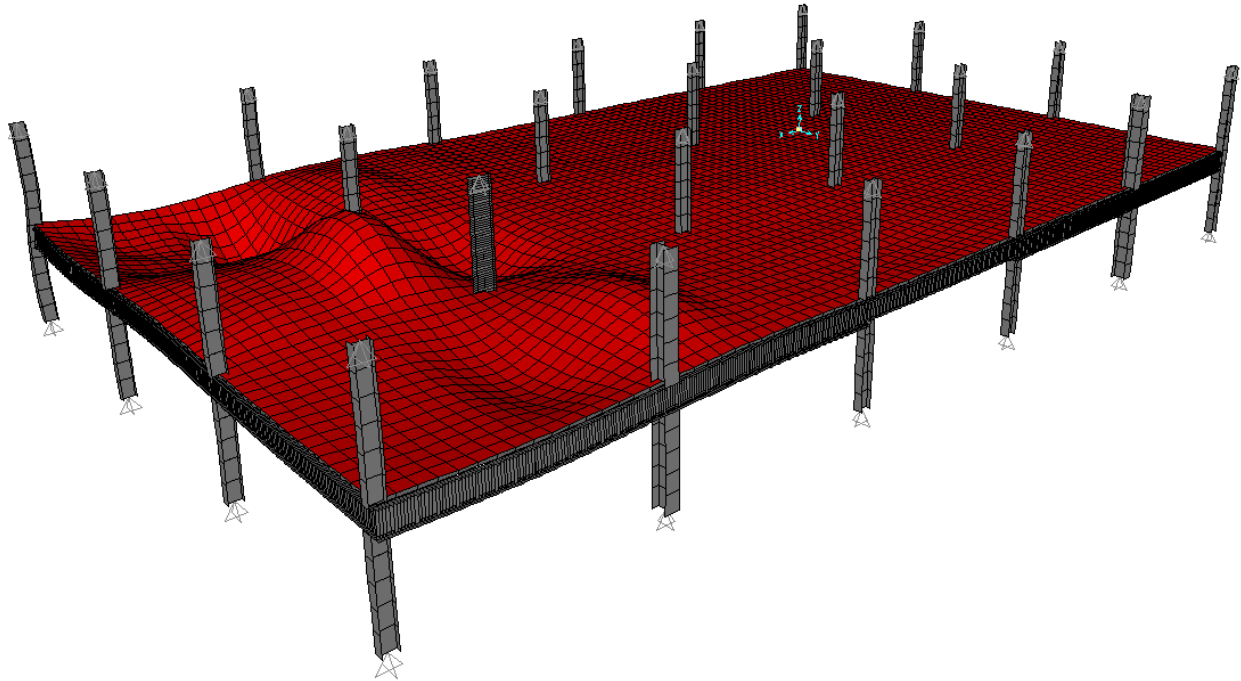
$A_{s \min} =$	0.81	in. ²				
$b_{\text{eff}} =$	36	in.	- joist spacing			
$d =$	10.56	in.				
$M_u/(4d) =$	1.60	in. ²				
try $A_s =$	1.76	in. ²	4 #7	$h =$	12.5	
$a =$	0.86	in.		rebar #	7	
$c =$	1.01	in.		diameter	0.875	in.
$\rho =$	0.46	OK		area	0.44	in. ²
$\epsilon_u =$	0.028	OK				
$\phi M_n =$	80.24	ft.*k	OK			

Existing Conditions Vibration Modeling

Modal Analysis Results

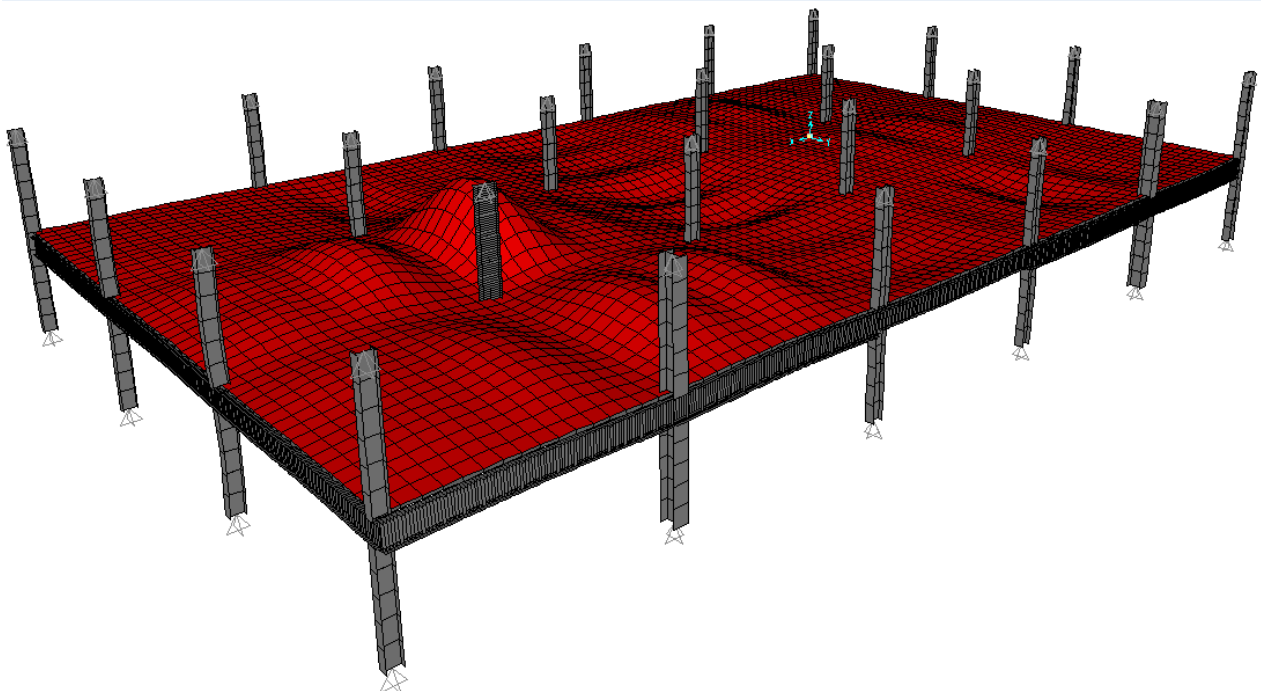
Bay-A: $T=0.05373s$, Rayleigh: $T=.0639s$

Deformed Shape (MODAL) - Mode 6 - $T = 0.05373$; $f = 18.61004$



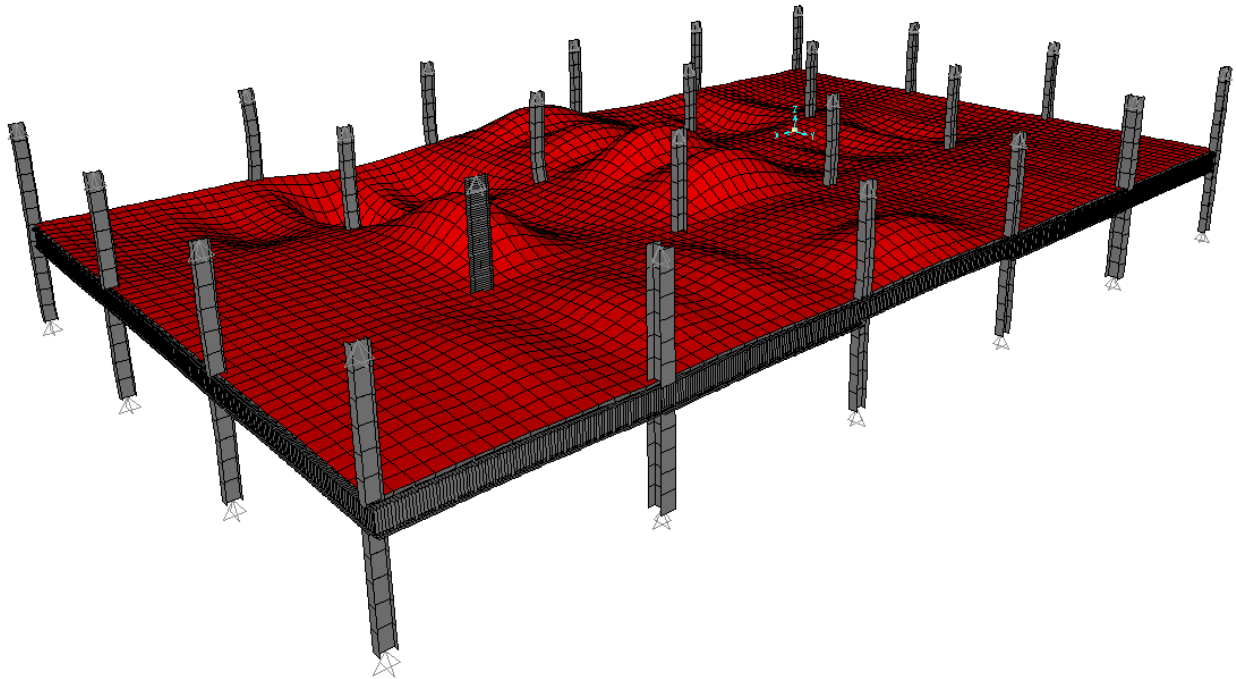
Bay-B: $T = 0.05092s$, Rayleigh: $T = 0.0601s$

Deformed Shape (MODAL) - Mode 11 - $T = 0.05092$; $f = 19.63806$



Bay-C: $T = 0.05053s$, Rayleigh: $T = 0.0649s$

Deformed Shape (MODAL) - Mode 12 - $T = 0.05053$; $f = 19.78940$

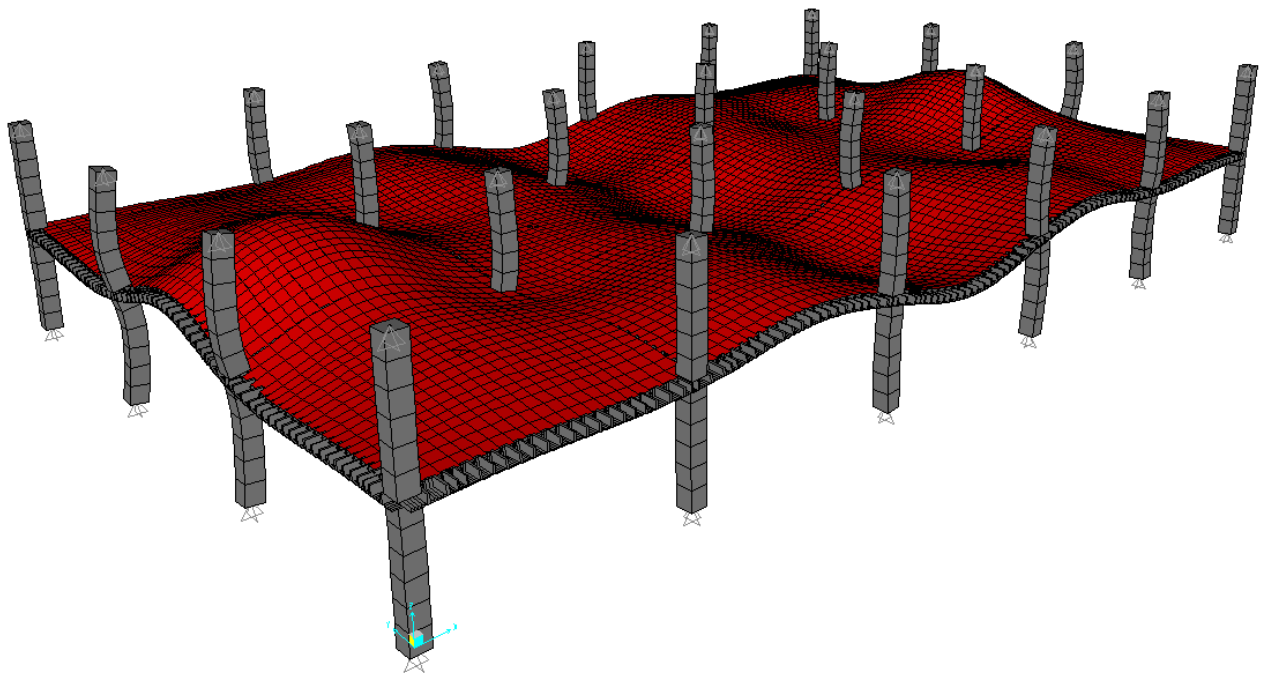


Waffle Slab Vibration Modeling

Modal Analysis Results Example

Bay-A: $T = 0.0597s$, Rayleigh: $T = 0.0695$

Deformed Shape (MODAL) - Mode 12 - $T = 0.06597$; $f = 15.15814$

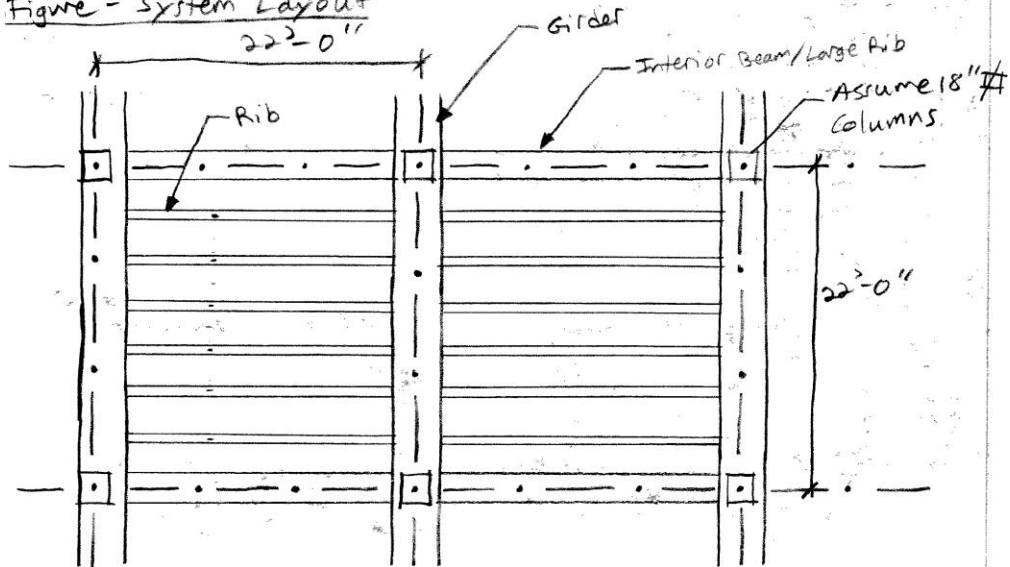


One Way Concrete Pan-Joist Designs

Gravity System Redesigns

One-Way Concrete Pan-Joist System

Figure - System Layout



Floor Loadings (1st to 3rd Floor)

SDL = 30 psf, LL = 150 psf (Laboratories)

$$w_u = 1.2(30) + 1.6(150) = 276 \text{ psf}$$

1) Minimum Thicknesses (Table 9.5A)

a) Solid one-way slabs, both ends continuous

$h \geq l/28$, need $h \geq 4.5''$ for 2-hr fire-rating

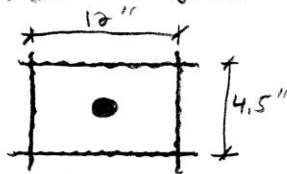
$$l \leq h(28) = \frac{4.5(28)}{12} = 10.5'$$

b) Beams/or ribbed one-way slabs, one end continuous

$$h \geq l/18.5 = \frac{22' \times 12}{18.5} = 14.27''$$

* Try 3' module: 30/6 pan-joist with 10" deep pans.

2) Slab Design



- reinforced @ $h/2$

$$w_u = 276 \text{ psf} (1') = 276 \text{ plf}$$

$$S.W. = \frac{4.5(12)}{144} (150 \text{ pcf}) \times 1.2 = 67.5 \text{ plf/ft}$$

$$w_u = 276 + 67.5 = \boxed{343.5 \text{ plf/ft}}$$

- Design Moments

• Positive - interior spans: $\frac{w_u l_n^2}{16}$ (ACI 318-08, 8.3.3)

$$M_{\max}^+ = \frac{343.5 \text{ plf/ft} \left(\frac{30}{12}\right)^2}{16} = \underline{134.2 \text{ lb-ft}}$$

• Negative - interior spans: $\frac{w_u l_n^2}{12}$ ($l_n \leq 10 \text{ ft}$)

$$M_{\max}^- = -\frac{343.5 \text{ plf/ft} \left(\frac{30}{12}\right)^2}{12} = \underline{-178.9 \text{ lb-ft}}$$

- Reinforcement

• Minimum: $0.0018(4.5)(12 \text{ in/ft}) = \underline{0.0972 \text{ in}^2}$

- use (1) #3 @ 12" = $0.11 \text{ in}^2/\text{ft}$

• strength check: using 4ksi concrete, 60ksi steel.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.11(60)}{0.85(4)(12 \text{ in/ft})} = 0.162 \text{ in}, c = \frac{a}{0.85} = 0.19 \text{ in}$$

$$E_s = \frac{0.003}{0.19} (2.25 - 0.19) = 0.098 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n_{\text{slab}} = 0.9(0.11)(60 \text{ ksi/ft})(2.25 - \frac{0.162}{2}) = \underline{1.07 \text{ K-ft}}$$

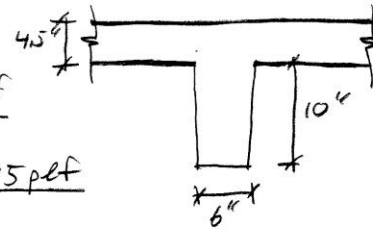
$\gg 0.18 \text{ K-ft}$
✓ OK

3) Joist Design : 30/6, $d=10''$ - Loads

$$\cdot \text{slab: } 343.5 \text{ pcf} \times 3' = 1.03 \text{ klf}$$

$$\cdot \text{joist (sw): } (1.2) \frac{(6 \times 10)}{144} (150 \text{ pcf}) = 75 \text{ pcf}$$

$$w_u = 1.106 \text{ klf}$$

- Design Moments (ACI 318-08, 8.3.3) $l_n = 22' - 3' = 19'$

$$\text{Max Pos. Mom.: } M_{\max}^+ = \frac{w_u l_n^2}{14} = \frac{1.106 (19)^2}{14} = 28.52 \text{ k-ft}$$

(end span)

$$\text{Max Neg. Mom.: } M_{\max}^- = \frac{w_u l_n^2}{10} = \frac{1.106 (19)^2}{10} = -39.92 \text{ k-ft}$$

- Bottom Reinforcement (Each Rib)

$$d = 10 + 4.5 - 1.5 - \frac{1}{8} - \frac{1}{2} = 12 \text{ in}$$

$$A_s = \frac{M_u}{4d} = \frac{28.52}{4(12)} = 0.59 \text{ in}^2 \Rightarrow \text{Try (1) \#7, } A_s = 0.6 \text{ in}^2$$

$$d_{\text{act}} = 14.5 - 1.5 - \frac{1}{8} - \frac{1}{16} = 12.06 \text{ in}$$

$$b_{\text{eff}} \leq \begin{cases} \frac{1}{4} l_n = 57 \text{ in} \\ b_w + 16 h_f = 78 \text{ in} \\ b_w + c_d = 36 \text{ in} \end{cases}$$

$$a = \frac{0.6(60)}{0.85(4)(36)} = 0.294 \text{ in}$$

$$c = 0.346 \text{ in}$$

$$\epsilon_s = \frac{0.003}{0.346} (12.06 - 0.346) = 0.1016 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n = 0.9(0.6)(60/12)(12.06 - \frac{0.294}{2}) = 32.1 \text{ k-ft} > 28.5 \text{ k-ft}$$

* check M_{uy}

$$M_{uy} = 0.9(0.85)(\frac{1}{2})(36)(4.5)(12.06 - \frac{4.5}{2}) = 405 \text{ k-ft} > M_u$$

* No T-beam behavior.

pg.

- Top Reinforcement

$$d_{act} = 14.5 - 2.25 = \underline{12.25 \text{ in}}$$

$$A_s = \frac{M_u}{4d} = \frac{39.92}{4(12.25)} = 0.815 \text{ in}^2 \Rightarrow \text{use (1) \#9}$$

$$A_s = \underline{1.00 \text{ in}^2}$$

$$a = \frac{1.00(60)}{0.85(4)(6)} = \underline{2.94 \text{ in}} \quad c = \underline{3.46 \text{ in}}$$

$$\epsilon_s = \frac{0.003}{3.46} (12.25 - 3.46) = 0.0076 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n = 0.9(1.00)(60/\text{in})(12.25 - \frac{2.94}{2}) = \underline{48.5 \text{ k-ft}} > 39.9$$

✓ ok

4) Joist Shear Design

a) Determine shear strength w/o stirrups

$$V_c = 2\lambda\sqrt{f'_c} \cdot b_w d = 2(1.0)\sqrt{4000}(6)(12.06) = \underline{9.15 \text{ K}}$$

$$\phi V_n = 1.1\phi V_c = 1.1(0.75)(9.15 \text{ K}) = \underline{7.55 \text{ K}}$$

b) $V_u @ d$

$$V_u = w_u l_n / 2 = \frac{1.106 \text{ k/ft}(19')}{2} = \underline{10.51 \text{ K}}$$

$$V_u @ d = 10.51 - \frac{12.06}{12}(1.106) = \underline{9.4 \text{ K}}$$

- what distance: x , is $\phi V_n \Rightarrow 7.55 = 10.51 - \frac{x}{12}(1.106)$

$$x = \underline{32.1 \text{ in}}$$

c) Shear strength required by reinforcement

$$V_s = \frac{V_u}{\phi} - V_c = \frac{9.4}{0.75} - 9.15 = \underline{3.38 \text{ K}}$$

$$4\sqrt{4000}(6)(12.06) = \underline{18.3 \text{ K}} > V_{s \text{ req}} \Rightarrow S_{\max} = \min \left\{ \frac{d}{2} = \underline{6.03 \text{ in}}, 24 \right\}$$

d) Minimum Shear Reinforcement

$$A_{v \min} = \max \left\{ \frac{0.75\sqrt{4000}(6)(6)}{60,000} = 0.0285 \text{ in}^2, \frac{50(6)(6)}{60,000} = \underline{0.03 \text{ in}^2} \right\}$$

- use (1) #3, $A_v = \underline{0.11 \text{ in}^2}$

Joist - Shear

pg.

e) Shear Reinforcement Design - Joist

$$S = 0.11(60)(12.06)/3.38k = 23.55 \text{ in}$$

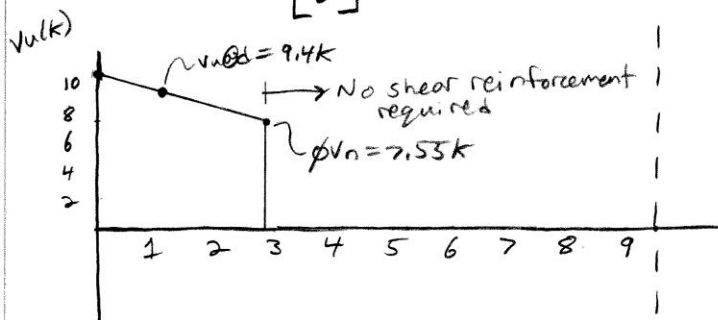
-when $S = 24''$

$$V_s = 0.11(60)(12.06)/24 = 3.317k$$

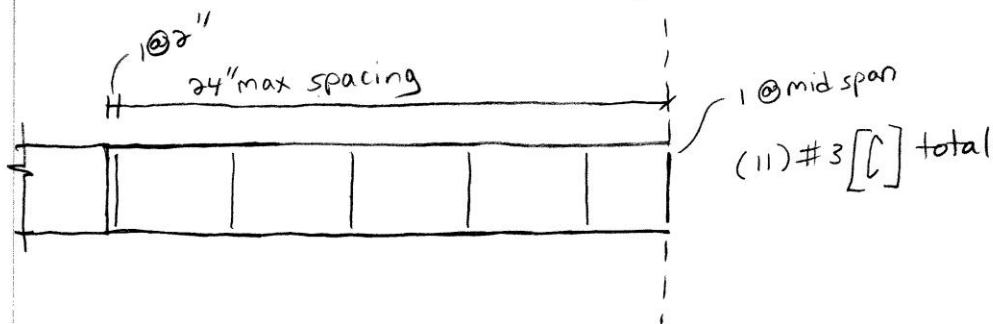
$$V_u = 0.75(3.317 + 9.15) = 9.35k$$

$$d_r = (9.4 - 9.35)(12)/1.106 = 0.542 \text{ in} < 2''$$

* use (1) #3  @ 2 in, then @ 24''



Symmetric



* For Large Rib/Interior Beams

$$V_u = \frac{1.255(19)}{2} = 11.92k, V_{u@d} = 10.8k, V_c = 27.6k, \phi V_n = 22.7k$$

$\phi V_n > V_{u@d}$, no shear reinforcement needed.

-use (2) #3 , spaced as detailed for joist above (for constructability)

P9.

3.1) Consider Larger Rib/Interior Beams

- slab: 1.03 k/ft

- SW: $(1.2) \frac{(18 \times 10)}{144} (150 \text{ pcf}) = 225 \text{ pcf}$

$$W_u = 1.255 \text{ k/ft}$$

• Design Moments

$$M_{\max}^+ = \frac{W_u l_n^2}{14} = \frac{1.255 (19)^2}{14} = 32.52 \text{ k-ft}$$

$$M_{\max}^- = \frac{W_u l_n^2}{10} = \frac{1.255 (19)^2}{10} = -45.31 \text{ k-ft}$$

• Bottom Reinforcement

$$d = 12 \text{ in}, A_s = \frac{M_u}{4d} = \frac{32.52}{4(12)} = 0.68 \text{ in}^2$$

$$\text{— use (2) \#6, } A_s = 0.88$$

$$b_{\text{eff}} \left\{ \begin{array}{l} \frac{1}{4} l_n = 57 \text{ in} \\ b_w + 16t_f = 90 \text{ in} \\ b_w + d = 18 + (30 - 6) = 42 \text{ in} \end{array} \right.$$

$$a = \frac{0.88(60)}{0.85(4)(42)} = 0.370 \text{ in}$$

$$c = 0.435 \text{ in}$$

$$E_s = \frac{0.003}{0.435} (12 - 0.435) = 0.0798 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n = 0.9(0.88)(60/12)(12 - \frac{0.370}{2}) = 46.8 \text{ k-ft} > 32.52 \quad \checkmark \text{ ok}$$

• Top Reinforcement

$$d = 12.25 \text{ in}, A_s = \frac{45.31}{4(12.25)} = 0.92 \text{ in}^2, \text{ use (2) \#6, } A_s = 0.88 \text{ in}^2$$

$$a = \frac{0.88(60)}{0.85(4)(18)} = 0.863 \text{ in}, c = 1.015 \text{ in}$$

$$E_s = \frac{0.003}{1.015} (12.25 - 1.015) = 0.033 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n = 0.9(0.88)(60/12)(12.25 - \frac{0.863}{2}) = 46.8 \text{ k-ft} > 45.31 \quad \checkmark \text{ ok}$$

5) Girder Design: Assume 36" wide (Interior Frame)

$$w_u = (343.5)(22') + \frac{75 \text{ pcf}(6)(19')}{22'} = \underline{7.95 \text{ klf}}$$

$$\text{s.w.} = 1.2 \left(\frac{10 \times 36}{144} \right) (150 \text{ pcf}) = \underline{450 \text{ pcf}}$$

$$\boxed{W_u = 8.4 \text{ klf}}$$

- Design Moments, $l_n = 22 - \frac{18}{12} = 20.5'$

• Positive Moments

$$\text{- End span: } \frac{W_u l_n^2}{14} = \frac{8.4(20.5')^2}{14} = \underline{252.15 \text{ k-ft}}$$

$$\text{- Int. span: } \frac{W_u l_n^2}{16} = \underline{220.63 \text{ k-ft}}$$

• Negative Moments

$$\text{- Ext. Face, 1st Int. supp.: } \frac{W_u l_n^2}{10} = \underline{-353 \text{ k-ft}}$$

$$M(\text{CF}) = -353 + \frac{8.4 \times (22-x)}{2} + (353 - 220.63) \times \frac{x}{22}$$

$$M(9'') = \boxed{-278.6 \text{ k-ft}}$$

$$\text{- Int. Face, Ext. Supp.: } \frac{W_u l_n^2}{16} = \underline{-220.63 \text{ k-ft}}$$

$$M(9'') = -220.63 + \frac{8.4 \times (22-x)}{2} + (353 - 220.63) \times \frac{x}{22}$$

$$= \boxed{-149.2 \text{ k-ft}}$$

$$\text{- All other Int. Faces: } \frac{W_u l_n^2}{11} = \underline{-320.92 \text{ k-ft}}$$

$$M(9'') = -320.92 + \frac{8.4 \times (22-x)}{2}$$

$$= \boxed{-254 \text{ k-ft}}$$

- Bottom Reinforcement

$$d = 14.5 - 1.5 - \frac{1}{8} - \frac{1}{2} = 12 \text{ in}$$

$$A_s = \frac{M_u}{4d} = \frac{252.15}{4(12)} = 5.25 \text{ in}^2 \Rightarrow \text{use } (6)\#9 \quad A_s = 6.00 \text{ in}^2$$

- Exterior span

$$b_{min} = 2(1.5) + 2(\frac{1}{8}) + 6(\frac{9}{8}) + 6(1.33) = 18.75 \text{ in} < 36 \text{ in} \quad \checkmark \text{ ok}$$

$$b_{eff} \leq \begin{cases} \frac{1}{4}(20.5)(12) = 61.5 \text{ in} \\ 36 + 16(4.5) = 108 \text{ in} \\ 36 + 19(12) = 264 \text{ in} \end{cases} \quad a = \frac{6.0(60)}{0.85(4)(61.5)} = 1.72 \text{ in}$$

$c = 2.02 \text{ in}$

$$\epsilon_s = \frac{0.003}{2.02} (12 - 2.02) = 0.0148 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n = 0.9(6.0)(60/2)(12 - \frac{1.72}{2}) = 300.8 \text{ k-ft} > 252 \quad \checkmark \text{ ok}$$

* use (6)#9 in Exterior span $\checkmark \text{ ok}$

* use (5)#9 in Interior span, $M_u = 232.8 \text{ k-ft} > 220$

- Top Reinforcement

$$A_s = \frac{278.16}{4(12)} = 5.8 \text{ in}^2 \Rightarrow \text{use } (6)\#9, A_s = 6.00 \text{ in}^2$$

- Ext. Face, 1st Int. supp.

$$b_{eff} = 36 \text{ in} \quad a = \frac{(6)(60)}{0.85(4)(36)} = 2.94 \text{ in}, \quad c = 3.46 \text{ in}$$

$$\epsilon_s = \frac{0.003}{3.46} (12 - 3.46) = 0.0074 > 0.005 \Rightarrow \phi = 0.9$$

$$\phi M_n = 0.9(6)(60/2)(12 - \frac{2.94}{2}) = 284.3 \text{ k-ft} > 278 \quad \checkmark \text{ ok}$$

* use (6)#9 @ Ext. Face, 1st Int. supp. $\checkmark \text{ ok}$

* use (4)#9 @ Int. Face, Ext. supp., $M_u = 198 \text{ k-ft} > 150 \quad \checkmark \text{ ok}$

* use (6)#9 @ All other Int. Faces, $\checkmark \text{ ok}$

P3.7

5.1) Girder Design: (Exterior Frame)

$$W_u = 4.95 \text{ k/ft}$$

- Design Moments: $l_n = 20.5'$

• Positive Moments

- End Span: 148.6 k-ft

- Int. Span: $130. \text{ k-ft}$

• Negative Moments

- Int. Face, Ext. Supp: -130 k-ft

$$M(9'') = -130 + 4.95 \times (22 - x) + (208 - 130) \times \frac{x}{22}$$

$$= -87.9 \text{ k-ft}$$

- Ext. Face, 1st Int. Supp: -208 k-ft

$$M(9'') = -165.9 \text{ k-ft}$$

- All other Int. Faces: -189 k-ft

$$M(9'') = -110 \text{ k-ft}$$

- Bottom Reinforcement

$$d = 12 \text{ in}, A_s = \frac{148.6}{(4)(12)} = 3.1 \text{ in}^2 \Rightarrow \text{use (5) \#7}, A_s = 3.10 \text{ in}^2$$

- Ext. span

$$a = 0.86 \text{ in}, \phi M_n = 0.9(3)(60/12)(12 - \frac{0.86}{2}) = 156 \text{ k-ft} > 148$$

- use (5) \#7 in Ext. span. and Int. span

- Top Reinforcement

$$d = 12.25 \text{ in}, A_s = \frac{166}{(4)(12.25)} = 3.39 \text{ in}^2 \Rightarrow \text{use (6) \#7}, A_s = 3.6 \text{ in}^2$$

$$a = 1.76 \text{ in}, \phi M_n = 0.9(3.6)(60/12)(12.25 - \frac{1.76}{2}) = 184 \text{ k-ft} > 166$$

- use (4) \#7, Int. Face, Ext. Supp.

- use (6) \#7, Ext. Face, 1st Int. Supp.

- use (4) \#2, All other Int. Faces

6) Girder Shear Design (Interior Frame)

a) Determine shear strength w/o stirrups

$$V_c = 2\lambda\sqrt{f'_c} \cdot b_w \cdot d = 2(1.0)\sqrt{4000} (36)(12) = 54.64K$$

$$0.5\phi V_n = 0.5(0.75)(54.64K) = \boxed{20.49K}$$

b) $V_u @ d$

$$V_u = \frac{w_u l_n}{2} = \frac{8.4klf(20.5')}{2} = 86.1K$$

$$V_u @ d = 86.1K - \frac{12}{12} (8.4) = \boxed{77.7K}$$

- what dist: x , is $\phi V_n \Rightarrow 20.49 = 86.1K - \frac{x}{12} (8.4)$

$$x = 94in$$

c) shear strength required by reinforcement

$$V_{sreq} = \frac{V_u}{\phi} - V_c = \frac{77.7}{0.75} - 54.64 = 48.96K$$

$$4\sqrt{4000} (36)(12) = 109.3K > V_{sreq} \Rightarrow S_{max} = \min \left\{ \begin{array}{l} d/2 = 6in \\ 24 \end{array} \right.$$

d) Minimum Shear Reinforcement

$$A_{vmin} = \max \left\{ \begin{array}{l} 0.75\sqrt{4000} (36)(6) / 60,000 = 0.171in^2 \\ 50(36)(6) / 60,000 = \boxed{0.18in^2} \end{array} \right.$$

- use (2) #3  at 6in as max reinforcing

$$A_v = 0.11 \times 2 = 0.22in^2 > 0.18$$

e) shear reinforcing design

$$s = 0.22(60)(12) / 48.96K = 3.23" < 4" \quad \underline{\text{X DNW}}$$

* Need more shear reinforcement

- use (4) #3  at 6in as max reinforcing

$$A_v = 0.11 \times 4 = 0.44$$

$$s = 0.44(60)(12) / 48.96 = 6.47in \Rightarrow \underline{6in}$$

Girder shear (Int.)

P9

- when could $s = 12$ in

$$V_s = 0.44(60)(12)/12 = 26.4k$$

$$V_u = 0.75(26.4 + 54.64k) = 60.78k$$

$$l_v = (86.1 - 60.78)(12)/8.4 = 36.17 \text{ in}$$

- when could $s = 18$ in

$$V_s = 0.44(60)(12)/18 = 17.6k$$

$$V_u = 0.75(17.6 + 54.64) = 54.18k$$

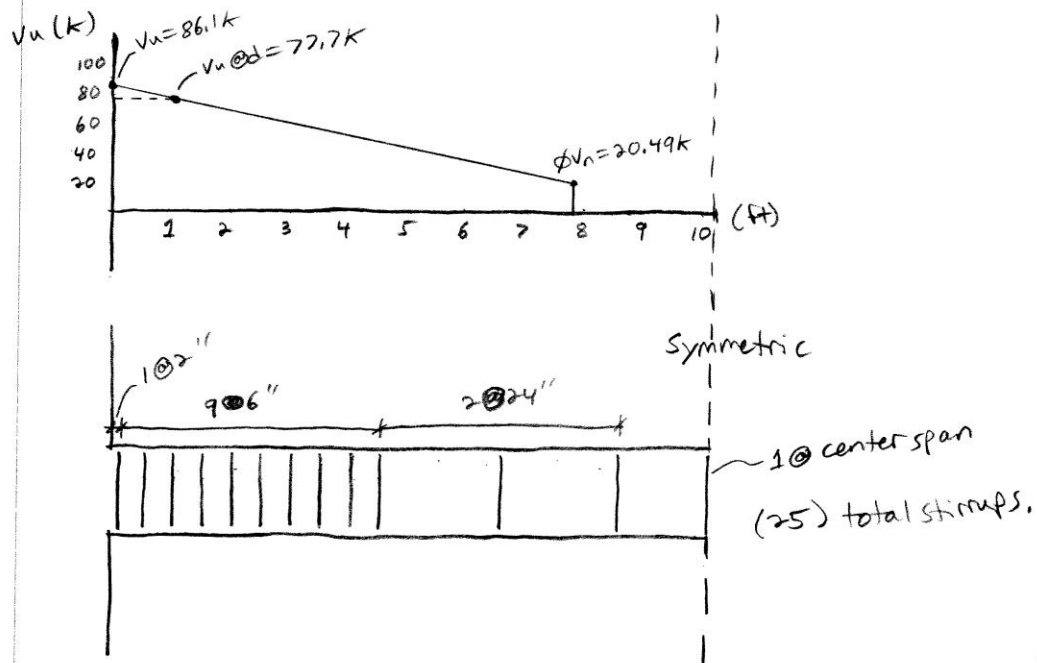
$$l_v = (86.1 - 54.18)(12)/8.4 = 45.6 \text{ in}$$

- when could $s = 24$ in

$$V_s = 0.44(60)(12)/24 = 13.2k$$

$$V_u = 0.75(13.2 + 54.64) = 50.88k$$

$$l_v = (86.1 - 50.88)(12)/8.4 = 50.3 \text{ in}$$



Girder Shear (Ext.)

Pg

6.1) Girder Shear Design (Exterior Frame)

a) $V_c = 54.64k$, $\phi V_n = 20.49k$

$$w_u = (343.5)(11+11.5) + \frac{75(6)(19)}{(2)(20.5)} = 4.5k\text{-lf}$$

S.W. = 450plf

$w_u = 4.95k\text{-lf}$

b) $V_u = \frac{4.95(20.5)}{2} = 50.74k$, $V_{u@d} = 50.74 - 4.95 = 45.79k$

- what dist: x , is $\phi V_n \Rightarrow 20.49 = 50.74 - \frac{x}{12}(4.95)$

$x = 73.3\text{ in}$

c) $V_{sreq} = \frac{45.79}{0.75} - 54.64 = 6.41k$

d) $A_{vmin} = 0.18\text{ in}^2$, $S_{max} = 6\text{ in}$

- use (2) #3 [U] @ 6in $\Rightarrow$ Max rein.

e) Shear Reinforcing Design

$S = 0.22(60)(12) / 6.41 = 24.7\text{ in}$

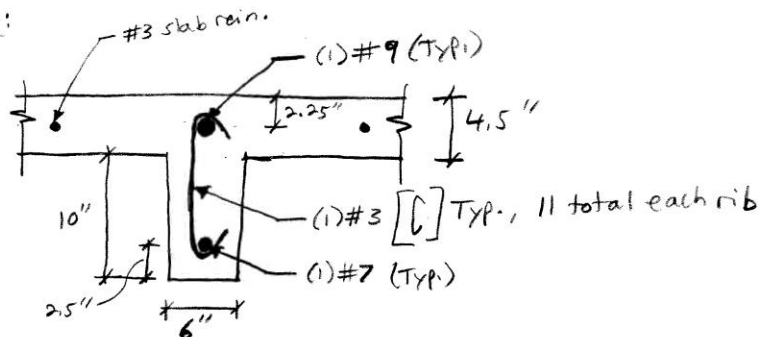
- use (2) #3 [U], (1) @ 2", 5 @ 24" (half span)

(9) total stirrups

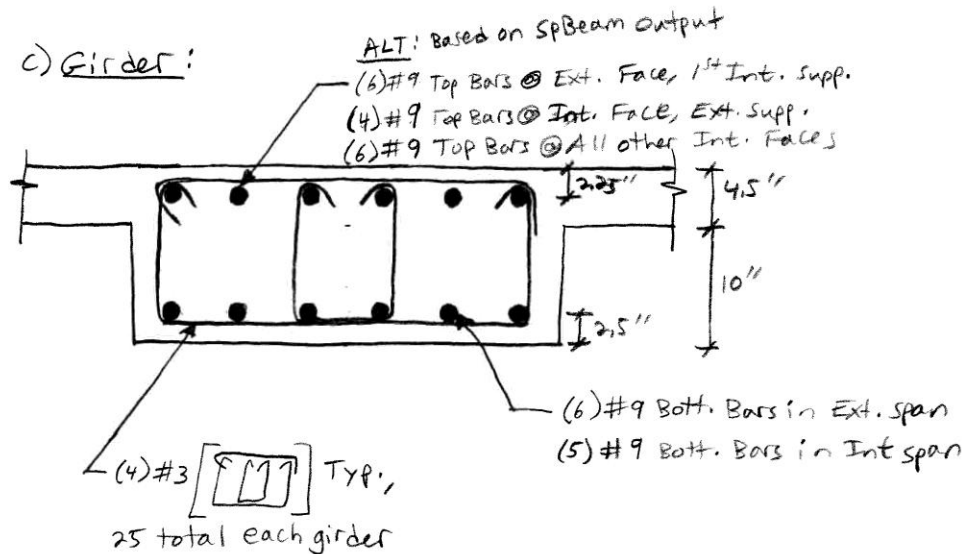
7) Final Design Details/Specs

a) Slab: dimensions - 4.5 in thick
reinforcing - (1) #3 @ 12", both directions.

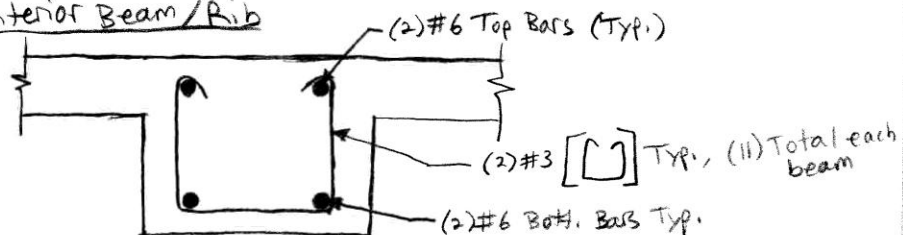
b) Joist:



c) Girder:



d) Interior Beam/Rib



7.1) Bar Development Lengths, Anchorage (Girder-Interior)

a) Exterior span (#9)

- Positive Rein. cut-offs : $l_d = 47.4d_b = \underline{53 \text{ in}}$

• center span : (6) #9 at bottom

* Must continue (4) #9 into supports 6" (Ext.)

- For (4) #9, $a = 1.15 \text{ in}$, $\phi M_n = \underline{205.65 \text{ k-ft}}$

$$205.65 = \frac{8.4x}{2} (20.5 - x) - 353 + (353 - 220.63)x / 20.5$$

$$0 = -4.2x^2 + 86.1x - 558.65 + 6.46x$$

$$0 = 4.2x^2 + 92.56x - 558.65$$

$$x = 4.93 \text{ ft} = 60 \text{ in (from C.F.R)}$$

$$x_R = \left[\frac{20.5 - 4.93}{2} \right] 12 = \underline{64 \text{ in}} \rightarrow \text{(right from Mid)}$$

$$205.65 = \frac{8.4x}{2} (20.5 - x) - 220.63 + (353 - 220.63)x / 20.5$$

$$0 = 4.2x^2 + 92.56x - 426.28$$

$$x = 3.91 \text{ ft} = 47 \text{ in (from C.F.L)}$$

$$x_L = \left[\frac{20.5 - 3.91}{2} \right] 12 = 76.08 \text{ in} \Rightarrow \underline{77 \text{ in}} \text{ (Left from Mid)}$$

- Negative Rein. cut-offs : $l_d = 61.7d_b = \underline{70 \text{ in}}$

Left : (4) #9 $\Rightarrow$ No cut-offs

Right : (6) #9

- For (4) #9, $a = 1.96 \text{ in}$, $\phi M_n = \underline{202 \text{ k-ft}}$

$$202 = \frac{8.4x}{2} (20.5 - x) - 353 + (353 - 220.63)x / 20.5$$

$$0 = 4.2x^2 + 86.1x - 555$$

$$x = 4.9 \text{ ft} = 58.8 \text{ in} = 59 \text{ in} < l_d \Rightarrow \text{use } \underline{70 \text{ in}} \text{ from C.F.}$$

pg. 10.

b) First Interior Span :

- Positive Rein. cut-offs : $l_d = 53\text{in}$, (5)#9 cut to (4)#9
 $0 = 4.2x^2 + 86.1x - 459.65 \Rightarrow x = 4.4', 1.5 \left[\frac{20.5}{2} - 4.4 \right] = 7.1\text{in}$
 (Left and Right)

- Negative Rein. Cut-offs : $l_d = 62\text{in}$
 Left: (6)#9, Right: (6)#9

- For (4)#9, $\alpha = 1.96\text{in}$, $\phi M_n = 202\text{K-ft}$

$$202 = \frac{8.14x}{2} (20.5 - x) - 254$$

$$0 = 4.2x^2 + 86.1x - 456$$

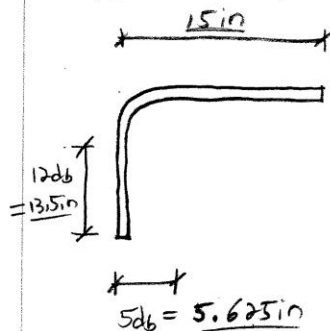
$$x = 4.37\text{ft} = 52.44\text{in} < 62\text{in}, \text{ use } 62\text{in from C.F.}$$

* Left and right

7.2) Anchorage At Exterior Columns (All Girder Ends: Int./Ext.)

$$l_{dh} = (0.02 \text{ re } f_y / \sqrt{f'_c}) d_b = \frac{0.02(1.0)(60,000)}{(1.0) \sqrt{4000}} \left(\frac{9}{8} \right) = 19d_b$$

- assume 90° hook with cover on bar extension beyond
 hook $\geq 2\text{in}$, use $0.17l_{dh} = 13.3d_b = 15\text{in}$



- Note: For Full Details of
 Anchorage and Development Length
 refer to AutoCAD Details.

2.3) Bar Development Lengths, Anchorage (Girder - Exterior)

a) Exterior span (#7)

- Positive Rein. Cut-offs: $l_d = 47.4d_b = \underline{42\text{ in}}$

• center span: (5) #7 at bottom

• Cut to (2) #7, continue to supports

- For (2) #7, $a = 0.344\text{ in}$, $\phi M_n = 63.87\text{ k-ft}$

$$63.87 = \frac{4.95X}{2} (20.5 - X) - 130 + (208 - 130)X / 20.5$$

$$0 = -2.48X^2 + 50.74X - 193.87 + 3.8X$$

$$0 = -2.48X^2 + 54.54X - 193.87$$

$$X = 4.46\text{ ft} = 53.5\text{ in}, \frac{20.5}{2} - 4.46 = 5.79\text{ ft} = \underline{70\text{ in}} > l_d \text{ (Left)}$$

$$63.87 = \frac{4.95X}{2} (20.5 - X) - 208 + (208 - 130)X / 20.5$$

$$0 = -2.48X^2 + 54.5X - 271.87$$

$$X = 7.64 = 91.7\text{ in}, \frac{20.5}{2} - 7.64 = 2.61\text{ ft} = 32\text{ in} < l_d$$

- use 42 in (Right)

- Negative Rein. Cut-offs: $l_d = 61.7d_b = \underline{54\text{ in}}$

Left (4) #7, Right (6) #7

- For (2) #7, $a = 0.588\text{ in}$, $\phi M_n = 64.56\text{ k-ft}$

$$(L) 64.56 = \frac{4.95X}{2} (20.5 - X) - 130 + (208 - 130)X / 20.5$$

$$0 = -2.48X^2 + 54.74X - 194.56$$

$$X = 4.47 \Rightarrow \underline{54\text{ in}} > l_d \text{ (Left)}$$

$$(R) 64.56 = \frac{4.95X}{2} (20.5 - X) - 208 + (208 - 130)X / 20.5$$

$$0 = -2.48X^2 + 54.74X - 272.56$$

$$X = 7.68 = 93\text{ in} > l_d \text{ (Right)}$$

pg. 10.

b) Interior span (#7): $l_d = 42\text{in}$ - Positive: center span: (5) #7 at bottom
cut to (2) #7, continue to supports-- For (2) #7, $a = 0.1344\text{in}$, $\phi M_n = 63.87\text{ k-ft}$

$$63.87 = \frac{4.95x}{2} (20.5 - x) - 110$$

$$0 = -2.48x^2 + 50.84x - 173.87$$

$$x = 4.34\text{ ft}, \quad \frac{20.5}{2} - 4.34 = 5.91\text{ ft} = \underline{71\text{in}} \geq l_d$$

(Left and Right)

- Negative Rein: $l_d = 54\text{in}$ - For (2) #7, $a = 0.1588\text{in}$, $\phi M_n = 64.54\text{ k-ft}$

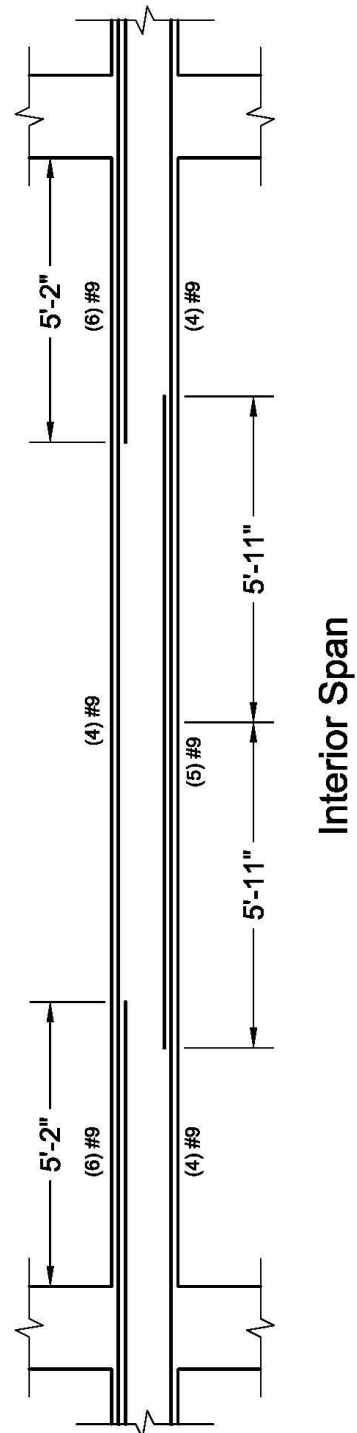
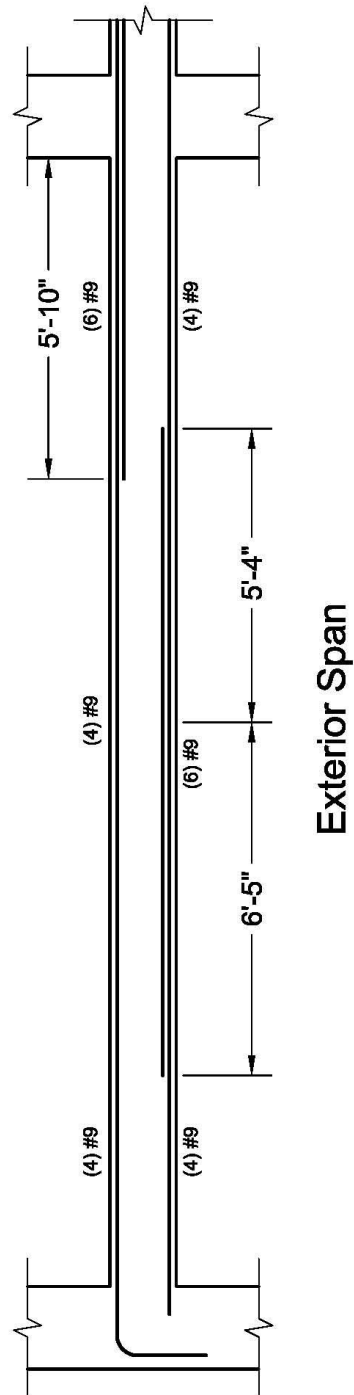
$$64.54 = \frac{4.95x}{2} (20.5 - x) - 110$$

$$0 = -2.48x^2 + 50.84x - 174.54$$

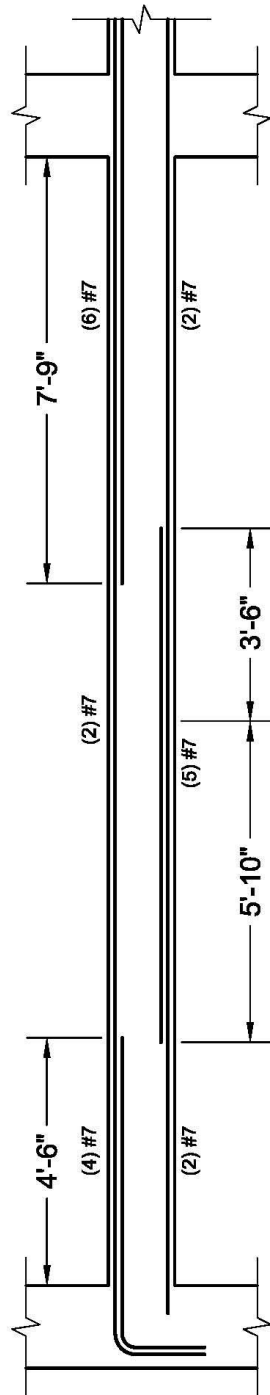
$$x = 4.36\text{ ft}, \quad = \underline{53\text{in}} < l_d \Rightarrow \text{use } \underline{54\text{in}}$$

(Left and Right)

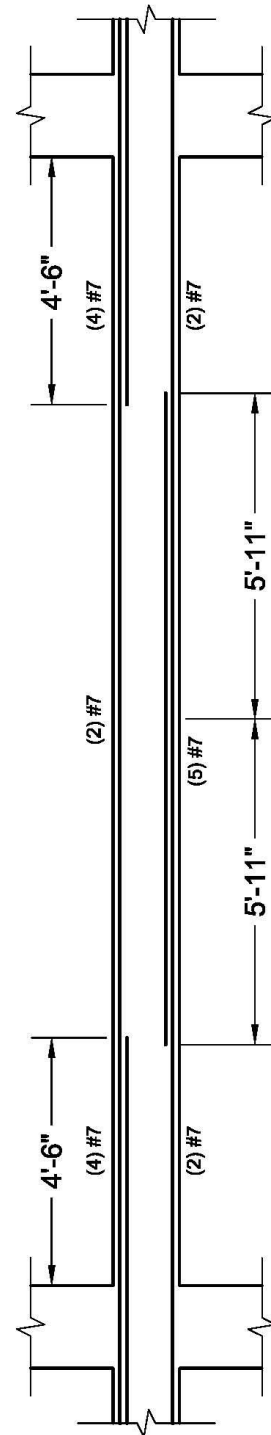
Interior Girder- Rebar Cut-off/ Development Lengths



Exterior Girder- Rebar Cut-off/ Development Lengths

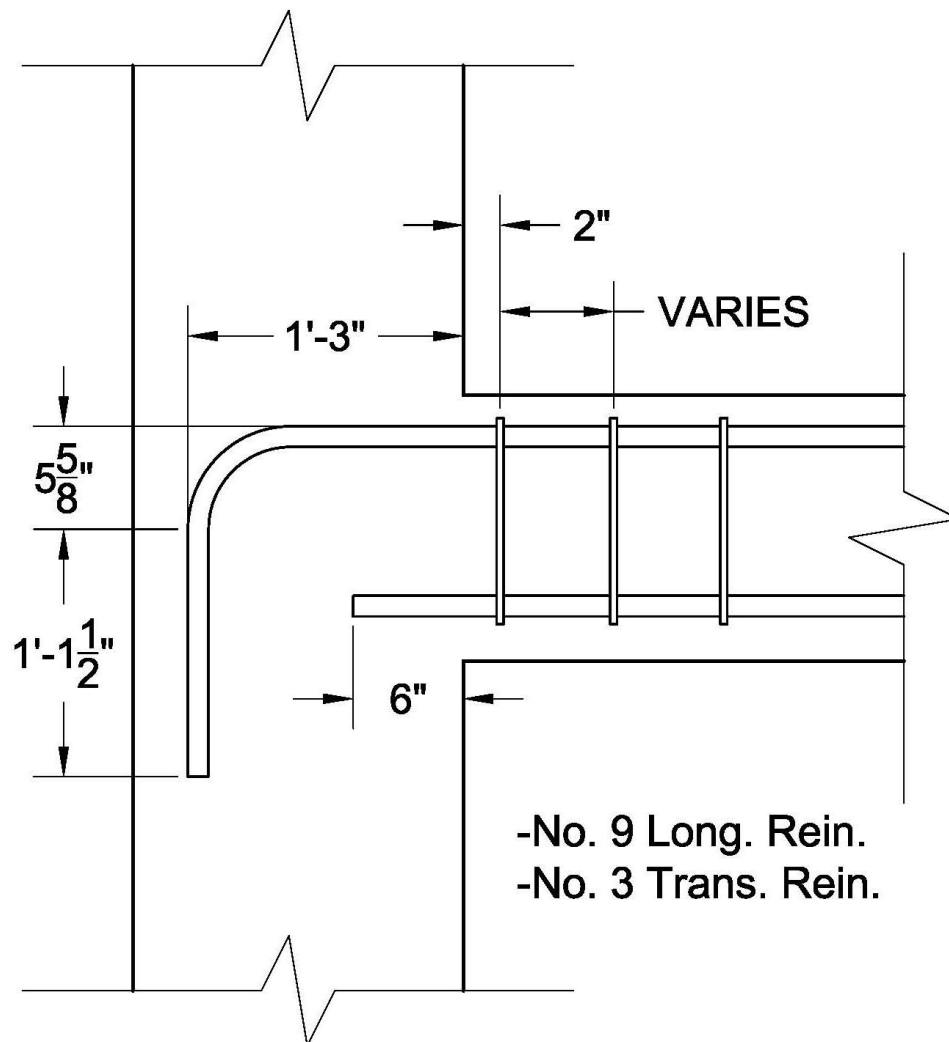


Exterior Span



Interior Span

Girder Anchorage Into Typical Column



8) Column Designs

- For a typical gravity column consider slenderness

a) calculate k using nomograph (10.11.0.1)

- for 1st story columns, $\psi_A = 0$,

$$\psi_B = \frac{EI_c / l_c}{EI_g / l_g} = \frac{2I_{col} / l_c}{2I_{bm} / l_g}$$

$$I_{col} = \frac{18(18)^3}{12} = 8748 \text{ in}^4$$

$$I_{bm} = 6665 \text{ in}^4 \text{ (includes slab within beff)}$$

$$\psi_B = \frac{2(8748) / 20^3}{2(6665) / 22^3} = 1.44$$

$$k = 0.64$$

$$r = 0.3(18) = 5.4 \text{ in}$$

$$\frac{k l_u}{r} = \frac{0.64(18.79)}{5.4 / 12} = 26.72$$

$$l_u = 20 - \frac{14.5}{12} = 18.79^{\circ}$$

$$34 - 12 (M_1 / M_2) \leq 40 \quad \frac{M_1}{M_2} = \frac{0}{43.3k\text{-ft}} = 0$$

$$26.72 \leq 34 \leq 40 \text{ (assuming frames are braced against side-sway)}$$

- Non-Sway Moments

$$S_{ns} = \frac{C_m}{1 - \frac{P_u}{0.75 P_c}} \geq 1.0, \quad P_c = \frac{\pi^2 EI}{(k l_u)^2}$$

$$C_m = 0.6 + 0.4 \frac{M_1}{M_2}$$

* $\frac{M_1}{M_2} = 0$, for 1st floor column and ≤ 1.0 for all other floors $\Rightarrow$ use $S_{ns} = 1.0$

- refer to flexural design for design moments.

- Column Design Loads due to Gravity Loads

Axial Loads (Factored, For Int. col.)

. Labs (Floor 2,3)

- slab: 343.5 psf (includes SDL and LL)

- ribs: 75 pcf

- girders: 450 pcf

- Int. Bms: 225 pcf

$$\begin{aligned} P_u &= 343.5(22')^2 + \\ &\quad (6)(75)(19') + \\ &\quad (1)(450)(20.5') + \\ &\quad (1)(225)(19') \\ &= \underline{188.3K} \end{aligned}$$

Green Roof

283.2 psf

75 pcf

450 pcf

225 pcf

$$\begin{aligned} P_u &= 283.2(22')^2 + \\ &\quad (6)(75)(19') + \\ &\quad (1)(450)(20.5') + \\ &\quad (1)(225)(19') \\ &= \underline{159.12K} \end{aligned}$$

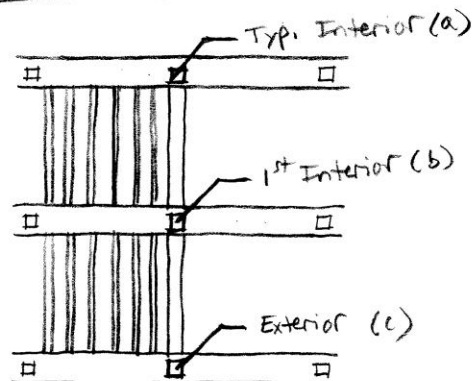
* Perimeter Columns:

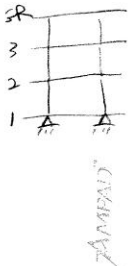
2nd/3rd Floor: $P_u = \underline{98.76K}$

Green Roof: $P_u = \underline{84.17K}$

* Corner Columns: (divide P_u for Per. col. by 2)

Typical Columns





- Column Design Moments Due to Interior Beams

* Summary of moments from previous calculations.

• Beam Moments (Girder Moments will cancel for Int. locations)

$$W_u = 1.255 \text{ k/ft}, L_n = 19'$$

$$\text{Ext. Supp., Int. Face: } M_u = -28.32 \text{ k-ft}$$

$$\text{1st Int. Supp., Ext. Face: } M_u = -45.31 \text{ k-ft}$$

$$\text{All other Int. Supp.: } M_u = -41.19 \text{ k-ft}$$

- Design Typical 1st Story Columns (Interior Frame)

a) Typ. Interior Column

$$P_u = 188.3(2) + 159.12 = \underline{536 \text{ k}}$$

$M_u = 0$, All interior moments cancel.

- SpColumn Design: (4) #9 bars, $\rho = 1.235\%$, #3 ties

b) 1st Interior Column

$$P_u = 536 \text{ k}, M_u = -45.31 + 41.19 = \underline{-4.12 \text{ k-ft}}$$

- SpColumn Design: (4) #9 bars, $\rho = 1.235\%$, #3 ties

c) Exterior Column

$$P_u = 98.76(2) + 84.17 = \underline{281.7 \text{ k}}$$

$$M_u = -28.32$$

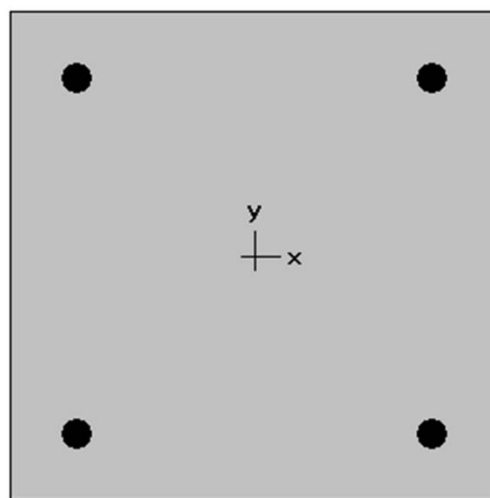
- SpColumn Design: (4) #9 bars, $\rho = 1.235\%$, #3 ties

* Column size were chosen based on the interior beam width of 18". This was dictated by the left over width due to fitting a 3 ft pan-foist Module. For constructability issues if smaller columns were to be used, 18" columns will be used although slightly over designed. 16" columns are a minimum size for the axial loads given.

spColumn Output- Column Design

1st Floor TYP. Column - Col. Grids: 13-20, and N-BB.

- All Columns are 18 x 18 with (4) No. 9
- Provide #3 Rectangular Ties/Hoops @ 18in along entire column height.
- Controlling factor for design is the 1% minimum reinforcing ratio



18 x 18 in
1.23% reinf.

MATERIAL:

=====

$f'_c = 4 \text{ ksi}$
 $E_c = 3605 \text{ ksi}$
 $f_c = 3.4 \text{ ksi}$
 $\text{Beta1} = 0.85$
 $f_y = 60 \text{ ksi}$
 $E_s = 29000 \text{ ksi}$

SECTION:

=====

$A_g = 324 \text{ in}^2$
 $I_x = 8748 \text{ in}^4$
 $I_y = 8748 \text{ in}^4$
 $X_o = 0 \text{ in}$
 $Y_o = 0 \text{ in}$

REINFORCEMENT:

=====

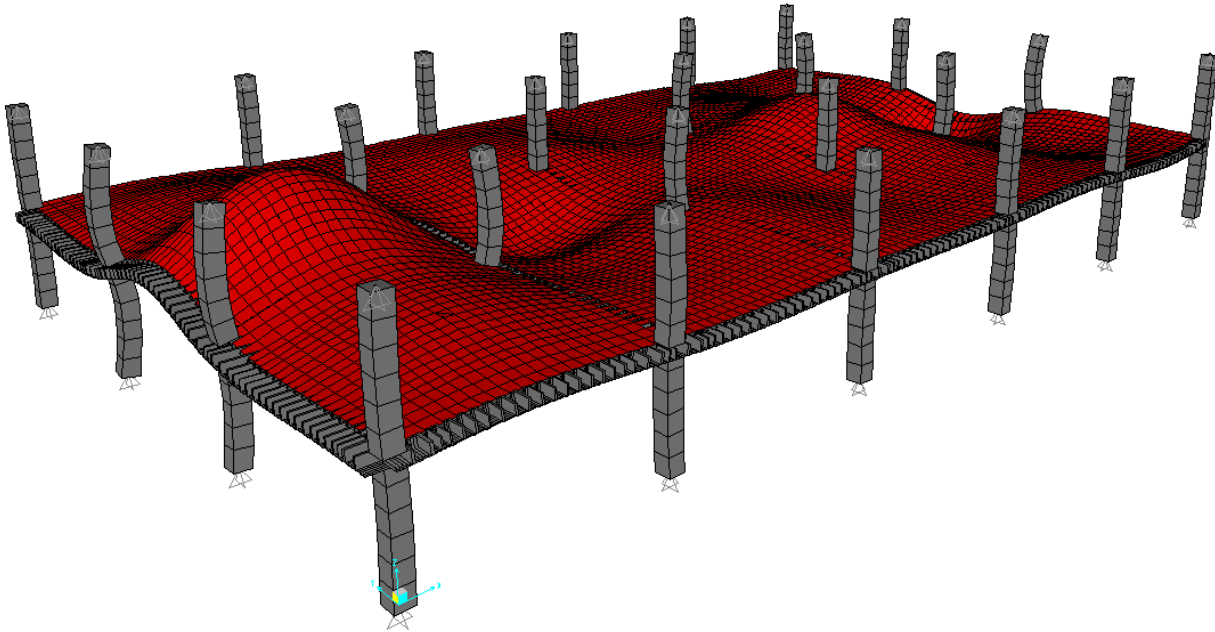
4 #9 bars @ 1.235%
 $A_s = 4 \text{ in}^2$
Confinement: Tied
Clear Cover = 1.88 in
Min Clear Spacing = 11.99 in

Pan-Joist Vibration Model

Modal Analysis Results Example

Bay-A: $T=0.06111$, Rayleigh: $T=0.0695s$

Deformed Shape (MODAL) - Mode 10 - $T = 0.06111$; $f = 16.36394$



Lateral System Redesigns

Existing Wind Calculations

MWFRS Wind Analysis (ASCE7-05)- MSC Complex

Location: University Park, PA
Topography: Campus Setting. Buildings to North, North West, West, and South. Mostly open terrain to East with small obstructions
Bulding Dimensions: L-Shaped. North Wing outside dimension = 550 ft, West Wing outside dimension = 440 ft. Building Heights (From Pollock Road): 85'-6" ft to Roof level, 66 ft to Mechanical Penthouse, 48 ft to Third Floor, 30 ft to second floor, 10 ft to first floor. Roof Step Backs: Roof steps to: North Wing- Steps Down to Mech. Penthouse level at 220 ft, Third Floor at 330 ft, and Second Floor at 440 ft. - Same on West Wing except the last step down does not exist
Framing: Primarily Steel Framing- W-Flange columns, beams, and cross-bracing. The floor system is a composite beam and concrete slab on metal deck.
Cladding: Alternate horizontal strips of precast concrete panels and exterior glazing for each floor of elevation. Assume no debris resistant glazing.
Roof Top: Primary Roof consists of EPDM Walkway Pads and EODM Fooring Membrane tapered. The lower roofs are all green roofs. All roofs flat.

a) Basic Wind Speed (Fig. 6-1): $V = 90\text{mph}$

b) Exposure: (6.5.2.3) Exposure B: Urban/Suburban, wooded, numerous closely spaced obstructions- single family dwellings and larger.

c) Building Classification: Construction Type IIIB, Occ. Cat: B with special Occ. areas of H-5

d) Velocity Pressure: $q_z = 0.000256k_zk_zt_kdV^2I$

k_z (Table 6-3) =	15	20	39	57	75.75	87	(ft)
	0.575	0.624	0.755	0.842	0.913	0.950	

kzt (Fig. 6-4) =	1	, assume homo-topo
kd (Table 6-4) =	0.85	, buildings
$V^2 = 90^2 =$	8100	
I (Table 6-1) =	1.15	
qz =	20.27	*kz psf *depends on height

e) Gust Effect
Factor:

G=

0.85

(Rigid Structure $T < 1.0s$, refer to Seismic Analysis)

f) Internal Pressure
Coefficient:

GCpi =

+/-

0.18

(assume Enclosed Building)

g) Design Wind Pressures:

$$P = qGCp - qi(Gcpi)$$

 $q = qz$ (windward, depends on height)

 $q = qh$ (leeward, taken at height-h)

 $G = 0.85$
 $qi = qh$ (windward, leeward, and roofs for enclosed buildings)

 $GCpi = +/- 0.18$
Cp values
determined:
h) Wall Cp:

(Fig. 6-6 cont'd)

Cpw =	0.8	(windward, with qz)
Cpsw =	-0.07	(side walls, with qh)
Cpl =	-0.5	L/B = 0-1 (Leeward, with qh)
	-0.3	L/B = 2
	-0.2	L/B = > 4

i) Roof Cp:

(Fig. 6-6 cont'd)

angle < 10deg., h/L

< 0.5

Hor. Dist. From Wind. Edge	Cp (1st)	Cp (2nd)
0-h/2, h/2-h	-0.9	-0.18
h-2h	-0.5	-0.18
> 2h	-0.3	-0.18

j) MWFRS Pressures $P = qGC_p - q_i(G_{cpi})$ **Terrain Exposure Constants**

Exposure	α	Zg(ft)	$\hat{a}$	$b^{\wedge}$	α_{-}	b_{-}	c
B	7.00	1200.00	0.14	0.84	0.25	0.45	0.30

l (ft)	ϵ	Zmin (ft)
320.00	0.33	30.00

Windward Walls

Height	qz	G	Cp	qzGCp
z= 15ft	11.65	0.85	0.8	7.92
z= 20ft	12.65	0.85	0.8	8.60
z= 39ft	15.31	0.85	0.8	10.41
z= 57ft	17.06	0.85	0.8	11.60
z= 75.75ft	18.50	0.85	0.8	12.58
z= 87ft	19.25	0.85	0.8	13.09

Leeward Walls

	qh	G	Cp	qhGCp
Wind- short side	19.25	0.85	-0.2	-3.27
Wind-Long Side	19.25	0.85	-0.5	-8.18
Side Walls	19.25	0.85	-0.7	-11.45

Roof- First Value

Length	qh	G	Cp	qzGCp
0-h	19.25	0.85	-0.9	-14.73
h-2h	19.25	0.85	-0.5	-8.18
>2h	19.25	0.85	-0.3	-4.91

Roof- Second Value

	qh	G	Cp	qzGCp
all lengths	19.25	0.85	-0.18	-2.95

Wall Areas

	Windward			Leeward-Long Side		Leeward-Short Side
Height	E/W(SF)	N/S(SF)		E/W(SF)	N/S(SF)	E/W=N/S(SF)
z= 0-15ft	6398	8335		4638	6571	1760
z= 15-20ft	2136	2778		1549	2195	587
z= 20-39ft	8444	10141		6215	7911	2229
z= 39-57ft	7564	7564		5452	5452	2112
z= 57-75.75ft	5753	5753		3553	3553	2200
z= 75.75-87ft	2740	2740		1420	1420	1320

Floor Loads by Area

	Windward		Leeward-Long Side		Leeward-Short Side
Floor Level	E/W(K)	N/S(K)	E/W(K)	N/S(K)	E/W=N/S(SK)
First Floor	52.2	67.9	38.0	53.8	5.8
Second Floor	87.9	105.5	50.8	64.7	7.3
Third Floor	87.7	87.7	44.6	44.6	6.9
Mech. Pent.	72.4	72.4	29.1	29.1	7.2
Roof	35.9	35.9	11.6	11.6	4.3

Final Story Forces

	y		x			
	Load		Shear		Moment	
Floor Level	E/W(K)	N/S(K)	E/W(K)	N/S(K)	E/W(K-ft)	N/S(K-ft)
First Floor	153	204	867	968	1534	2040
Second Floor	234	284	713	764	7009	8523
Third Floor	223	223	480	480	10694	10694
Mech. Pent.	174	174	257	257	11473	11473
Roof	83	83	83	83	7087	7087
Totals*(1.6)			867	968	37798	39817

Components and Cladding

Wall Panels

$$p = q(GCp) - qh (GCpi) \text{ (lb/ft}^2\text{)}$$

Windward

	Wall Area	h	qz	qh	Area 4/5	Gcpi	P(psf)
Floor Level					GCp		
First Floor	440	20	12.65	19.25	0.638	0.18	11.53
Second Floor	418	39	15.31	19.25	0.651	0.18	13.43
Third Floor	396	57	17.06	19.25	0.665	0.18	14.81
Mech. Pent.	412.5	75.75	18.50	19.25	0.655	0.18	15.58
Roof	214.5	87	19.25	19.25	0.778	0.18	18.45

Leeward					Area 4	Area 5			
Floor Level	Wall Area	h	qz	qh	GCp	GCp	Gcpi	P4(psf)	P5(psf)
First Floor	440	20	12.65	19.25	-0.725	-1.100	0.18	-17.42	-24.64
Second Floor	418	39	15.31	19.25	-0.734	-1.137	0.18	-17.60	-25.35
Third Floor	396	57	17.06	19.25	-0.743	-1.173	0.18	-17.77	-26.05
Mech. Pent.	412.5	75.75	18.50	19.25	-0.736	-1.146	0.18	-17.64	-25.52
Roof	214.5	87	19.25	19.25	-0.819	-1.476	0.18	-19.23	-31.87

Existing Seismic Calculations

Design Seismic Base Shear (ASCE7-05)

$$V = C_s W \quad 12.8-1$$

W: Effective Weight- 12.7.2

Cs: Seismic Coeff.- 12.8.1.1

$$C_s = \min \left\{ \begin{array}{l} S_{ds}/(R/I) \\ S_{D1}/(T^*R/I) \\ S_{D1}*T/(T^2*R/I) \end{array} \right\} > 0.01$$

In addition, where $S_1 > 0.6$

$$C_s > 0.5S_1/(R/I) \quad \text{Eq. 12.8-6}$$

Fa, Fv- Table 11.4-1, 11.4-2

Ss, S1- USGS website, using long./lat. of site location

R: Response Mod. Coeff.- Table 12.2-1

I: Importance Factor- 11.5

Occ. Cat.- Table

1-1

$$T = \min \left\{ \begin{array}{l} C_u * T_a \\ T_b \end{array} \right\} \quad \begin{array}{l} S_{ds} = 2/3(S_{MS}) \\ S_{D1} = 2/3(S_{M1}) \end{array} \quad \begin{array}{l} S_{MS} = F_a * S_s \\ S_{M1} = F_v * S_1 \end{array}$$

Design Seismic Base Shear- MSC Complex, University Park, PA

Latitude: 40.802 Site Class: D
Longitude: -77.86 Occ. Cat: III

S_s = 0.147 g (Site Class B)
S₁ = 0.049 g (Site Class B)

F_a = 1.6
F_v = 2.4

S_{MS} = 0.2352 g S_{DS} = 0.1568 g
S_{M1} = 0.1176 g S_{D1} = 0.0784 g

Lateral Force Resisting System: Ordinary Steel Concentrically Braced Frames

R = 3.25
I = 1.25
SDC: B (No Limitations)
T_l = 6 s (Fig. 22-15)

Design Base Shear

T _a = 0.512 s	C _s = Min	$\left \begin{array}{c} 0.0603 \\ 0.0346 \\ 0.2386 \end{array} \right = 0.0346$
C _u = 1.7		
C _u *T _a = 0.871 s	0.38	

Building Weight Calculation (above ground)

Frame Weights

	Columns	Beams	Braces	
	Weight(K)	W (K)	# braces	W (K)
1st Floor	503.31	770.26	32	358.35
2nd Floor	440.87	889.46	72	806.28
3rd Floor	325.36	1011.99	95	1063.84
Mech.	234.69	762.95	88	985.45
Roof	59.93	481.01	24	268.76
		Total	311	3482.68

Frame Weights

	Columns	Beams	Braces	
	Weight(K)	W (K)	# braces	W (K)
1st Floor	503.31	770.26	32	358.35
2nd Floor	440.87	889.46	72	806.28
3rd Floor	325.36	1011.99	95	1063.84

Mech.	234.69	762.95	88	985.45
Roof	59.93	481.01	24	268.76
		Total	311	3482.68

Precast Panels- Unit Weight

	t (in)	width (ft)	length(ft)	pcf	W(K)
Returns(x2)	6	2.00	unit/ft	150	unit/ft
Side Ret(x2)	6	2.00	-	150	
Level-2	7	11.72	1811.33	150	2264.30
Level-3	7	9.72	1650.00	150	1770.12
Mech.	7	9.72	1496.00	150	1604.91
Roof	7	9.72	968.00	150	1038.47
			Total=		6677.79

1.25 k/ft

1.07 k/ft

1.07 k/ft

1.07 k/ft

~15% BLDG

Revised Loads

	W(K)
Roof	1331
Pent	1890
Third	2213
Second	2590
First	0
	8024 ~23%BLDG

Superimposed Dead Loads

	psf	Area (SF)	W (K)
Roof	25	33202.82	830.07
Pent	25	40174.27	1004.36
Third	30	53742.49	1612.27
Second	30	64818.42	1944.55
Green Roofs	120	63584.00	7630.08
	Total	255522.00	13021.33

Floor Weights (slabs, beams, columns, façade)

	slabs(K)	columns(K)	beams(K)	braces(K)	façade(K)	W(K)	Mass	Area(ft2)
Level-2	4186.6	472.09	889.46	582.3126	1331	7461.03	1.73E-06	77440
Level-3	4670.6	383.12	1011.99	935.0597	1890	8890.80	1.98E-06	80828
Mech.	6258.12	280.02	762.95	1024.646	2213	10538.70	2.94E-06	64372
Roof	1771.44	147.31	481.01	761.4857	2590	5751.22	2.85E-06	36300
					Total	32642		258940

$$V = CS * W$$

$$Cs = 0.0346$$

$$W = 45663 \text{ K}$$

$$V = 1581 \text{ K}$$

Seismic Load Distribution- Existing Steel

X/Y-Direction Loading

T=	0.871	s
k=	1.185	
V _b =	1581	kips

i (Level)	Story Height h _i (ft)	Effective Height h (ft)	Story Weight w (K)	w*h ^k	C _{vx}	Lateral Force f _i (K)	Story Shear V _i (K)	Moment M _i (K-ft)
Roof	19.5	75.5	5751	968094	0.309	488	488	36849
Mech.	18.0	56.0	10539	1244874	0.397	628	1116	35146
3	18.0	38.0	8891	663207	0.211	334	1450	12706
2	20.0	20.0	7461	260056	0.083	131	1581	2622.1
Totals	75.5	75.5	32642	3136231	1.000	1581	1581	87323

Impacts of Concrete Pan Joist/Girder System on Weights

Typical Weight per Bay

New Concrete System

	Width(in)	Depth(in)	Length(in)	lb/cf	Count	Weight(K)
slab	264	4.5	264	150	1	27.2
Ribs	6	10	228	150	6	7.1
Interior Bm	18	10	228	150	1	3.6
Girders	36	10	264	150	1	8.3
Columns	18	18	240	150	1	6.8

Total = 52.9 K/bay

Existing Steel System

	W-Shape	Unit Weight	Length(ft)	Width(ft)	Count	Weight(K)
slab		48.8 psf	22	22	1	23.6
Beams	18x76	76 plf	22		2	3.3
Girders	24x84	84 plf	22		1	1.8
Columns	14x62	62 plf	20		1	1.2

Total = 30.1 K/bay

Weight Change per Floor

Floor	No. Bays	Weight Difference(K)	New Weight(K)	Mass
Level-2	65	1486	8947.01	2.076E-06
Level-3	40	914	9805.26	2.180E-06
Mech.	15	343	10881.62	3.038E-06
Roof	0	0	5751.22	2.847E-06

Total 35385

$$V = CS * W$$

$$CS = 0.0346$$

$$W = 48406 \text{ K}$$

$$V = 1676 \text{ K}$$

Seismic Load Distribution- New Concrete

X/Y-Direction Loading

T=	0.871	s
k=	1.185	
V _b =	1676	kips

i (Level)	Story Height h _i (ft)	Effective Height h (ft)	Story Weight w (K)	w*h ^k	C _{vx}	Lateral Force f _i (K)	Story Shear V _i (K)	Moment M _i (K-ft)
Roof	19.5	75.5	5751	968094	0.294	492	492	37161
Mech.	18.0	56.0	10882	1285381	0.390	654	1146	36597
3	18.0	38.0	9805	731421	0.222	372	1518	14131
2	20.0	20.0	8947	311850	0.095	159	1676	3171.0
Totals	75.5	75.5	35385	3296746	1.000	1676	1676	91059

Check of Existing Lateral System

Base Shear Contributions- Seismic Loads

NS-Load Direction

Frame	Total	Col	Brace	Wall
A	0	0	0	0
B	395.0119	5.6586	30.3466	359.0067
C	0.0457	0.0457	0	0
D	0.1928	0.1928	0	0
E	352.1036	5.5897	31.4656	315.0483
F	0.132	0.0335	0	0.0985
G	0	0	0	0
H	0.429	0.429	0	0
J	0.48	0.48	0	0
K	687.2726	4.686	6.271	676.3156
L	11.2206	0.031	0	11.1896
M	6.6218	0.2942	0	6.3276
N	0.1065	0.0102	0	0.0963
P	0.0675	0.0675	0	0
Q	0.6474	0.6474	0	0
R	0.5752	0.0027	0	0.5725
S	0	0	0	0
T	0.0023	0.0023	0	0
U	0.0178	0.0178	0	0
V	106.8865	1.8679	0	105.0186
W	0.022	0.022	0	0
X	0.0005	0.0005	0	0
Y	0.0003	0.0003	0	0
Z	0	0	0	0
AA	5.6249	0.5613	5.0637	
BB	0	0	0	0
Radial	0.7654	0.7654	0	0

Total 1568.2263

Applied 1581

% diff 0.81

EW-Load Direction

Frame	Total	Col	Brace	Wall
1	0.4053	0.1355	0	0.2698
2	393.6461	5.2453	13.1252	375.2756
3	0.0374	0.0374	0	0
4	0.2228	0.2228	0	0
5	316.6231	4.9592	28.0517	283.6122
6	4.6241	0.0207	0	4.6034
7	0	0	0	0
8	0.1356	0.1356	0	0
9	0.3765	0.3765	0	0
10	666.1471	4.8363	5.5675	655.7433
11	7.4544	0.4752	6.9792	0
12	3.2325	0.0622	3.1703	0
13	0.0201	0.001	0	0.0191
14	0.0285	0.0285	0	0
15	83.525	2.2138	0	81.3112
16	0.07	0.07	0	0
17	0.00833	0.00833	0	0
18	0.00078	0.00078	0	0
19	0.0012	0.0012	0	0
20	15.7909	0.1521	0	15.6388
21	0	0	0	0
Radial	21.9897			21.9897

Total 1514.34

Applied 1581

% diff 4.22

Check for Torsional Irregularity

Roof			
Quake	(0,0)	(2640,0)	
East-	0.041235	0.067931	
West	0.054583	1.244545	Torsional Irregularity
	avg.	max/avg.	
Quake	(0,2640)	(0,0)	
North-	0.067717	0.042757	
South	0.055237	1.225936	Torsional Irregularity

Mech. Penthouse		
(0,0)	(3960,0)	
0.027331	0.027255	
0.027293	1.001392	OK
avg.	max/avg.	
(0,3960)	(0,0)	
0.026746	0.028852	
0.027799	1.037879	OK

Check of Wall on Frame 15

**Check Concrete
Wall**

$V_u =$	81	K	$l_w =$	22	ft
$V_c =$	481	K	$h_w =$	20	ft
$\phi =$	0.75		$t_w =$	18	in

$$\phi V_c = 361 > V_u, \text{ OK}$$

Check Columns

$V_u =$	2.21	K
ϕV_n		
W14X99	206	K
W14X99	206	K

$$\text{Total} = 412 > V_u, \text{ OK}$$

Check of Wall on Frame 10

Check Concrete Wall

$V_u =$	666	K	$l_w =$	66	ft
$V_c =$	1282	K	$h_w =$	56	ft
$\phi =$	0.75		$t_w =$	16	in

$\phi V_c = 962$ **> V_u ,OK**

Check Braces

$V_u = 5.57$ K

ϕV_n

Check Columns

$V_u = 4.84$ K

ϕV_n

W14x283 648 K

W14x283 648 K

W14x90 185 K

W14x90 185 K

Total = 1666 **> V_u ,OK**

Check of Wall on Frame 2

Check Concrete Wall

$V_u =$	375	K	$l_w =$	44	ft
$V_c =$	1603	K	$h_w =$	56	ft
$\phi =$	0.75		$tw =$	30	in

$$\phi V_c = 1202 > V_u, \text{ OK}$$

Check Braces

$$V_u = 13.13 \text{ K}$$

$$\phi V_n$$

W14x90	185	K
W14x99	206	K
W14x120	256	K

$$\text{Total} = 647 > V_u, \text{ OK}$$

Check Columns

$$V_u = 5.25 \text{ K}$$

$$\phi V_n$$

W14X550	1450	K
W14X550	1450	K
W14x283	648	K
W14x283	648	K
W14x283	648	K

$$\text{Total} = 4844 > V_u, \text{ OK}$$

Check of Proposed Lateral System Redesigns

Proposed Lateral System- Element Check

Etabs Output

Period of Vibration

Tb = 0.264s mode-1

LS Wing- E/W Loads

Frame-15: 18in NWC Wall

Vu =	52 K		lw =	22 ft
Vc =	481 K	$V_c = (2 \cdot \sqrt{f'_c} \cdot t \cdot d)$ $d = 0.8 l_w$	hw =	56 ft
ϕ =	0.75		tw =	18 in

$\phi V_c = 361$ **>Vu, OK**
*use minimum reinforcement

Horizontal Reinforcement

$\rho_l = 0.0025$
 $s_t = 18$ in
 $A_{v_{min}} = 0.165$ in²/ 18in
***use (1) #4 @ 18in**

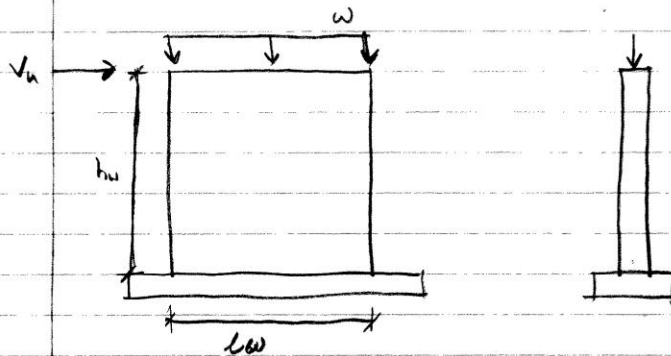
Vertical Reinforcement

$\rho_l = 0.0025 + .5(2.5 - h_w/l_w)(\rho_{t-.0025})$
 $s_t = 18$ in
 $A_{v_{min}} = 0.165$ in²/ 18in
***use (1) #4 @ 18in**

Note: This design is typical for all proposed concrete shear walls within the updated lateral system.

Shear Wall Design- Design procedures, equations, and practice example

Shear Wall Design ACI 318-08 §11.9



$$\phi V_n = V_u = V_c + V_s$$

$$V_u \leq 10\sqrt{f'_c} \cdot h_d$$

$$d = 0.8l_w$$

V_c

Simplified $V_c \leq 2\sqrt{f'_c} \cdot h_d$ or $h = l_w$

Complex $V_c \leq 3.3\sqrt{f'_c} h_d + \frac{N_u d}{4l_w}$ or

$$V_c = h_d \left[0.6\sqrt{f'_c} + l_w \left(1.25\sqrt{f'_c} + 0.2 \frac{N_u}{l_w h} \right) \right]$$

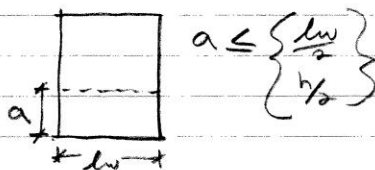
$$\frac{M_u}{V_u} - \frac{l_w}{2}$$

* Take smallest of two

- if $V_u \geq \phi V_c$, need shear reinforcement

$$V_s = \frac{A_v f_y d}{s}$$

- critical section



$$a \leq \left\{ \begin{array}{l} \frac{l_w}{2} \\ h/2 \end{array} \right\}$$

- if $V_u \leq 0.5\phi V_c$, provide per ACI ch.14

- if $V_u > 0.5\phi V_c$, ACI 11.10.9(05)

Shear Reinforcement Design

$$V_u > \phi V_c, V_s = A_v f_y d / s$$

$$\boxed{\frac{A_v}{s} = \frac{V_s}{f_y d}}$$

Limits

Horizontal: p_t

$$p_t = \frac{A_v}{s h} \geq 0.0025$$

Spacing

$$s_t \leq \begin{cases} \frac{d_w}{5} \\ 3h \\ 18'' \end{cases}$$

Vertical: p_e

$$\begin{aligned} p_e = \frac{A_v}{s h} &\geq 0.0025 + 0.5 \left(2.5 - \frac{h_w}{d_w} \right) (p_t - 0.0025) \\ &\geq 0.0025 \\ &\leq p_t \end{aligned}$$

$$s_e \leq \begin{cases} d_w/3 \\ 3h \\ 18'' \end{cases}$$

Cantilever Redesigns

Steel Cost Savings

Existing Cantilever Design

Exterior Frame-B

Chords	Size(W14)	Length(ft)	Weight(lb)	Braces	Size(W14)	Length(ft)	Weight(lb)	
B-Chord-1	311	22	6842	B-Brace-1	455	28	12740	
B-Chord-2	211	22	4642	B-Brace-2	193	24	4632	
B-Chord-3	211	22	4642	B-Brace-3	193	27	5211	
B-Chord-4	257	11	2827	B-Brace-4	193	27	5211	
B-Chord-5	257	11	2827	B-Brace-5	311	27	8397	
B-Chord-6	257	11	2827	B-Brace-6	193	27	5211	
B-Chord-7	257	11	2827	B-Brace-7	61	29	1769	
B-Chord-8	257	11	2827	B-Brace-8	145	29	4205	
B-Chord-9	257	11	2827	B-Brace-9	145	29	4205	
B-Chord-10	211	22	4642	B-Brace-10	145	29	4205	
B-Chord-11	211	22	4642	B-Brace-11	145	29	4205	
B-Chord-12	211	22	4642	B-Brace-12	145	29	4205	
B-Chord-13	211	11	2321	B-Brace-13	145	29	4205	
B-Chord-14	211	11	2321	B-Brace-14	145	29	4205	
B-Chord-15	211	11	2321	B-Brace-15	145	29	4205	
B-Chord-16	211	11	2321	B-Brace-16	145	29	4205	
B-Chord-17	211	11	2321	B-Brace-17	145	29	4205	
B-Chord-18	211	11	2321					
B-Chord-19	211	11	2321					
B-Chord-20	211	11	2321			Total Weight =	208311	lb
B-Chord-21	211	11	2321				104.2	ton
B-Chord-22	211	11	2321					
B-Chord-23	211	11	2321					
B-Chord-24	211	11	2321					
B-Chord-25	211	11	2321					
B-Chord-26	211	11	2321					
B-Chord-27	283	11	3113					
B-Chord-28	283	11	3113					
B-Chord-29	283	11	3113					
B-Chord-30	283	11	3113					
B-Chord-31	283	11	3113					
B-Chord-32	283	11	3113					
B-Chord-33	283	11	3113					
B-Chord-34	283	11	3113					
B-Chord-35	283	11	3113					
B-Chord-36	283	11	3113					
B-Chord-37	283	11	3113					
B-Chord-38	283	11	3113					
B-Chord-39	283	11	3113					
B-Chord-40	283	11	3113					

Existing Cantilever Design

Interior Frame-B

Chords	Size(W14)	Length(ft)	Weight(lb)	Braces	Size(W14)	Length(ft)	Weight(lb)	
B-Chord-1	370	22	8140	B-Brace-1	283	28	7924	
B-Chord-2	370	22	8140	B-Brace-2	90	24	2160	
B-Chord-3	370	22	8140	B-Brace-3	90	27	2430	
B-Chord-4	211	11	2321	B-Brace-4	90	27	2430	
B-Chord-5	211	11	2321	B-Brace-5	90	27	2430	
B-Chord-6	211	11	2321	B-Brace-6	90	27	2430	
B-Chord-7	211	11	2321	B-Brace-7	90	27	2430	
B-Chord-8	211	11	2321	B-Brace-8	145	27	3915	
B-Chord-9	211	11	2321	B-Brace-9	193	27	5211	
B-Chord-10	211	22	4642	B-Brace-10	90	29	2610	
B-Chord-11	211	22	4642	B-Brace-11	90	29	2610	
B-Chord-12	211	22	4642	B-Brace-12	90	29	2610	
B-Chord-13	211	11	2321	B-Brace-13	90	29	2610	
B-Chord-14	211	11	2321	B-Brace-14	90	29	2610	
B-Chord-15	211	11	2321	B-Brace-15	109	29	3161	
B-Chord-16	211	11	2321	B-Brace-16	109	29	3161	
B-Chord-17	211	11	2321	B-Brace-17	159	29	4611	
B-Chord-18	211	11	2321	B-Brace-18	176	29	5104	
B-Chord-19	211	11	2321	B-Brace-19	193	29	5597	
B-Chord-20	211	11	2321					
B-Chord-21	211	11	2321					
B-Chord-22	211	11	2321					
B-Chord-23	211	11	2321					
B-Chord-24	211	11	2321					
B-Chord-25	211	11	2321					
B-Chord-26	211	11	2321					
B-Chord-27	211	11	2321					
B-Chord-28	211	11	2321					
B-Chord-29	211	11	2321					
B-Chord-30	211	11	2321					
B-Chord-31	211	11	2321					
B-Chord-32	283	11	3113					
B-Chord-33	283	11	3113					
B-Chord-34	283	11	3113					
B-Chord-35	283	11	3113					
B-Chord-36	283	11	3113					
B-Chord-37	283	11	3113					
B-Chord-38	283	11	3113					
B-Chord-39	283	11	3113					
B-Chord-40	283	11	3113					
B-Chord-41	283	11	3113					
B-Chord-42	283	11	3113					
B-Chord-43	283	11	3113					
B-Chord-44	283	11	3113					
B-Chord-45	283	11	3113					
							Total Weight =	179731 lb
								89.9 ton

Final Cantilever Redesigns with Added Brace
Frame-B

Chords	Size(W14)	Length(ft)	Weight(lb)	Braces	Size(W14)	Length(ft)	Weight(lb)	
B-Chord-1	211	22	4642	B-Brace-1	311	28	8708	
B-Chord-2	211	22	4642	B-Brace-2	193	24	4632	
B-Chord-3	211	22	4642	B-Brace-3	145	27	3915	
B-Chord-4	211	11	2321	B-Brace-4	193	27	5211	
B-Chord-5	211	11	2321	B-Brace-5	311	27	8397	
B-Chord-6	211	11	2321	B-Brace-6	193	27	5211	
B-Chord-7	211	11	2321	B-Brace-7	61	29	1769	
B-Chord-8	211	11	2321	B-Brace-8	132	29	3828	
B-Chord-9	211	11	2321	B-Brace-9	132	29	3828	
B-Chord-10	193	22	4246	B-Brace-10	145	29	4205	
B-Chord-11	193	22	4246	B-Brace-11	145	29	4205	
B-Chord-12	193	22	4246	B-Brace-12	145	29	4205	
B-Chord-13	211	11	2321	B-Brace-13	145	29	4205	
B-Chord-14	211	11	2321	B-Brace-14	145	29	4205	
B-Chord-15	211	11	2321	B-Brace-15	145	29	4205	
B-Chord-16	211	11	2321	B-Brace-16	145	29	4205	
B-Chord-17	211	11	2321	B-Brace-17	193	29	5597	
B-Chord-18	211	11	2321					
B-Chord-19	211	11	2321	B-Brace-Add	311	33	10263	
B-Chord-20	211	11	2321					
B-Chord-21	211	11	2321					
B-Chord-22	211	11	2321					Total Weight = 196372 lb
B-Chord-23	211	11	2321					98.2 ton
B-Chord-24	211	11	2321					
B-Chord-25	211	11	2321					Weight Saved = 6.0 ton
B-Chord-26	211	11	2321					
B-Chord-27	211	11	2321					Cost/ton (steel) = 1328.8 dollars
B-Chord-28	211	11	2321					
B-Chord-29	211	11	2321					Cost Savings= 7991 dollars
B-Chord-30	211	11	2321					
B-Chord-31	211	11	2321					
B-Chord-32	211	11	2321					Total Cantilever Savings
B-Chord-33	211	11	2321					
B-Chord-34	211	11	2321					
B-Chord-35	211	11	2321					
B-Chord-36	211	11	2321					
B-Chord-37	211	11	2321					
B-Chord-38	211	11	2321					
B-Chord-39	211	11	2321					
B-Chord-40	211	11	2321					

Exterior Trusses	15983	dollars
Interior Trusses	36929	dollars
Total Savings	52911	dollars

Final Cantilever Redesigns with Added Brace
Frame-E

Chords	Size(W14)	Length(ft)	Weight(lb)
E-Chord-1	159	22	3498
E-Chord-2	159	22	3498
E-Chord-3	159	22	3498
E-Chord-4	145	11	1595
E-Chord-5	145	11	1595
E-Chord-6	145	11	1595
E-Chord-7	145	11	1595
E-Chord-8	145	11	1595
E-Chord-9	145	11	1595
E-Chord-10	145	11	1595
E-Chord-11	145	11	1595
E-Chord-12	145	11	1595
E-Chord-13	145	11	1595
E-Chord-14	145	11	1595
E-Chord-15	145	11	1595
E-Chord-16	145	11	1595
E-Chord-17	145	11	1595
E-Chord-18	145	11	1595
E-Chord-19	145	11	1595
E-Chord-20	145	11	1595
E-Chord-21	145	11	1595
E-Chord-22	145	11	1595
E-Chord-23	145	11	1595
E-Chord-24	145	11	1595
E-Chord-25	145	11	1595
E-Chord-26	145	11	1595
E-Chord-27	145	11	1595
E-Chord-28	145	11	1595
E-Chord-29	145	11	1595
E-Chord-30	145	11	1595
E-Chord-31	145	11	1595
E-Chord-32	145	11	1595
E-Chord-33	145	11	1595
E-Chord-34	145	11	1595
E-Chord-35	145	11	1595
E-Chord-36	145	11	1595
E-Chord-37	145	11	1595
E-Chord-38	145	11	1595
E-Chord-39	145	11	1595
E-Chord-40	145	11	1595
E-Chord-41	145	11	1595
E-Chord-42	145	11	1595
E-Chord-43	145	11	1595
E-Chord-44	145	11	1595
E-Chord-45	145	11	1595

Braces	Size(W14)	Length(ft)	Weight(lb)
E-Brace-1	283	28	7924
E-Brace-2	90	24	2160
E-Brace-3	90	27	2430
E-Brace-4	90	27	2430
E-Brace-5	90	27	2430
E-Brace-6	90	27	2430
E-Brace-7	90	27	2430
E-Brace-8	145	27	3915
E-Brace-9	193	27	5211
E-Brace-10	90	29	2610
E-Brace-11	90	29	2610
E-Brace-12	90	29	2610
E-Brace-13	90	29	2610
E-Brace-14	90	29	2610
E-Brace-15	109	29	3161
E-Brace-16	109	29	3161
E-Brace-17	159	29	4611
E-Brace-18	176	29	5104
E-Brace-19	193	29	5597
B-Brace-Add	257	33	8481

Total Weight = 152009 lb
76.0 ton

Weight Saved = 13.9 ton

Cost/ton (steel) = 1328.8 dollars

Cost Savings= 18464 dollars

Total Cantilever Savings

Exterior Trusses	15983	dollars
Interior Trusses	36929	dollars
Total Savings	52911	dollars

APPENDIX H: BIM Execution Planning

BIM Goals

Priority (1-3)	Goal Description	Potential BIM Uses
1- Most Important	Value added objectives	
1	Life Cycle Cost / Value Engineer all design decisions	Cost Estimation, Engineering Analysis, Building System Analysis, Design Reviews, Existing Conditions Modeling
1	Optimize Building Performance	Engineering Analysis, Building System Analysis, Design Reviews, Existing Conditions Modeling, Site Analysis
1	Eliminate Field Conflicts	3D Coordination, Design Reviews, Existing Conditions, Modeling, Design Authoring
1	Improve Energy Efficiency	Engineering Analysis, Building System Analysis, Design Reviews, Site Analysis, Existing Conditions Modeling, Design Authoring
1	Improve Daylighting	Engineering Analysis, Building System Analysis, Design Reviews, Site Analysis, Existing Conditions Modeling, Design Authoring
1	Optimize Sequence and Schedule	4D Modeling

BIM Software

Revit Architecture 2011
 Revit MEP 2011
 Revit Structure 2011
 Trane Trace 700
 Daysim
 Navisworks Manage
 AGi32
 ETABS
 SAP2000
 spColumn
 3ds Max Design
 AutoCAD 2011
 Project Vasari
 Quantity Take-Off - QTO

BIM Uses

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resour	Notes	Proceed with Use
	High / Med / Low		High / Med / Low	Scale 1-3 (1 = Low)					YES / NO / MAYBE
				Resources	Competency	Experience			
Maintenance Scheduling	Low								NO
Building Systems Analysis	High	MEP	High	3	3	2			YES
		STR	Med	3	3	2			
		L/E	High	3	3	2			
Record Modeling	Low								NO
Cost Estimation	High	CM	High	3	3	2			YES
4D Modeling	High	CM	Med	3	3	2			YES
Site Utilization Planning	Low								NO
Layout Control & Planning	Low								NO
3D Coordination (Construction)	Low								NO
Engineering Analysis	High	MEP	High	3	3	2			YES
		STR	High	3	3	2			
		L/E	High	3	3	2			
Site Analysis	Med	MEP	Med	3	3	2			YES
		L/E	Med	3	3	2			
Design Reviews	High	MEP	High	3	3	2			YES
		STR	High	3	2	2			
		CM	High	3	2	1			
		L/E	High	3	2	1			
3D Coordination (Design)	High	MEP	High	3	3	2			YES
		STR	High	3	2	2			
		CM	Med	3	2	1			
		L/E	Low	3	2	1			
Existing Conditions Modeling	Low	MEP	Low	3	3	2			YES
		STR	Med	3	3	3			
		CM	Low	3	3	2			
		L/E	High	3	3	3			
Design Authoring	Med	MEP	Low	3	3	2			YES
		STR	High	2	2	2			
		L/E	Med	2	3	3			
Programming	Low								NO
Energy Analysis	High	MEP	High	3	3	2			YES
		L/E	Med	3	3	2			