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UNIT 1:
IPD/BIM DISCUSSIONS

KGB Maser
Management. Engineering. Consulting.

BIM/IPD TEAM #3

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EXECUTIVE SUMMARY

KGB Maser is pleased to present the team's year-long senior capstone thesis project for AE482. Over the course of the year, the team has collaboratively assessed the current Millennium Science Complex building design and targeted areas where the team could explore design enhancements through integrated project deliver and building information modeling platforms. The KGB Maser team consists of a student from each discipline within Architectural Engineering at Penn State. Each discipline came into the IPD/BIM thesis with sufficient background in building information modeling programs. Together, KGB Maser has analyzed engineering systems of the Millennium Science Complex using BIM software in an IPD environment. Specifically, the team made efforts to analyze the façade, optimize energy performance, and redesign the structure to attempt to save cost of the building.

The existing façade consists of a pre-cast panel system sized to span each 22'-0" bay. The brick veneer wraps around the approximately 27-inch deep reveal to eight feet of window wall. The windows are separated vertically by a louvered overhang that reaches out to the plane of the pre-cast panels. Team members dissected daylight delivery, structural integrity, indoor environment, and constructability to achieve a cost-effective alternative to the existing façade composition. Through substituting a triple-pane glazing for the existing double-pane glazing, reducing the depth of the panel flanges, and optimizing the overhangs for daylight and indoor environment, the team is able to reduce mechanical operating costs by 1.5%. Additionally, the dimming system in public perimeter zones saves 6.97% in automated areas. The flange thickness reduced to 15.75" resulting in $243,932 savings in estimated construction costs.

The next phase of KGB Maser's analysis aims to reduce energy consumption through optimizing the mechanical distribution system. Research in ASHRAE Journal articles and Labs21 design guides has shown that chilled beam application in a laboratory facility can produce substantial savings in operating costs. The chilled beam redesign was applied to the whole building with the use of single enthalpy wheel and enthalpy-sensible wheel air handling units. The system was sized in response to façade design changes and the resulting electrical system implications were assessed. Annually operating costs are 14.1% less than the existing VAV design. Life cycle cost analyses demonstrated that the high initial cost will be suppressed over a thirty year span. A separate study was performed to quantify energy savings for reducing fume hood face velocity. Through analysis with a computational fluid dynamics model, similar containment effectiveness was found to warrant energy savings with lower face velocities.

The expensive cantilever structure was investigated for redesign possibilities that could reduce materials and therefore structural cost. The 154 foot cantilever is supported by four main trusses whose members are controlled by stiffness rather than strength. By placing two columns underneath the intersections of these four trusses, stresses are reduced and truss members can be downsized. Bays of bracing that once resisted the cantilever's inherent overturning moment can now be removed due to different end conditions. A sculpture was added underneath the overhang to enhance the support of the cantilever and prohibit pedestrian traffic over the nano-technology labs relieve the space visually.

Through each of KGB Maser's phases of analysis, communications between team members and model sharing software needed continuous input. KGB Maser chose to continue use of Revit analytical models provided by the design team and share information across a spectrum of BIM software.

FOREWORD: INTENT AND USE OF THIS DOCUMENT

Being part of the IPD/BIM Thesis pilot program has its inherent challenges. Teamwork is a major theme throughout the duration of projects. Groups do their best to perform as a single, full-service design firm – a well-oiled machine. The challenge for IPD/BIM groups is hinged on two goals – working as a team and presenting a cohesive product that embodies the team dynamic used during the 2010-2011 academic year. Not only must each student be part of the team, but must also display knowledge and proficiency in engineering studies. The structure of this document tries to accommodate both team and individual requirements for the Architectural Engineering senior capstone thesis project.

The reader will be introduced to two binders collectively form one final report – the body and the appendices. Using two books will allow readers to consult tables, figures, drawings, and manufacturer information while concurrently examining the analysis portion of the report.

The body of the report has been divided into 5 units: IPD/BIM, Construction Management, Lighting/Electrical, Mechanical, and Structural. In no way is this document structure intended to imply disconnects in teamwork throughout the academic year. Rather, the document separates information based on topic. The reader can easily maneuver to the portion of the document they are most interested in. Supporting engineering calculations and explanations are grouped together in option-specific units to highlight discussions of teamwork and integration.

The appendices section of the final report is structured in the same fashion as the body. Each unit of the body has its associated set of appendices to support design discussions, also named and numbered by unit. Again, this format is designed to keep readers on the same naming and numbering convention between analysis and appendices so as not to become disoriented within the document.

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IPD INTERACTIONS: FULL SERVICE DESIGN

KGB Maser maintained three objectives throughout the entire redesign process. Reducing the cost of the façade, creating more energy efficient lighting, electrical and mechanical systems, and reducing the cost of the structure were the collaborative goals. Through negotiation and communication, BIM goals were attained. The process included consistent negotiations and compromises, which replicate engineering as it is practiced in the field.

ENERGY CONSUMPTION REDUCTION

CHILLED BEAMS ELECTRICAL SYSTEM IMPACT

KGB Maser's team goal to reduce energy consumption by applying chilled beams instead of a VAV system also impacts the electrical distribution system. The proposed active chilled beam necessitated some equipment changes. The existing air handling units will be resized or deleted while the pumps will be consolidated into a motor control center. The redesign air handling units have a single electrical connection for the entire assembly. Since this is the case, the air handling units will be excluded from the motor control center and simply replace the existing air handling units on their associated distribution panelboards. The air handling unit changes can be reviewed in the "Revised Panelboard Schedules" and "Revised Panelboard Feeder Sizing" section of Unit 3. A summary of the total equipment changes is as follows:

Existing Equipment				
Tag	Service	Location	Supply Motor (hp)	Exhaust Motor (hp)
AHU-1	Lab	Mechanical Penthouse	100	(2) 50
AHU-2	Lab	Mechanical Penthouse	100	(2) 50
AHU-3	Lab	Mechanical Penthouse	100	(2) 50
AHU-4	Lab	Mechanical Penthouse	100	(2) 50
AHU-5	Lab	Mechanical Penthouse	100	(2) 50
AHU-6	Offices	Mechanical Penthouse	60	N/A
AHU-7	Offices	Mechanical Penthouse	60	N/A
AHU-8	Offices	Mechanical Penthouse	60	N/A
CWP-1	Chilled Water	Basement Mezzanine	150	N/A
CWP-2	Chilled Water	Basement Mezzanine	150	N/A
CWP-3	Chilled Water Standby	Basement Mezzanine	150	N/A
CWP-4	Chilled Water Low Flow	Basement Mezzanine	60	N/A
HWP-5	Ventilation Heating	First Floor	40	N/A
HWP-6	Ventilation Heating	First Floor	40	N/A

Redesign Equipment				
Tag	Service	Location	Supply Motor (hp)	Exhaust Motor (hp)
AHU-EXT-1	Lab/Office	Mechanical Penthouse	50	50
AHU-EXT-2	Lab/Office	Mechanical Penthouse	50	50
AHU-INT-LS1	Interior Labs Life Science	Mechanical Penthouse	75	75
AHU-INT-LS-2	Interior Labs Life Science	Mechanical Penthouse	75	75
AHU-INT-MS1	Interior Labs Material Science	Mechanical Penthouse	75	75
AHU-INT-MS2	Interior Labs Material Science	Mechanical Penthouse	75	75
CWP-1	Active Chilled Beams CLG	Basement Mezzanine	150	N/A
CWP-2	Active Chilled Beams CLG Standby	Basement Mezzanine	150	N/A
CWP-3	AHUs + Process Chilled Water	Basement Mezzanine	100	N/A
CWP-4	AHUs + Process Chilled Water Standby	Basement Mezzanine	100	N/A
CWP-5	Chilled Water Low Flow	Basement Mezzanine	60	N/A
HWP-5	Active Chilled Beams HTG	First Floor	50	N/A
HWP-6	Active Chilled Beams HTG Standby	First Floor	50	N/A
Will be consolidated to a motor control center in the basement Mezzanine				

A detailed discussion of the motor control center design can be viewed in Depth Topic 2 of Unit 3 in this document. In summary, the six pumps that are consolidated to the motor control center yield a 15'-0" long structure that must be located within the basement of the building. The basement has been chosen due to the location of the pumps served by the center. An isometric view of the unit can be seen in Figure 1.1 below:

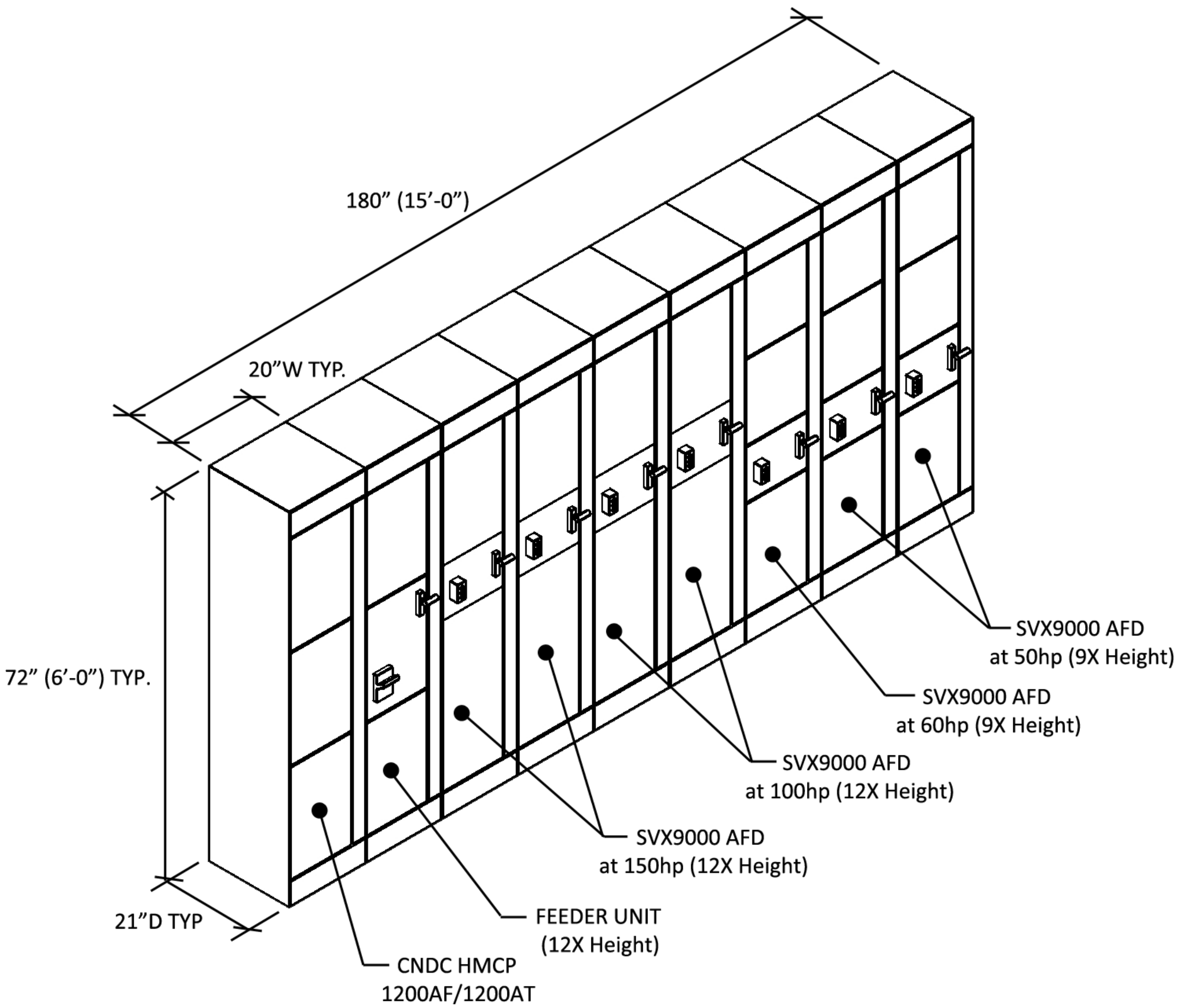


Figure 1.1: Motor Control Center Design Isometric View

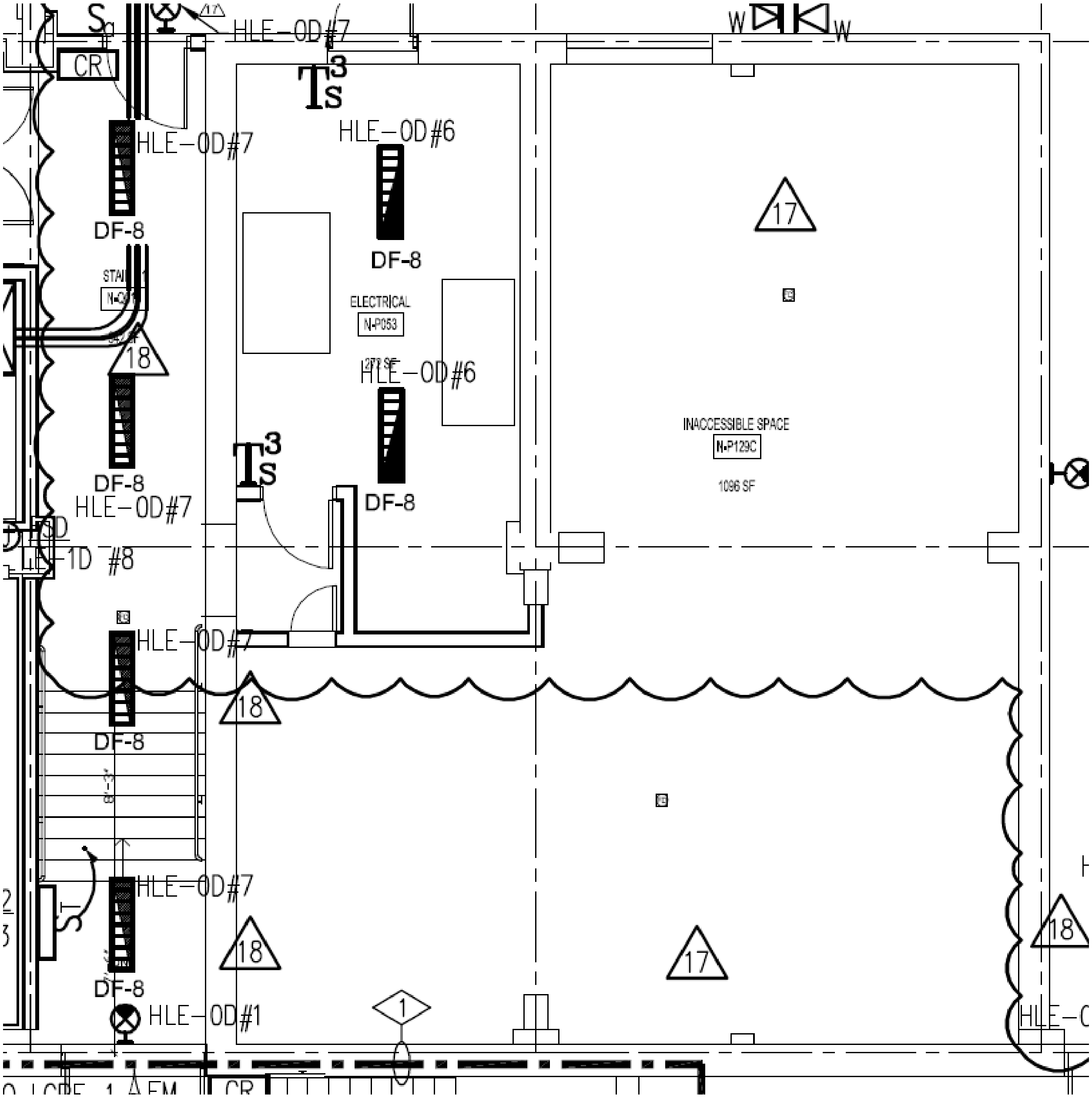


Figure 1.2: Available Space for Motor Control Center, NTS

The dimensions from the aforementioned data result in a motor control center that is 15’-0” in length. With the space now available, the motor control center can be located in the newly formed room using Revit Architecture. The plan for locating the MCC can be seen in Figure 1.3 below:

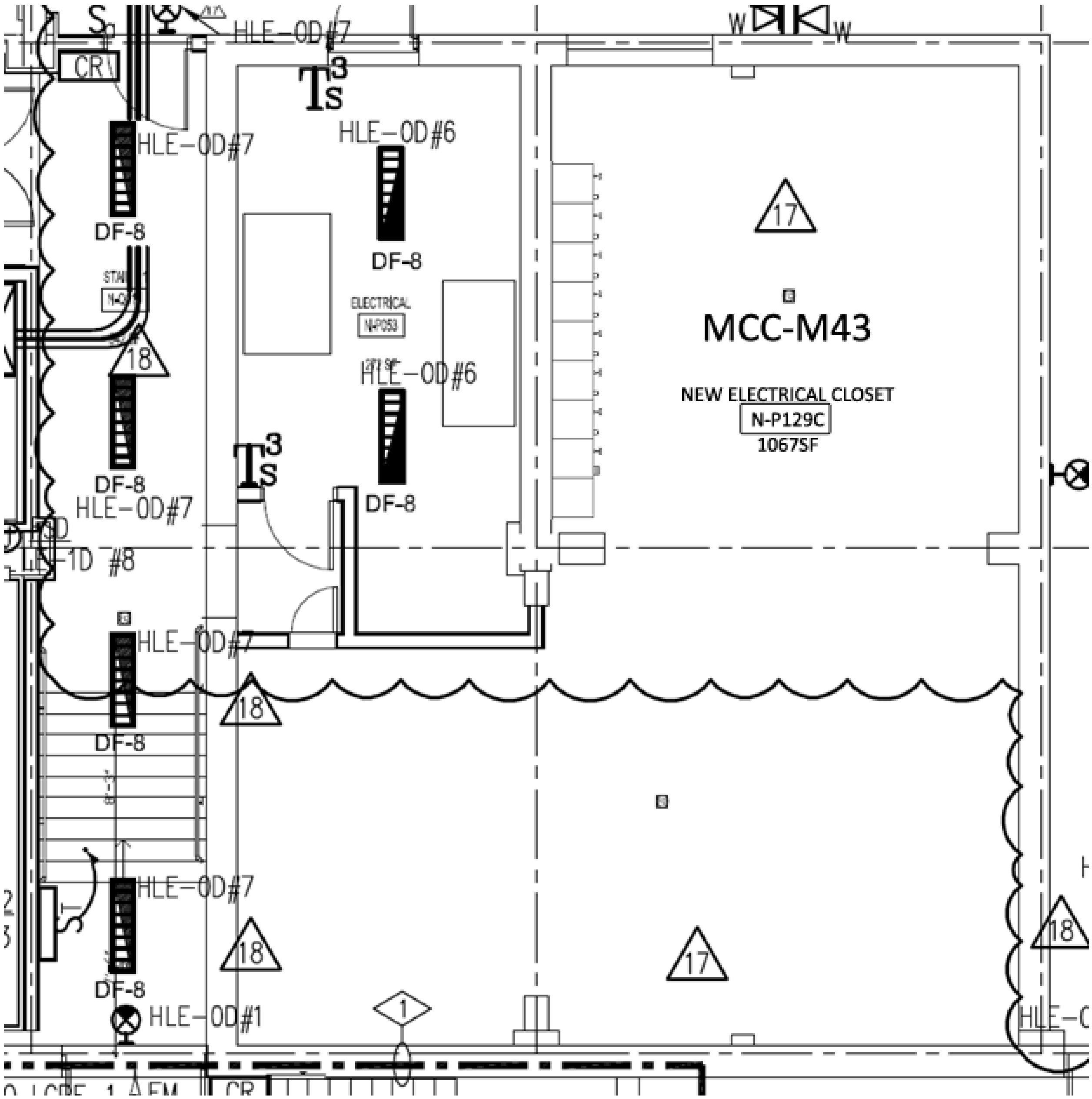


Figure 1.3: Motor Control Center Location Plan, NTS

The feeders running to the pumps will need to be resized according to voltage drop regulations according to the National Electrical Code. I the figure above, they are sized at 125% of the full load current of each motor.

The mechanical engineer used a Trane TRACE model to track the operating costs associated with the existing VAV design and the proposed active chilled beam redesign. The model compares the effectiveness of the two distribution systems. However, to analyze the energy use of each system, the adjusted pump and fan demands needed to be included in the model.

Comparison of Fan and Pump Energy		
	Fan Energy (kWh/yr)	Pump Energy (kWh/yr)
Existing VAV	309,022	390,077
Proposed Active Chilled Beam	257,607	438,177

The results in the table above correlate to what would be expected for the systems compared. The next step in system comparison was to assign economic costs to each of the utilities. The rates for purchased chilled water, purchased district steam, and electricity consumption/demand were obtained from Penn State's Office of Physical Plant. The following table compares the results of the final energy model simulated. The detailed energy model was completed for the 3^{rd} floor only to gain accurate results. The results were extrapolated by area to provide an estimate of the building's energy use.

3^{rd} Floor and Estimated Building Operating Costs			
		3^{rd} Floor	Building
Existing VAV	Building Energy kBtu/yr	16,478,534	98,871,204
	Source Energy kBtu/yr	26,688,590	160,131,540
	Operating Costs	$250,288	$1,501,728
	Cost/SF	$\$5.84/ft^2$	
Proposed ACB + Triple Pane Glazing	Building Energy kBtu/yr	13,912,786	83,476,716
	Source Energy kBtu/yr	24,018,516	144,111,096
	Operating Costs	$214,983	$1,289,898
	Cost/SF	$\$5.02/ft^2$	
	Percent Savings	14.1%	

Additionally the mechanical engineer studied the effect of downsizing the face velocity of fume hoods from 100 fpm to 80 fpm. The results of the energy study showed a savings of 30% when operating fume hoods at 80 feet per minute. The lowered face velocity was also modeled in a computational fluid dynamics program to compare the leakage rage of a tracer gas. The simulation of the tracer gas test showed slight increases of contaminant levels at the face of the fume hood. Overall, the concentrations observed in all conditions were less than 0.015% of the tracer gas inlet. For more information on CFD results, please refer to Unit 4. If the lowered face velocity fume hoods were approved by Penn State and the Industrial Hygiene & Safety Officer for the project, additional operating cost savings and equipment changes could be attained. The potential changes are summarized in the following table.

Summary of Fume Hood Makeup Air Costs and Savings		
Metric	100 fpm VAV	80 fpm ACBs
Cooling/Dehumidification	$233,356.06	$122,597.17
Heating	$6,479.29	$13,447.52
Fan	$110,512.71	$81,042.65
Humidification	$17,610.24	$33,343.69
CAV Operation Costs	$367,958.30	$250,431.03
VAV Multiplier for Operation	0.32	0.32
Adjusted Operation Costs	$116,704.95	$79,428.95
Percent Savings		31.94%

Fume Hood Exhaust Fan Comparison				
Design	Fan Type	CFM	Static Pressure	HP
Existing 100 fpm	(3) Greenheck Vektor MD-33	21,400	5"	50
	(3) Greenheck Vektor MD-33	11,600	5"	25
Proposed 80 fpm	(3) Greenheck Vektor MD-33	17,200	5"	40
	(3) Greenheck Vektor MD-33	9,280	5"	15

FLOOR SYSTEM AND MECHANICAL DISTRIBUTION

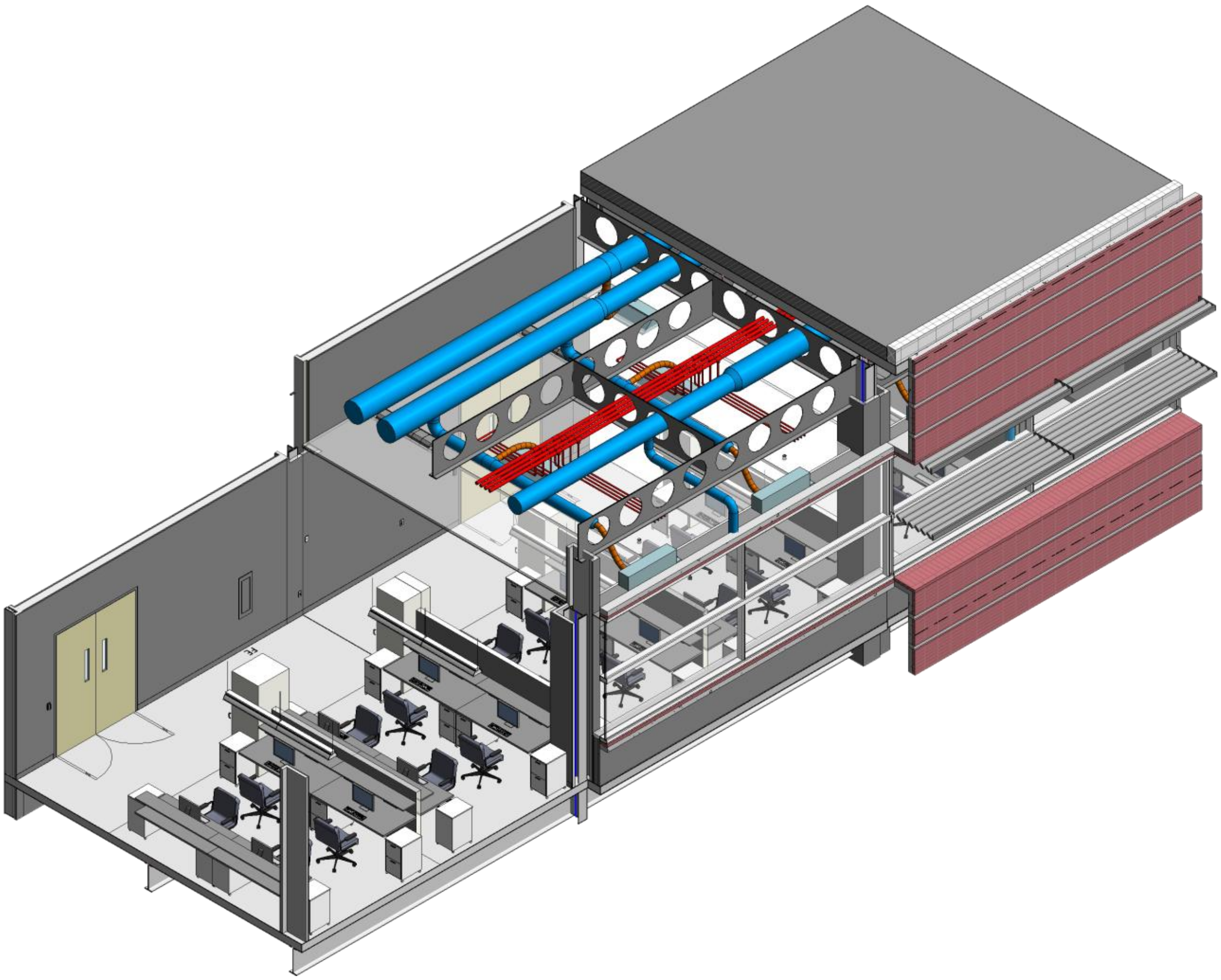


Figure 1.4: 3D Section of Student Area

The smaller mains were sized to fit in the cellular members and had a maximum diameter of 17". One main served the first half of the wing while the second main continued to serve the further half. Within other cellular members, mechanical hot and chilled water piping was easily distributed.

The existing floor system utilizes steel beams and girders to support a composite deck in square, 22' x 22' bays. Wide Flange, 21 inch deep beams frame into 24 inch deep girders in typical fashion. Strict vibrational criterion necessitates the use of heavier beams and lightweight concrete in areas where labs and offices are located. It is this limit on vibrational velocity that controls the design of the current floor system. Velocities were limited to 2000 micro inches per second in the material sciences wing and 4000 micro inches in the life sciences wing. To minimize weight while maintaining stiffness, the engineers used lightweight concrete. Beams and girders had to be sized two to three times larger than required by gravity.

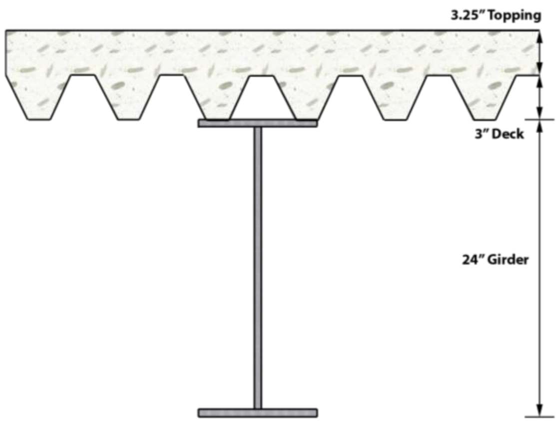


Figure 1.5: Existing Floor Profile

The combination of lightweight concrete and oversized beams allowed the velocities to be limited to around 3900 micro inches per second in both wings; this was discovered after an investigation of vibrations of the existing conditions. Unfortunately this stiffness was acquired by a deep floor profile, 30 inches from top of slab to the bottom of each girder. Plenum space was limited to 7 feet in the third floor and with two and a half being devoted solely to structure, it leads to congestion with the rest of the MEP equipment. In the existing design, holes are cut into the girders and beams at locations of maximum congestion, which also decreases the stiffness of these beams. A proposal was drawn up to maintain the vibrational criteria required of the building while alleviating congestion in the plenum space.

This would be accomplished two ways. The mechanical equipment would use more energy efficient methods to downsize the ducts running through the current plenum, and the existing wide flange beams and girders would be replaced with cellular beams, whose voids would provide an inherent alleyway through which the mechanical ducts could snake.

Using cellular beams has two distinct advantages. The first was mentioned above, as it contains manufactured voids through which mechanical equipment can flow. The second advantage comes in the form of weight and stiffness. Since cellular beams are made from normal wide flanges, their weights are relatively the same as shallower, w-shapes but with a large increase in inertia. The components of these cellular beams are really just the two halves of a typical wide flange cut in a way such that they can be put back together, forming a deeper, stiffer beam.

Figure 1.6: Cellular Beam Fabrication

The biggest issue with this concept is that cellular beams are typically used in longer spans, in buildings whose loads are far less than those seen in the millennium science complex. It is also untraditional for it to be used in a laboratory requiring large exhaust and delivery ducts which cannot be fit through the small voids in a cellular beam. The process of redesign was nonetheless begun with a vibrational study of the existing conditions. Based on this analysis, a baseline was formed to which the redesign was desired to meet.

Because of the large ducts, the cellular beams were sized deeper than would have been normally considered under a purely structural premise. 30-inch deep beams were chosen with 20.75-inch diameter voids in order to accommodate the larger ducts. But even with the larger voids, the existing mechanical equipment was far too large to fit through them.

The mechanical engineer was able to downsize the ducts run to the proposed chilled beams. It was initially decided that while the branch ducts would be able to utilize these voids, the mains could not be fit through such a limited space. The mains would be run underneath the structure. This option would still relieve congestion as it would not require every duct to be run in the same 4-foot space. The mechanical design altered the distribution of the mains to utilize multiple runs of smaller supply and return ductwork runs that can be integrated within the cellular voids and allowed only the branch ductwork to run beneath the structure. One main served the first half of the wing while the second main continued to serve the further half. Within other cellular members, mechanical hot and chilled water piping was easily distributed. This redesign allowed much of the plenum to be freed of large ductwork allowing space for other distribution systems to be designed without congestion.

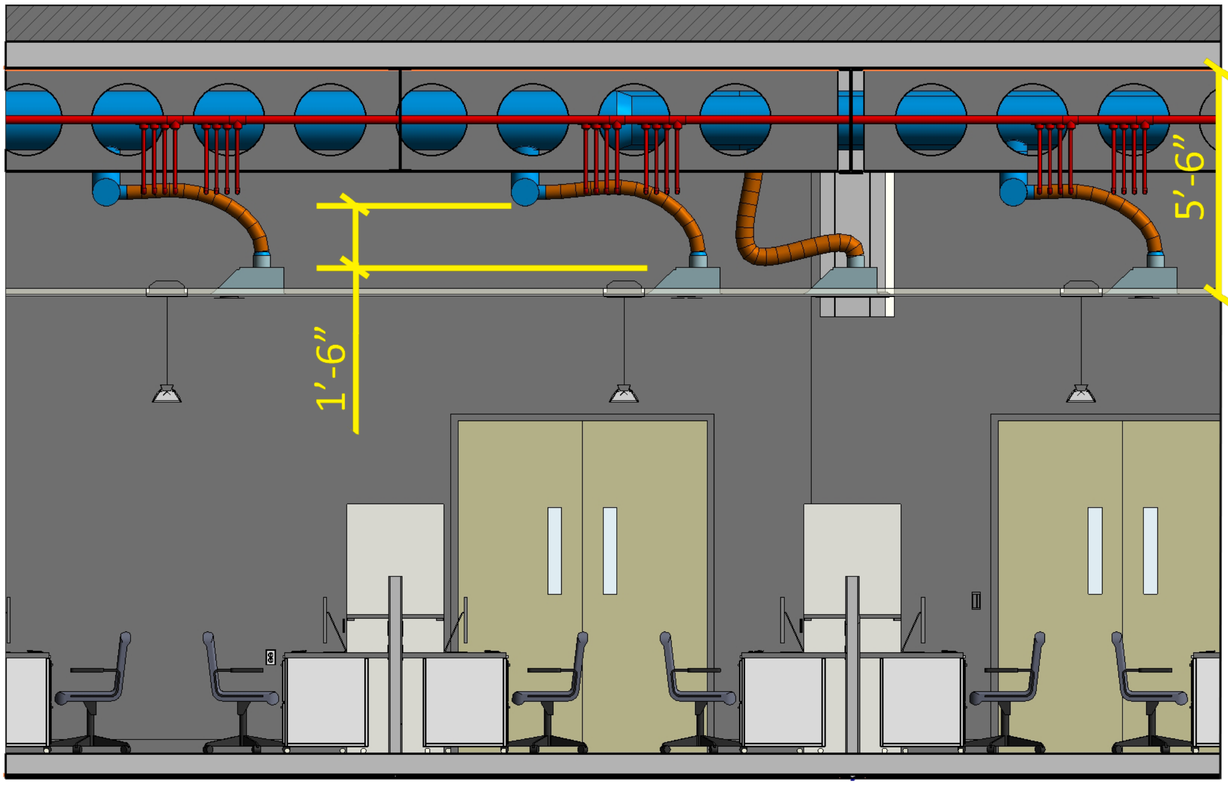


Figure 1.7: Available Plenum Space

ENERGY EFFICIENCY AND COST MANAGEMENT

The cost management aspect of working toward energy efficiency required close interaction with KGB Maser's mechanical engineer and construction manager. In terms of upfront cost, it was important to the construction manager to limit the amount of excess piping that would be needed for the chilled beams. In terms of construction, the chilled beams have a high upfront cost and are very labor intensive. The cost of each of the mechanical engineers designs was easily estimated for a defined area to quickly assess what the upfront costs would be. The chilled beams were also expected to have a negative effect on the schedule duration for the mechanical system.

FAÇADE REDESIGN

As part of KGB Maser's objective for energy efficiency, the team performed analyses of overhang depths for both daylighting and envelope load. The end goal is to pick a façade shading system that will be a compromise between mechanical energy usage and daylight dimming energy savings. In aesthetics, the new design is intended to not break up horizontal lines and the overall "length" of the building. The analyses presented take into account overhang depth with and without redesign, energy usage, and operating costs. An overhang depth will be chosen after each analysis is "overlaid" with the other.

MECHANICAL ANALYSIS

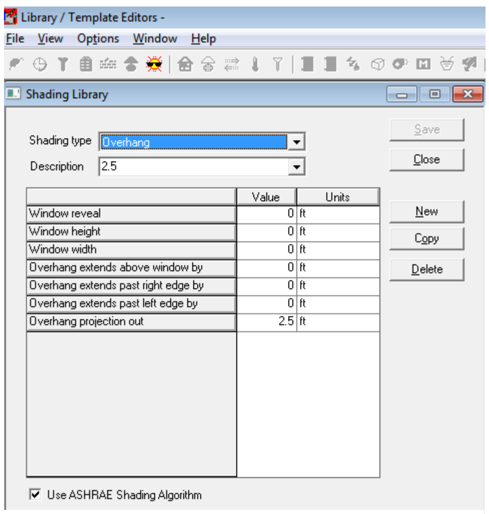


Figure 1.8 Trace Overhang Imports

Modeling the effect of different overhang depths and adding triple pane glazing was done using two different computer modeling platforms. Trane TRACE was used to model the change in overhang depth by adding external overhangs of varying depths within the shading libraries. The existing precast panels created a roughly 2.5 foot overhang. With material costs, and effect on daylighting in consideration, energy models were ran with existing glazing and overhang depths of 2.5 feet, 3.0 feet, and 3.5 feet. Similarly, the existing glazing was changed to triple pane glazing in the Trane TRACE construction templates within the models with the same overhang depths and rerun. The overhangs had to be manually changed for each opening in the third floor. There was no option found that enabled mass changes of overhang to the whole model.

To compares the results of changes in overhang depths and glazing, a mass model was created in Project Vasari. Project Vasari, a technology lab from Autodesk, is meant to provide quick calculations during the conceptual phase of a project. In Project Vasari, The shading depth and window construction was changed as shown in Figure 1.9 and Figure 1.10.

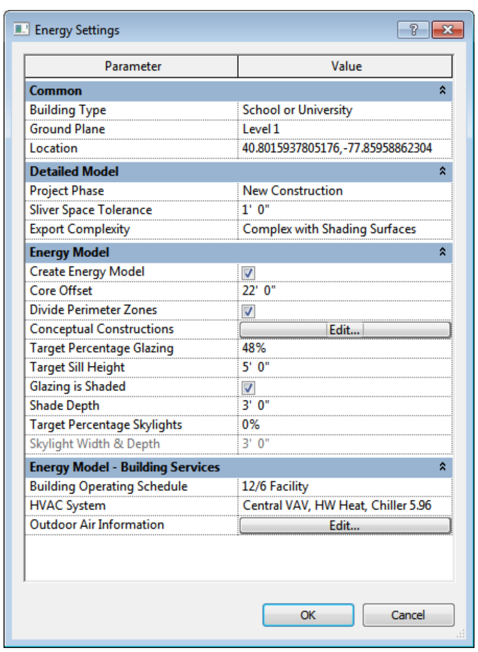


Figure 1.9: Project Vasari Energy Settings

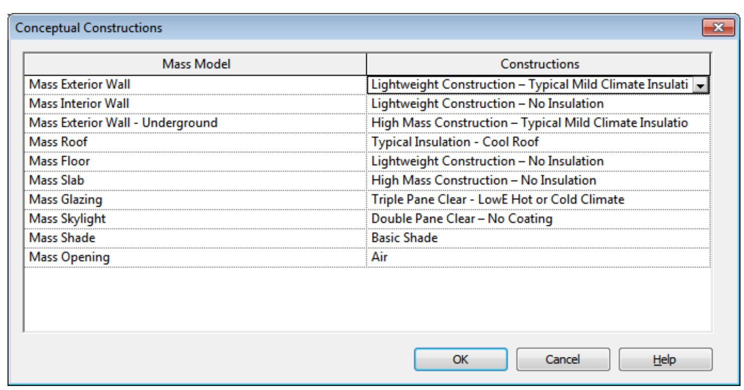


Figure 1.10: Project Vasari Construction Template

Overhang and Glazing Analysis: Summary of Effect on HVAC Operating Cost							
	Existing Glazing			Proposed Glazing			
Overhang Depth	2.5	3	3.5	0	2.5	3	3.5
TRACE Building Costs	$1,501,728	$1,494,852	$1,490,400	$1,512,576	$1,481,418	$1,478,640	$1,478,268
% Decrease from Existing	-	0.45%	0.75%	-0.7%	1.35%	1.53%	1.56%
Vasari Building Costs	$953,470	$952,430	$951,956	$888,241	$884,272	$883,823	$883,286
% Decrease from Existing	-	0.11%	0.16%	6.84%	7.26%	7.30%	7.36%

Due to the more detailed load related data input into the TRACE model, it is believed that the numbers from Trane TRACE reports are more accurate than those from Project Vasari. As shown by the case modeled in TRACE without overhangs, the building benefits from shading devices. However, increasing the shading depth after 2.5 proved to have little additional benefit on the operating cost of the Millennium Science Complex. With daylighting and material costs of longer shading considered as well, the best option for the 2.5 feet overhang and triple pane window should be used to maximize efficiency of the façade.

DAYLIGHTING AND ENERGY

Overhangs are a two-fold advantage in daylight delivery. First, they limit the direct gains on occupants of the space. Secondly, they allow for occupants to use shades less often, depending on overhang depth. This increases the visual interaction between the occupant and the exterior environment. Both of these advantages coexist with the application of a dimming system within the Millennium Science Complex in both the existing design and the redesign of the space. The following study models the existing and redesign student study area for energy usage and utility cost for four of the facades of the Millennium Science Complex – Life Science East and West; and Material Science North and South.

The daylight energy analysis was performed using Daysim – a Penn State Beta release of radiance with a graphical user interface. When using Daysim, a building model can be created in AutoCAD, 3D Studio Max, or Ecotect Analysis. For this study, the model had to be created from scratch in AutoCAD. It is possible to use BIM technologies to arrive at a model for Daysim; however, the process from Revit to AutoCAD does not produce a model that is entirely 3D faces. For more information on lighting analysis processes, see the "BIM Processes for Lighting Design" section of this document. One major advantage to using Daysim over other energy modeling programs is the ability to install and estimate energy usage of shades and dimming systems. Due to the variable nature of shading within the perimeter spaces, shading was left out of this analysis.

The analysis is able to be examined by a "grand total" savings or a "zone savings" from Daysim. In order to estimate savings for the entire perimeter area, the "zone savings" of the redesign space will be applied to the perimeter of the building on a per square foot basis. The initial results are shown in the table below. This initial result is for the Material Science South façade and perimeter area.

Energy Savings (kWh)														
Design Overhang	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% Savings
Actual Grand	135.01	112.46	118.70	107.26	123.12	117.71	117.71	123.17	113.72	127.98	128.93	125.25	1451.08	0.00%
New Grand	100.58	78.23	73.52	61.91	70.60	63.21	63.13	69.44	70.10	83.76	93.91	99.26	927.72	36.07%
3' Grand	97.35	75.36	70.71	60.18	68.73	62.67	62.82	67.96	67.78	81.56	91.47	96.10	902.75	37.79%
3.5' Grand	100.16	77.80	73.03	61.65	70.54	63.10	63.02	69.23	69.73	83.36	93.51	98.95	924.12	36.32%
4' Grand	96.29	74.55	70.08	59.68	68.31	62.60	62.78	67.51	67.09	80.87	90.47	95.06	895.33	38.30%
Actual Zone	49.61	38.20	37.02	33.01	37.73	36.03	36.03	37.78	35.75	42.59	47.24	47.28	478.33	0.00%
New Zone	60.40	43.29	35.08	26.96	30.42	24.77	24.69	29.25	33.41	43.58	55.47	62.57	469.95	1.75%
3' Zone	57.17	40.42	32.27	25.24	28.55	24.23	24.38	27.77	31.09	41.38	53.04	59.41	444.99	6.97%
3.5' Zone	59.97	42.86	34.59	26.70	30.35	24.66	24.58	29.05	33.04	43.17	55.07	62.26	466.36	2.50%
4' Zone	56.11	39.61	31.64	24.74	28.12	24.16	24.34	27.32	30.40	40.68	52.03	58.36	437.57	8.52%

Each façade interacts with daylight differently. The original Daysim model was edited and rotated to account for the other three facades of the Millennium Science Complex. The results of the new models are shown in the table below:

Orientation Change Summary							
Design Overhang	MS South kWh from Table X	Mat. Science North		Life Science East		Life Science West	
		Total kWh	% of MS South	Total kWh	% of MS South	Total kWh	% of MS South
Actual Grand Total	1451.08	1446.46	99.68%	1457.40	100.44%	1447.28	99.74%
Actual Zone Total	478.33	473.70	99.03%	484.65	101.32%	474.53	99.21%

Since the results from changing orientation varied on average of +/- 1%, the Material Science South model was used to calculate energy usage for the entire perimeter. This 1% difference will only add up to a few pennies of savings for the operation of the whole system. Figure 1.11 below shows the results of the analysis in chart-form.

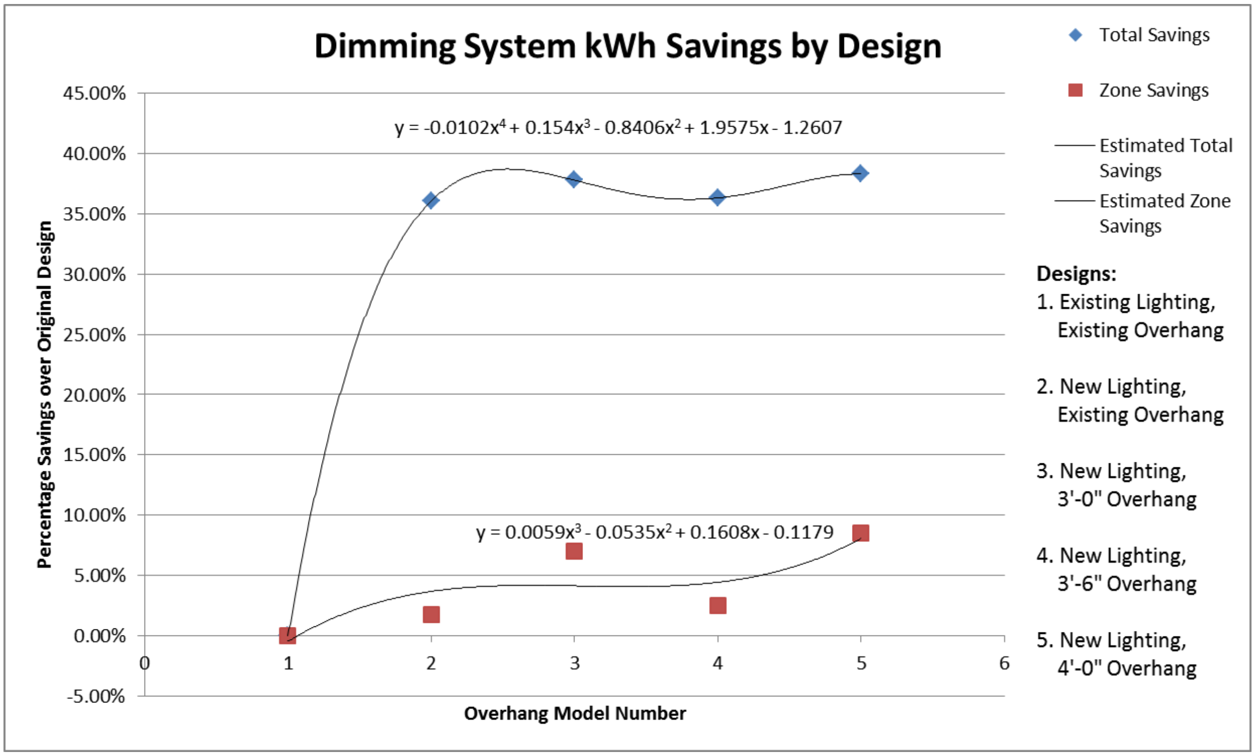


Figure 1.11: Daysim energy analysis results

The maximum savings for daylighting are as follows:

Total Optimum Overhang:	2.756 ft, 40.26 % savings	867.17 kWh	
Zone Optimum Overhang:	2.796 ft, 4.24 % savings	458.05 kWh	810 SF
Existing Overhang and Ltg:	n/a 0% savings	478.33 kWh	810 SF

At the maximum zone savings of the overhang (approximated to 2.8 ft), the savings density is as follows:

Existing System	0.5905 kWh/SF applied to 14115 SF of perimeter area
2.8' Overhang	0.5655 kWh/SF applied to 14115 SF of perimeter area

Existing System	8335.34 kWh energy usage
2.8' Overhang	7981.95 kWh energy usage
Net Difference	353.40 kWh energy usage

Total operating cost savings at $0.08/kWh is $28.27

This total energy cost savings is minimal once analysis is performed, but it does not tell the entire story of the design. The existing dimming system utilizes three two-lamp fixtures connected to the Lutron Ecosystem dimming controls. The redesign consists of two two-lamp fixtures connected to the same Lutron Ecosystem. For an in-depth description of the lighting redesign, see Unit 3. The redesign will save on up-front costs by having one less luminaire per dimming row. However, this initial cost savings is balanced out by the operating characteristics of the system. The initial design dimmed three fixtures, which is essentially 50% more light output than the redesign. More light output will be dimmed to a lower level more often than the redesign. For this reason, the two systems are essentially the same operating cost. The major difference in light delivery is in the aesthetics and goals of the design. For more discussion on the aesthetic goals of the study area lighting design, see Unit 3.

In choosing the 3'-0" overhang, a new analysis of operating cost for the electrical system was performed. The analysis assumptions were the same as discussed in the "Daylight Analysis" section previous to this section. At 3'-0", the zonal savings was at a measurable peak. This resulted in more savings than the mathematical optimal overhang depth.

At 3'-0" the zone savings density is as follows:

Existing System	0.5905 kWh/SF applied to 14115 SF of perimeter area
3'-0" Overhang	0.5494 kWh/SF applied to 14115 SF of perimeter area

Existing System	8335.34 kWh energy usage
3'-0" Overhang	7754.36 kWh energy usage
Net Difference	580.98 kWh energy usage

Total operating cost savings at $0.08/kWh is $46.48 for the third floor perimeter spaces of the Millennium Science Complex.

A side note must be addressed – these models do not take shading into consideration. At the time of the analysis, programs were not cooperating with shading inputs. Without the use of analysis programs, such as Daysim and Trane Trace, some shading analysis may be performed with appropriate graphs from the IES handbook. Figure 1.12 below illustrates profile angles seen by each façade of the Millennium Science Complex. Each colored line in the graph represents the maximum profile angle that is cut-off by the decided upon overhang construction. Profile angles that lie below these colored lines will penetrate the windows.

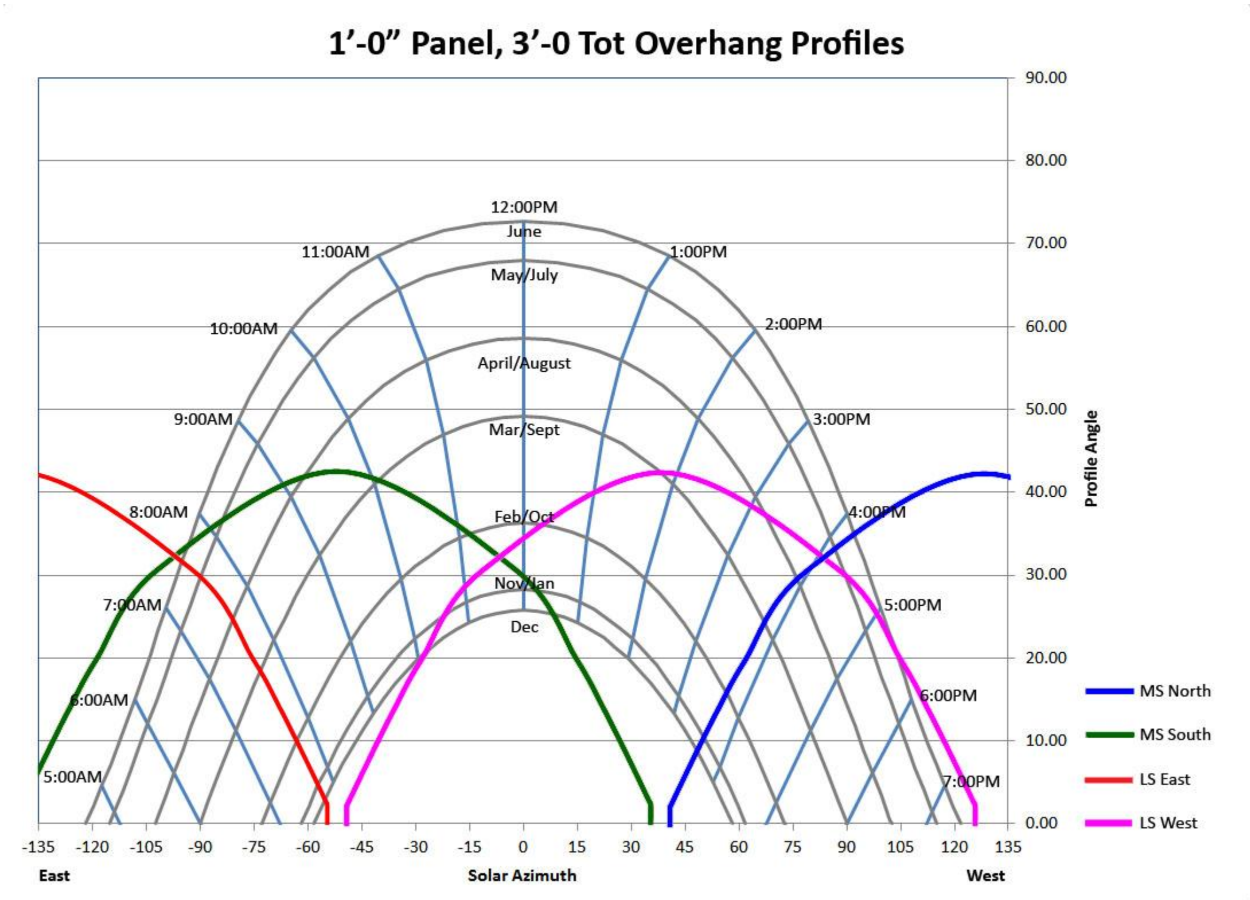


Figure 1.12: Profile angles with redesign of 3'-0" overhang in solar time

In summary of the figure above, the largest sunlight penetration will be on the Material Science South and Life Science West Façades. These two façades will utilize the MechoShade Solar Trac system to provide automatic shade adjustment in public spaces and labs. The offices will utilize user-controlled shades. For a more in-depth discussion on shading delivery, see Unit 3. The perimeter spaces on the Life Science East and Material Science North façades interact with daylight in the early morning and late afternoon hours. The shading delivery along their façades will be user-controlled only.

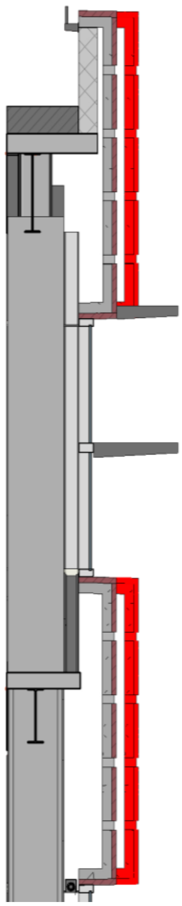


Figure 1.13: Proposed Facade Changes

From an energy cost perspective only, the best condition for maximum operating cost savings is to install a 3.5' foot overhang. However, the 3.5' overhang provided only a small margin of savings when compared to the 3.0' overhang. A larger first cost will likely be incurred if a 3.5' overhang was used. Also, in both models, more significant savings are seen with the installation of triple pane glazing. For this reasoning, coupled with daylight and initial cost considerations, 3.0' overhang shading devices placed at the top and middle of the glazing as well as a triple pane glazing assembly will be recommended for the Millennium Science Complex. Figure 1.13 shows the addition of the 3' overhangs and the reduction of the panel depth versus existing conditions (shown in red). For more information concerning the panel reduction reference Unit 5.

CONSTRUCTABILITY AND STRUCTURAL IMPACT

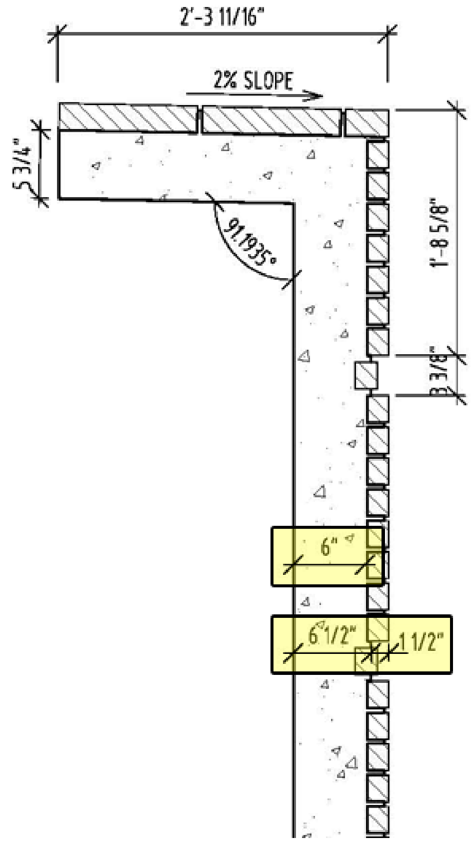


Figure 1.14: Existing Panel Design Detail

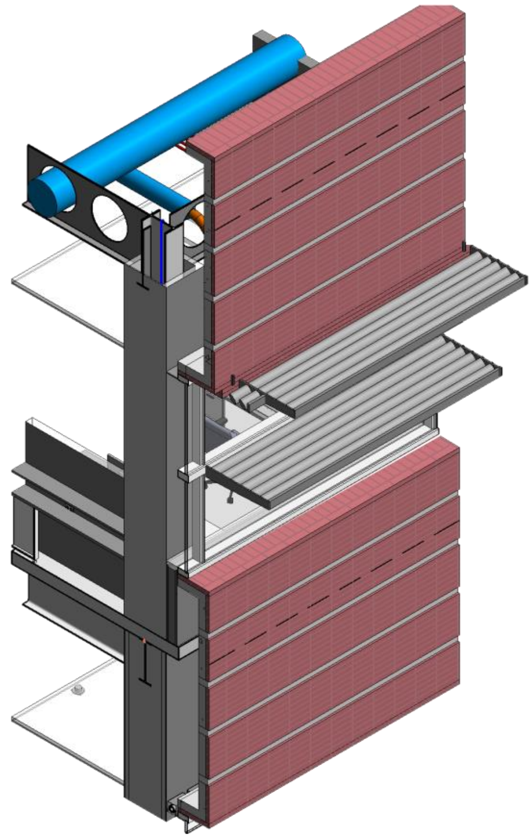


Figure 1.15: 3D Representation of Proposed Facade

From the outset of the redesign process, it was thought that the existing panels were larger than need be. The existing precast panels weigh 36 thousand pounds each. Due to the architect's desire to avoid interfering with the interior space, the panels have a C-shape section in order to avoid the cantilevered slab edge and to retain as much interior area as possible. They span 22 feet across each bay from column to column. Two bearing connections at either end of each panel were placed near its bottom, with lateral connections being placed at its top. The simplicity of connections made panel erection easy, despite their heavy weight. This weight comes by way of sheer volume. The panels were designed 6 inches thick at the face, with flanges recess back towards the building adding nearly 2 feet of depth to the profile. Panels were designed to fit multiple instances across the entire exterior of the building.

Initially, KGB Maser had hoped to reduce the weight of the façade by simply making the panels thinner. Several strength calculations were carried out on the existing panels with dimensions being taken from the provided construction documents. These calculations revealed a few facts about each panel. The "larger than need be" thickness was warranted, as it prevents cracking under the panel's own self-weight. When lain on its back, the panel face is subjected to bending from the combined weight of the concrete and masonry brick on its exterior. Although the panel face could be made thinner and still remain uncracked under its own self weight, the risk of cracking under poor quality control when being transported led to the engineers to size the panels conservatively. Unfortunately, this also means that the panels gain a large amount of weight.

Assuming the architect wanted to maintain the aesthetic of a real brick façade, the face of each panel was covered in 2-inch face brick. These masonry units appear to be normal bricks split in two and laid into the face of the panel. This amount of brick adds a large amount of mass to the concrete panels. The method of attaching the bricks to the panel was also examined, as it was feared that the bricks would eventually pop out of their housings due to cyclic expansion and contraction.

A further investigation was performed for alternatives that could be implemented in place of the existing design. An early proposition included adding a green wall to the face of the panels but was considered unviable with the climate of State College. Another idea extended the existing panel depth to 4 feet beyond the interior walls in order to produce better shading for the interior spaces. One last proposal shrunk the profile of the façade profile to less than a foot and a half. This proposal was considered the best alternative to the current system and adopted as a design objective.

In order to shrink the panel profile, the panel must be designed to resist wind and gravity loads while remaining uncracked. An excel spreadsheet was created in order to check the proposed dimensions. However, before completing the strength analysis the weight was first reconsidered.

As mentioned before, the existing façade uses 2-inch brick to imitate the appearance of real brick construction. This was seen as inefficient. Not only does it add excess mass to the panels, but if the bricks, are in fact simply typical masonry bricks cut in two, they may be susceptible to popping out of their housings. The panel concrete and masonry behave differently when introduced to moisture. The clay used to make typical bricks expands and contracts at a different rate than concrete, absorbing a higher percentage of moisture. It was proposed to replace these half bricks with thin brick.

Thin brick is denser than traditional masonry, aligning more with the properties of the precast panel. The brick, a half-inch thick, is textured on the face in contact with concrete and adheres to it during the process of curing. They are laid down before the panel concrete is poured in a grid formed by polystyrene or rubber. The concrete is then poured over the brick and the grid is removed later. The thin brick is engineered to behave similarly to concrete, absorbing less water, about 3-6% versus 8-17% of traditional masonry. The issues that raised concern in the existing design are resolved with the use of similarly behaving materials.

With the weight resolved, applying the thin brick to the façade and measuring its new mass, the existing panel dimensions were analyzed for strength. A few gravity and wind checks were conducted in order to calculate the minimum panel thickness, as well as the minimum flange depth required in order to meet strength requirements without cracking. 4.25 inches were required to maintain structural integrity, but 5 inches was used to allow for stress induced under the erection and transportations processes; a precast manufacturer who had come to lecture during the semester also suggested this.

The flange depth was under two constraints. Strength limits how small the flange could be, as it braces the face of the panel against wind loads and also provides the bearing connection at the column, and the cantilevered slab prevents the panel to be placed directly against the columns. Connections were considered first.

Two types of connections were designed for, one placing the bearing connection at the top of the panel, while the other places it at the bottom. A dap steel connection was examined first, as that is what is used in the existing design. Reinforcement development length for this connection type requires the rebar to penetrate the concrete 17 inches, more than what was desired for panel depth. A corbel connection was then considered. The corbel required only 9 inches of rebar development, which would provide a slimmer profile along the lines of 16”.

	Precast Panel Dimensions		
	Panel Height	141.125	in.
	Panel Depth	5	in.
	Brick Depth at Face	0.75	in.
	Flange Height	10	in.
	Brick Height at Flange	0.5	in.
	Flange Depth	15.75	in.
	Panel Width	263.25	in.
	Return Thickness	14	in.
	Return Depth	10	in.
	Return Height	121.125	in.
	Volume Concrete	157.593	ft.3
	Weight Concrete	23638.96	lb.
	Volume Brick	18.52405	ft.3
	Weight Brick	2222.886	lb.
(factored)	Total	36206.58	lb.
(factored)	Total with Planters	43930.29	lb.

	Wind Force	
(factored)	50.992	psf.

Cracking Stress		
477.2971	psi	(factored)

Self Weight Check Upright			
Weight/in.	137.5369	lb./in.	
Inertia of Panel	2032473	in.4	
Moment	1191423	lb.in.	
Stress	41.36329	psi.	OK

Self Weight Check Prostrate			
Weight/in.	8.166667	lb./in.	(factored)
Inertia of Strip	125	in.4	
Moment	14730.64	lb.in.	
Stress	294.6128	psi.	OK

Wind Check On Face			
Weight/in.	4.249333	lb./in.	
Inertia of Strip	125	in.4	
Moment	10578.86	lb.in.	
Stress	211.58	psi.	OK

Wind Check On Flange			
Weight/in.	24.98697	lb./in.	
Inertia of Flange	2812.5	in.4	
Moment	172855.3	lb.in.	
Stress	460.9476	psi.	OK

Figure 1.16: Panel Redesign Strength Checks

The final profile measures 15.75" at the flange with thin brick. Prior concerns of shading were resolved with shades, which can attach directly to the façade. By decreasing the flange depth, material was saved, allowing for lighter panels and a faster erection time. One drawback to this redesign is its connections. Since a corbel was considered appropriate for the panel depth, the bearing connection was moved to the top of the panel, which puts much of the concrete in tension leading to a potential for cracking over time. One solution that was not explored due to time constraints is pre-tensioning the concrete panels. Although this would add cost to the façade, and is not a typical application for pre-tensioning, it would neutralize the tension due to gravity with tensioned steel chords running through the concrete vertically, compressing the concrete.

STRUCTURAL REDESIGN

STRUCTURE AND COST MANAGEMENT

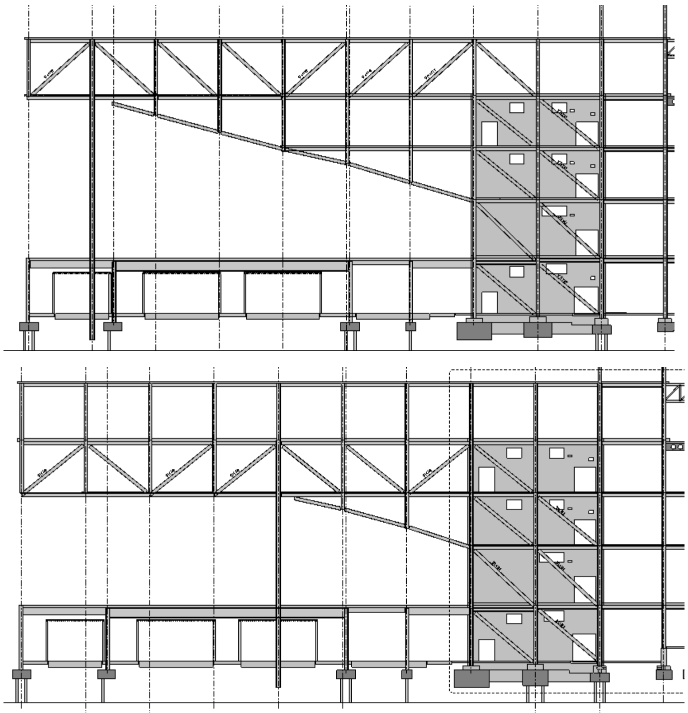


Figure 1.17: Cantilever Redesign

KGB Maser's second goal is to maximize energy efficiency in the building. Team mechanical and electrical engineers examined several options to increase energy efficiency as discussed previously. The structural system costs $90 per square foot, an unusually higher number due mainly to the 150-foot-plus cantilever that overhangs the plaza entrance between the life sciences and material sciences wings. It was proposed that redesigning this particular corner could reduce the cost of the structure, and the savings could then be applied to the distribution systems.

Removing the cantilever completely was a viable option considered. By inserting a column at the end, the stresses in the truss members could be reduced drastically allowing them to be sized based on strength rather than stiffness. Stiffness governs the design of the existing cantilever. The 154-foot overhang is limited to just 2 inches of live load deflection. This fact has necessitated nearly every member in the four main supporting trusses in the cantilever to be moment connected.

By introducing a column to the end of this overhang, the need for moment connections would be removed, allowing each web member to be pinned. This would save on construction costs and expedite erection, increasing constructability with less field welding.

The existing cantilever by virtue of itself induces a very large moment at its base, requiring the need for bracing in the bays beyond its two main base columns to resist an overturning moment. Using a column at the end of the cantilever would fundamentally change the end conditions eradicating the overturning moment and eliminating bracing beyond the main supports; fewer members therefore are needed to be erected.

Using more than one column would further reduce stresses in the trusses, as the trusses would have one more point to which forces could be distributed. Unfortunately with these changes come implications, including architectural interference.

ARCHITECTURAL IMPLICATIONS

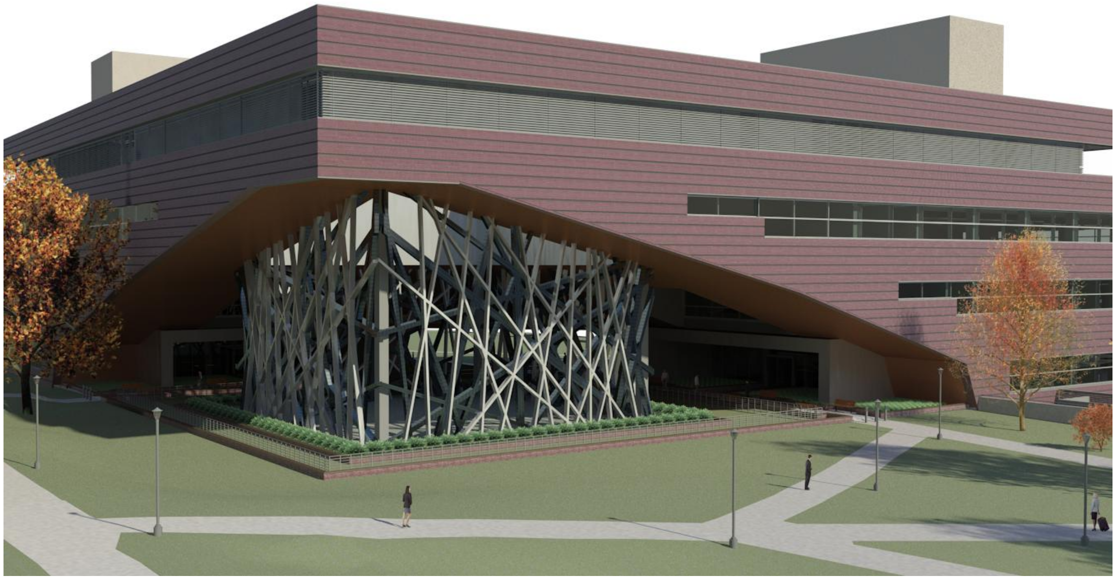


Figure 1.18: Exterior Render in Revit Architecture

Introducing a naked column underneath the overhang would ruin the visual effect created by the architect. It was envisioned by KGB Maser that a feature could be used along with the columns in order to smooth over their presence. Drawing inspiration Beijing's Olympic stadium, The Bird's Nest, a mesh of overlapping metallic tubes was proposed to envelope the plaza following the footprint of the window box in the cantilever. This architectural feature would also serve to brace the columns intermediately to reduce their buckling loads. This feature could successfully mask the columns, but it could not solve the problem encountered at the basement level.

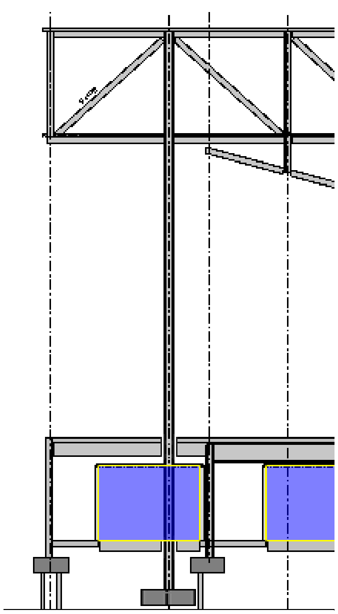


Figure 1.19: Isolation Lab Column Interference

Directly below the cantilever courtyard are 3 isolation labs that sit sequestered from the surrounding foundation, on top of two 2-foot thick slabs. Another 1-foot slab then surrounds these three thicker slabs before the foundation for the rest of the building is met at its edge. The engineers were able to limit vibrations in these laboratories to 130 micro inches per second. The 2 columns proposed in the redesign would run right through two of these labs.

Moving the isolation labs would require reorganizing the entire basement, possibly necessitating further systems redesign. It was posited that the easiest solution would be to simply extend the columns deep into the foundation, several feet below the bottom of the isolation slabs, to pile caps that would then receive the truss loads. The isolation slabs would have to be poured around the column, allowing approximately a one-inch gap between the concrete and column. In order to minimize vibrational propagation from the columns into the labs, a compressive material would fill in the gap creating a barrier between the columns and the concrete slab.

After an analysis was run on the cantilever with two columns in place at opposite corners of the window box, the truss members were sized for strength. The concept was a success as all strength and deflection requirements could be met while drastically reducing the amount of members allowing the existing ones to be sized smaller. Constructability was increased with the use of pinned connections, and only one extraneous task introduced to the construction process was the erection of a column. Since the columns would be too large to ship as two long pieces, each would be shipped in halves and bolted and welded together in the field.

SUMMARY OF PROPOSED DESIGN COST IMPLICATIONS

KGB Maser's main design schemes in Façade, Structure, Mechanical/Energy, and the Architectural Redesign, are currently being priced that there will be a savings of close to $350,000. This savings however is relying on the cost of the cage structure to not trump the savings, at least in terms of upfront costs. The Mechanical/Energy Redesign may cost a significant amount of money upfront by does have the capability of paying for itself with time.

Currently the structural redesign has comprised a savings of close to $2.3 million in upfront costs for the structural systems. This savings come from the comparison of the detailed estimate performed by our team. However, our detailed estimate of the existing structure came in at a total of $10,566,550. This cost does not include general conditions, nor does it cover having multiple cranes on site to erect the steel. It is believed by our team, that given the conservative nature of the detailed estimates that were completed, that a higher savings could come from the use of the columns beneath the cantilever.

Summary of System First Costs				
	Façade Redesign	Structural Redesign	Mechanical/Energy Redesign	Courtyard Design
Existing Cost	$3,295,766.00	$10,566,550.00	$19,188,000.00	$271,745.00
Proposed Cost	$3,051,834.00	$8,275,735.00	$21,040,000.00	$604,910.00
Savings/Expenses	$243,932.00	$2,290,815.00	($1,852,000.00)	($333,165.00)
Total First Cost Savings =$349,582.00				

Additionally, the existing and proposed systems were compared on a life cycle cost basis. Only the first and operating costs associated with the mechanical system was analyzed. Per year, the proposed mechanical system saved 14.1% on energy costs. However, the rise in initial cost needed to be tested over the life cycle of the mechanical system to ensure altering designs was a worthwhile investment. A life cycle cost was done comparing the VAV and active chilled beam systems over 30 years. The evaluation considered the potential switch from Penn State's existing coal powered power plant to natural gas. The life cycle cost analysis was performed without inflation and with inflation rates of 2% and 5%. The table below summarizes the Net Present Value of the systems in different scenarios.

Life Cycle Cost Summary						
	Coal Plant			Natural Gas Plant		
	Real Rate	2% Inflation	5% Inflation	Real Rate	2% Inflation	5% Inflation
VAV	$54,813,916	$63,883,395	$63,856,220	$64,693,985	$77,435,022	$90,744,775
ACB	$55,346,191	$62,693,273	$62,647,108	$59,478,486	$69,307,263	$69,259,831
Percent Savings	-0.97%	1.86%	1.89%	8.06%	10.50%	23.68%
NPV Differential	($532,275)	$1,190,122	$1,209,111	$5,215,499	$8,127,758	$21,484,944

Note: Operating cost savings from reduction in fume hood velocities were not included in this study.

CONSTRUCTION MANAGEMENT BIM PROCESSES

ARCHITECTURAL DESIGN BIM PROCESS

Figure 1.20: Preliminary Sculpture Sketch

The BIM process for the development of the cage structure and the landscape architecture of the courtyard began with a pencil and paper to begin brainstorming ideas. Moving on, we were able to take site pictures of the existing building and see how our designs would affect the architecture. Microsoft Paint was used to quickly drawn in our designs and see how these designs would look alongside real life aspects. Below is one of the sketches as a JPEG from Microsoft Paint.

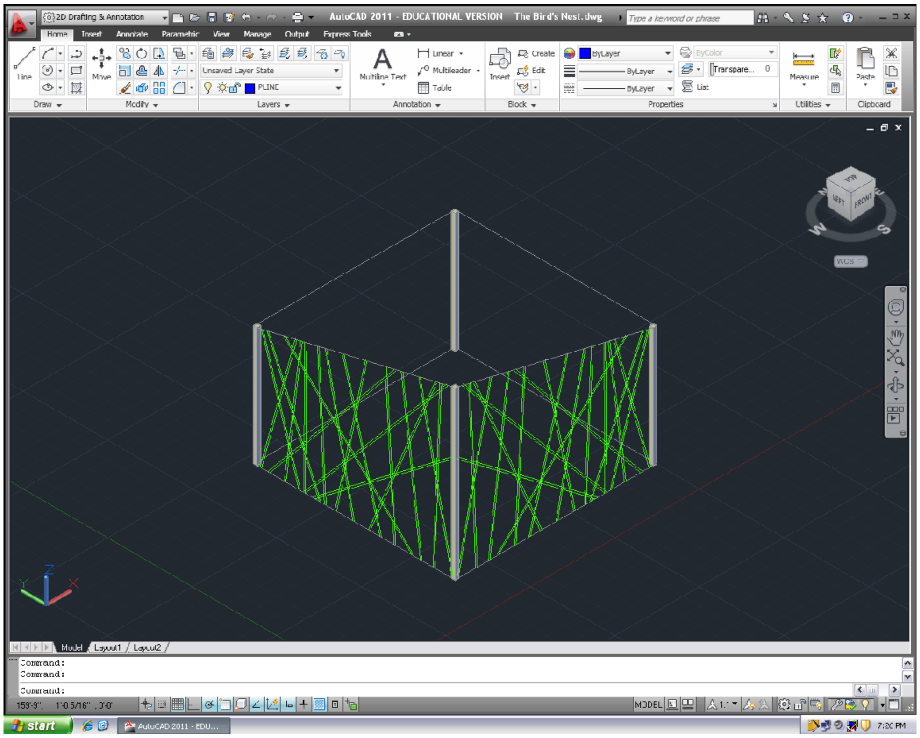
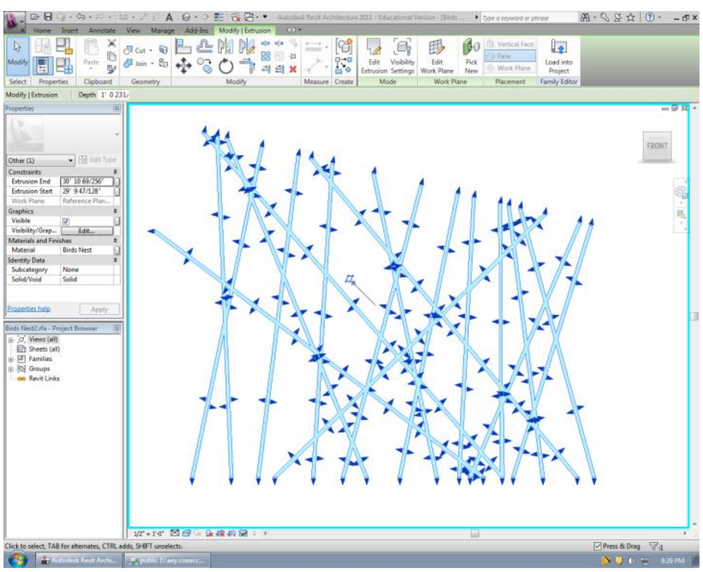


Figure 1.21: AutoCAD Model of Steel Sculpture

The next step in our design process was to begin to work in programs that have interoperability with Revit Architecture. It was necessary to have the interoperability with Revit Architecture, because this is the main default program from which all of KGB Maser's modeling content was derived. The cage structure was again simply modeled and developed in AutoCAD 2011 as a 3D DWG seen below. Dimensions were taken from the Revit Structural model to know where the columns would attach and what dimensions the cage structure would have to fulfill in order to provide bracing support.



From this point, with a 3D DWG we were able to import the DWG into Revit Architecture and create a generic model Revit Family. (RFA File) Creating a 3D model of the 2D lay out was as simple as tracing the 2D layout with the solid function of Revit Families. After tracing the 2D layout, a thickness must be applied to the structure. After the solid is drawn, it is as simple as click and drag to modify each segment of the solid, as seen below in the image showing the blue arrows to modify each segment.

Figure 1.22: Steel Sculpture Revit Modeling

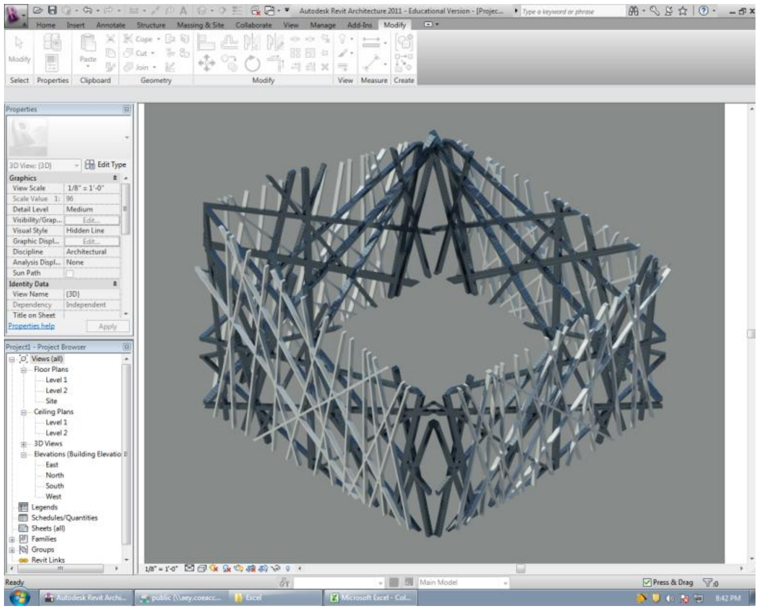


Figure 1.23: Advanced Model of Steel Sculpture

With the geometry of one of the panels set, it was easy to create the other four sides of the cage structure. The other three sides of the cage were simply mirrored aspects of the original design. After setting the geometry to its final design, the materials were chosen using the Properties Tool of Revit. Materials where chosen and rendering where completed to apply these materials to a realistic image. A sample of one of our progress renderings can be seen below.

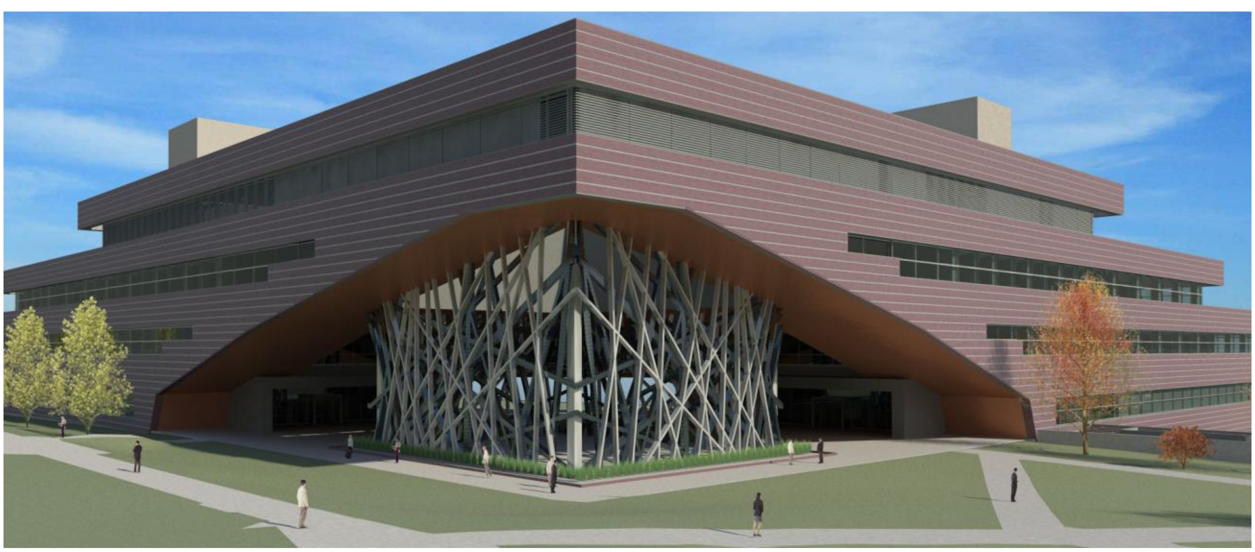


Figure 1.24: Preliminary Courtyard Space Render

After the Revit Family is designed and all materials have been chosen, the family can be imported into the central file via the Component Tool, and the family will have to be loaded from its saved location. If the family needs to be edited, the family should be selected in the central model and click edit family in the top tool ribbon.

MODEL BASED ESTIMATION BIM PROCESS

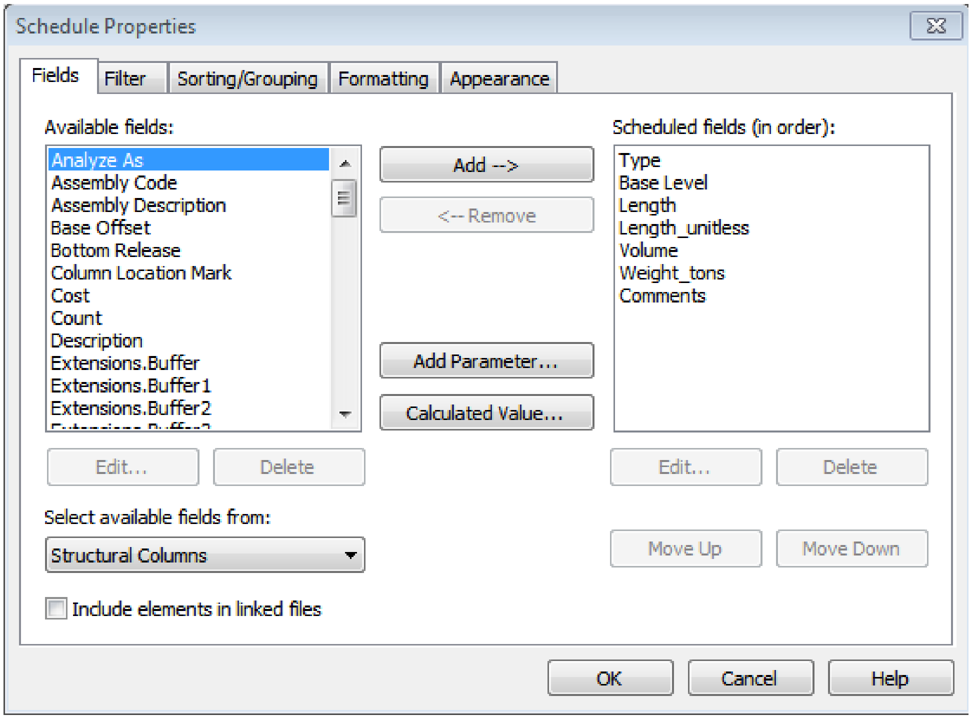


Figure 1.25: Modifying Schedule Parameters

This model based estimation process will cover the process that was used for the estimation of the structural steel. The structural steel was modeled in Revit Structure and the quantities were able to be exported via Revit schedules. The image below shows the creation of a Revit Schedule.

Structural Column Schedule				
Type	Length_unitle	Volume	Weight_tons	Comments
2-L3x3x1/4	173.979167	3.64 CF	0.900238	
2-L3x3x1/4: 22	173.979167	3.64 CF	0.900238	
16"x12" PIER	15	9.72 CF	2.405788	
16"x12" PIER: 2	15	9.72 CF	2.405788	
24"x24" PIER	1287.5	4765.43 CF	1179.444108	
24"x24" PIER: 81	1287.5	4765.43 CF	1179.444108	
30"x30" PIER	412	2321.67 CF	574.6125	
30"x30" PIER: 32	412	2321.67 CF	574.6125	
33"x24" PIER	399.5	2197.25 CF	543.819375	
33"x24" PIER: 26	399.5	2197.25 CF	543.819375	
54"x54" PIER	23	292.81 CF	72.470444	
54"x54" PIER: 10	23	292.81 CF	72.470444	
66"x60" PIER	14	215.00 CF	53.2125	
66"x60" PIER: 8	14	215.00 CF	53.2125	
HSS4X4X.25	27.416667	0.67 CF	0.166355	
HSS4X4X.25: 4	27.416667	0.67 CF	0.166355	
HSS4X4X.500	39.129321	1.79 CF	0.44207	
HSS4X4X.500: 4	39.129321	1.79 CF	0.44207	
HSS5X5X.250	65.627161	2.04 CF	0.50395	
HSS5X5X.250: 6	65.627161	2.04 CF	0.50395	

Figure 1.26: Revit Schedule Export

The first thing to consider when making a Revit Schedule is what fields are needed. For estimation purposes, the type of each piece, the lengths, and weight, are the main fields of interest. However, in order to create a schedule field that is useful in Microsoft Excel, the unit must be taken away from the fields that you wish to do calculations with. For example, the length field is given a unit of feet, in order to be able to perform calculations with ease in Microsoft Excel, the unit had to be deleted out using the Calculated Value function of the Schedule Properties. The calculated value function will prompt for an equation in which this case, Length/1' will provide a unitless length. The units have to be canceled out via a mathematical equation. For square feet of area, it would be necessary to divide by ((1')^2).

By using the Sorting/Grouping function of the Schedule Properties, it is possible to sort each instance of the schedule by any of the fields selected before. Sorting by Type enables the schedule to calculate totals for each field of each type. Instead of exporting the schedule to Microsoft Excel and calculating Type totals, Revit Schedules can calculate the total Length, Weight, and other fields for each type in the model. This can be seen in the image above that shows the sorting of all instances by Type and the creation of a footer for each type that will calculate the total of each field. The following image will also show the schedule that will be created with these Fields and Sorting options.

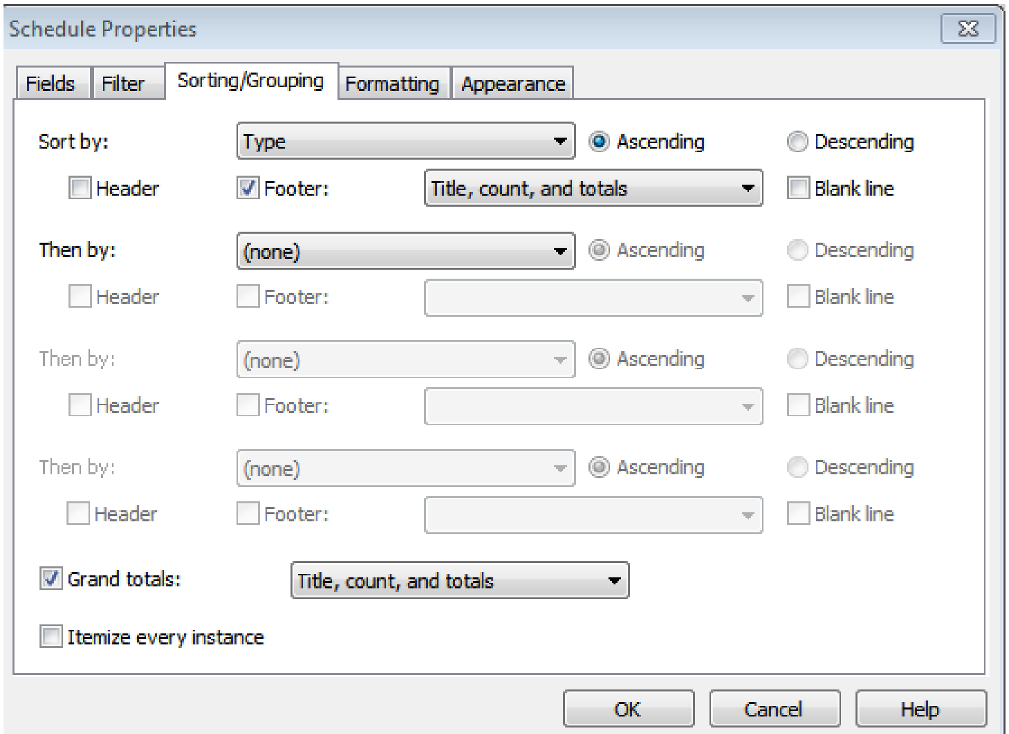


Figure 1.27: Fields and Sorting Options in Revit

After creating the schedule in Revit, it was possible to export the schedule to Microsoft Excel with the Revit Export option. To export to Microsoft Excel, a TXT file report from Revit was used and opened in Microsoft Excel. This enabled each Type to have its totals already calculated, and ready for cost information from RS Means. Each type of instance was researched through RS Means cost information, and the cost related fields were entered into the excel spreadsheet. A column was created for Material, Labor, Equipment, and Total cost for each type. The total cost of the schedule is easily calculated by using the Autosum function in Microsoft Excel to total the Cost column. An example of the spreadsheet in Microsoft Excel can be seen below.

Structural Column Schedule - EXISTING - ENTIRE BUILDING.xlsx

Type	Total	Unit	Material	Labor	Equipment	Total	Unit	COST
2-L3x3x1/4	173.97	LF	3.65	14.7	1.55	19.9	LF	$ 3,462.00
HSS12-3/4X0.250	0.2299	TONS	1.65	0.15	0.1	1.9	LB	$ 873.62
HSS12X8X.500	2.8771	TONS	1.65	0.15	0.1	1.9	LB	$ 10,932.98
HSS4X4X.25	0.1663	TONS	1.65	0.15	0.1	1.9	LB	$ 631.94
HSS4X4X0.5	0.442	TONS	1.65	0.15	0.1	1.9	LB	$ 1,679.60
HSS6X6X0.5	1.3648	TONS	1.65	0.15	0.1	1.9	LB	$ 5,186.24
W10X68	51.53	LF	47	3.8	2.75	53.55	LF	$ 2,759.43
W14X109	84.95	LF	71.5	2.55	1.95	76	LF	$ 6,456.20
W14X120	294.75	LF	82	2.58	1.97	86.55	LF	$ 25,510.61
W14X132	889	LF	86	3.2	2.2	91.4	LF	$ 81,254.60
W14X145	99.25	LF	98.94	2.72	2.07	103.73	LF	$ 10,295.20
W14X176	1189.79	LF	119.95	2.9	2.21	125.06	LF	$ 148,795.14
W14X193	174.25	LF	131.47	3	2.28	136.75	LF	$ 23,828.69
W14X211	410.45	LF	143.68	3.1	2.36	149.14	LF	$ 61,214.51
W14X233	362.83	LF	158.58	3.23	2.45	164.26	LF	$ 59,598.46
W14X257	193.91	LF	174.85	3.37	2.56	180.78	LF	$ 35,055.05
W14X283	1376.08	LF	192.47	3.52	2.67	198.66	LF	$ 273,372.05
W14X311	59.95	LF	223.45	3.68	2.79	229.92	LF	$ 13,783.70
W14X370	150	LF	253.44	4.02	3.05	260.51	LF	$ 39,076.50
W14X43	348.36	LF	30	2.29	1.75	34.04	LF	$ 11,858.17
W14X48	100.84	LF	33	2.3	1.76	37.06	LF	$ 3,737.13
W14X53	18	LF	36.5	2.32	1.78	40.6	LF	$ 730.80
W14X550	316.58	LF	359.05	4.75	3.5	367.3	LF	$ 116,279.83
W14X61	1627.49	LF	43.5	2.38	1.82	47.7	LF	$ 77,631.27
W14X68	510.56	LF	44.5	2.4	1.82	48.72	LF	$ 24,874.48
W14X74	406.16	LF	51	2.44	1.87	55.31	LF	$ 22,464.71
W14X82	341.6	LF	56	2.48	1.89	60.37	LF	$ 20,622.39
W14X90	4032.34	LF	61.5	2.51	1.92	65.93	LF	$ 265,852.18
W14X99	342.7	LF	68.5	2.53	1.94	72.97	LF	$ 25,006.82
								$ 1,372,824.32
							TIME	$ 1,743,486.89
							CONNECTIONS	$ 2,039,879.66
							Total Including O & P	$ 2,386,659.20

Structural Column Schedule | Summary Totals

Figure 1.28: MS Excel of A Schedule Export

3D COORDINATION BIM PROCESS

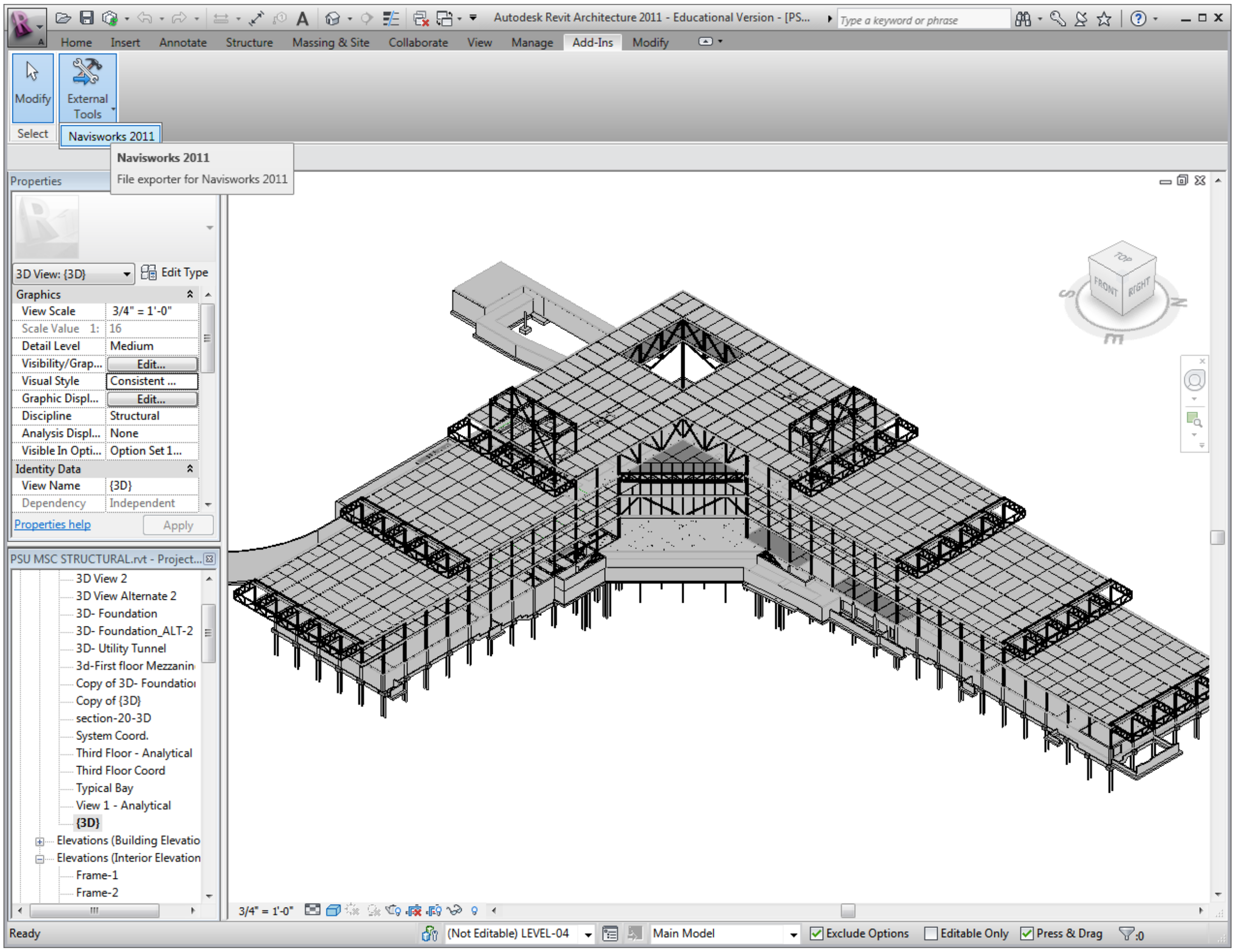


Figure 1.29: Navisworks Coordination Model

The 3D coordination process begins with the creation of discipline specific models in each of the modeling software programs. It is not necessary that every model come from an Autodesk based software, but it is beneficial to maintain 3D solid geometry instead of 3D faces. Secondly, the models were exported from there modeling programs to Navisworks Manage. The PSU MSC STRUCTURAL.rvt model was able to be exported to Navisworks via the Add-Ins External Tools Navisworks file exporter. This exporter creates a NWC file that can be opened directly in Navisworks and used for 3D coordination. The image below shows the Revit file exporter to Navisworks.

After the files were established, they were able to be appended together in Navisworks to create a coordination model. With the coordination model created, the clash detective tool of Navisworks was used to find where systems clashed with each other. A hard clash is where two objects physically occupy the same space and collide with each other. A clearance setting can also be set to account for insulation around piping if it is not modeled. The clash detective tool has two selection trees in which models can be chosen to check for clashes against the other models. Our models for clash detection did not contain the full coordinate requirements for construction, but an example of this can be seen below in a Navisworks image of the Millennium Science Complex Coordination model from Whiting-Turner.

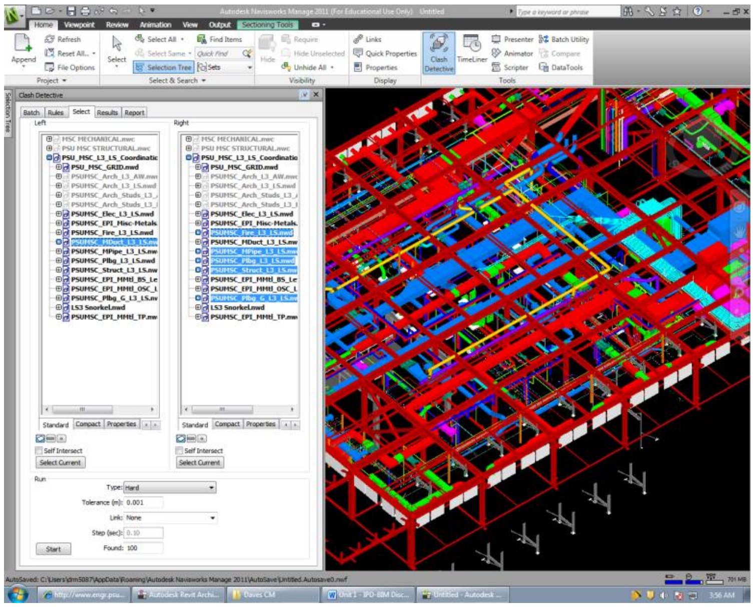


Figure 1.30: Clash Detection in Navisworks

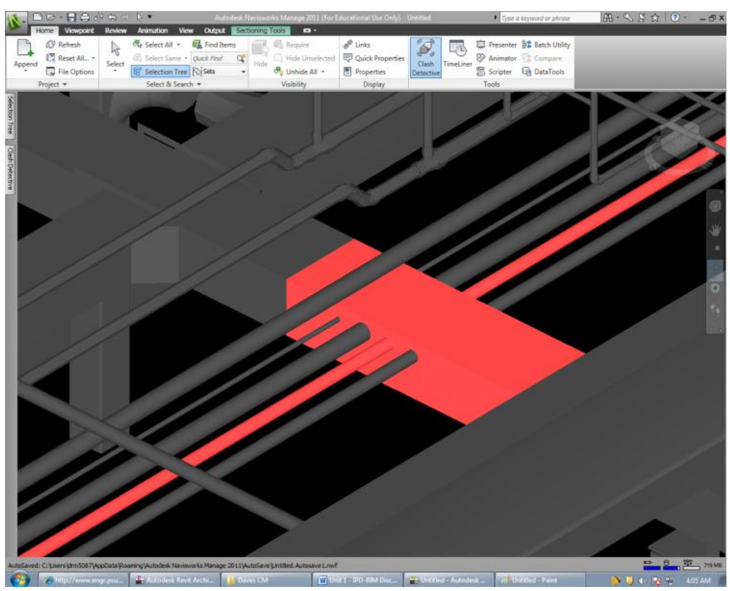


Figure 1.31: Sample Clash in Navisworks

With the coordination model in Navisworks and the layers chosen to be clash detected, the clash detection can be started. After the clash detection is complete, the results tab will show instance by instance of each clash. Each clash can be examined and measured with the Review Tools to find a fix for each clash. A clash detection report can also be exported as an HTML file for team members to view. Each instance of the clash detection will save the last camera view that was shown for each clash. The final step is to go back to the original modeling program, perform the necessary changes to each discipline model and the export the new models to Navisworks to test for clash detection again. Below is a sample image of a clash and how the camera can be set up to view clashes.

LIGHTING/ELECTRICAL BIM PROCESSES

Building information modeling can be used for lighting design in different software. There is no program that can perform all analyses accurately. Programs for coordination such as Revit and Navisworks can produce renderings, but cannot perform in-depth calculations. Programs for calculations include AGI32, Daysim, and 3D Studio Max. File type sharing exists between these programs, but may involve "clean-up" before importing to ultimate destinations. This section outlines how BIM was used in lighting designs and the aforementioned process of transporting files from geometry platforms (Revit Architecture) to analysis platforms (AGI32 and 3D Studio Max).

MODELING FIXTURES AND FAMILIES

Figure 1.32: Student Area Revit Section

For this thesis project, it is paramount that all appropriate information be shared between disciplines. Challenges in sharing information are first encountered within different Revit platforms. When a family is created for a light fixture in Revit Architecture, those parameters will operate within Revit Architecture only. This is the same or other platforms such as Revit MEP. For example, when creating light fixture families for the Student Area redesign, there is an option to create the family in Revit MEP or Architecture. If the recessed fixture is created in Revit Architecture and loaded into an MEP-based model, the fixture may not cut out its place in the ceiling. If the fixture is created in MEP, then it is able to have all necessary electrical and lighting properties such as operating voltage, power usage, and photometrics. A sample family type parameter setting can be seen in Figure 1.33 below. Again, when this family is used in Revit MEP and mounted on an architecture model, it does not cut a space within the ceiling for its recessed mounting. These issues are minimal in the overall process of using BIM for design coordination. Figure 1.32 illustrates a sample section of KGB Maser's redesign of the student study areas. The luminaires visible in this section of the building can be created accurately to the specification of the lighting redesign. For a further discussion on the lighting redesign, see Unit 3 of this document. Once family parameters have been modeled, their properties can be extracted in schedules within any platform of Revit. Upon creation of these schedules, the construction manager can assign prices for each fixture type as well as the labor costs involved with installing them.

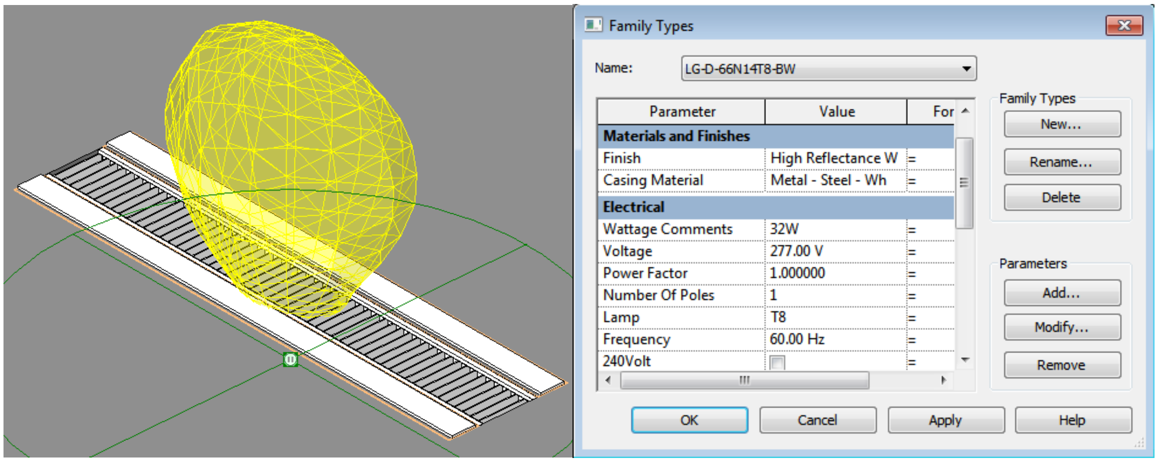


Figure 1.33: Custom Luminaire Properties

As discussed in Lighting Technical Assignment 1, light loss factors can also be assigned to family types within Revit. For more information on Revit task plane illuminance estimates, see Lighting Technical Assignment 1. Once fixtures and equipment is accurately modeled into the central file, equipment can be circuited to appropriate panelboards. For a more in-depth discussion about modeling power systems and families in Revit Architecture, please see Building Stimulus's thesis report, as this report does not cover circuiting in Revit MEP.

MODEL SHARING BETWEEN AUTODESK REVIT AND AGI32

The first question that needs to be answered when sharing models is "what format does my model need to be in at my final destination?" KGB Maser has chosen two routes to answer this question. The student study area lighting analysis was performed ultimately in AGI32 and the office design was completed in a combination of Revit Architecture and AGI32. The final space – the courtyard beneath the cantilever – was completed in 3ds Max Design with assurance in AGI32.

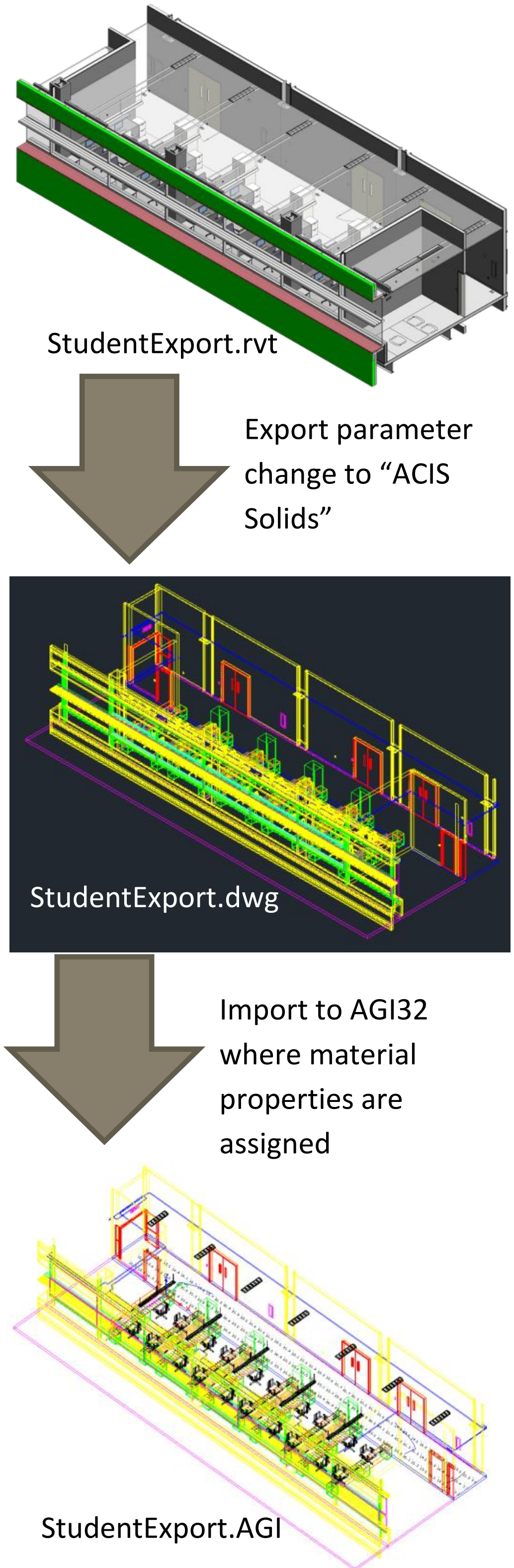


Figure 1.34: Simplified model sharing process Revit to AGI32

The ultimate format for analysis in AGI32 is an AutoCAD .dwg file extension. There are particular variables within AGI32 that need to be considered when exporting files from the model source also. AGI32 interfaces with solids, 3D faces, and meshes from AutoCAD. Secondly, the designer should not have luminaires visible when exporting from Revit. Luminaires can be defined, positioned, and oriented within AGI32.

When exporting from Revit, the designer must be viewing the project in a 3D view. Revit will export whatever format the view is in – plans are 2D drawings when exported and 3D views are 3D drawings when exported. Knowing that AGI32 utilizes solids and 3D faces, the export parameters can be set to “ACIS Solids” when the export dialog box is viewed.

Upon opening in AutoCAD, the .dwg file must be exploded in order to organize material types upon import into AGI32. Components in Revit are imported in block format in AutoCAD. These blocks can be exploded into 3D solids. The easiest way to assure that materials are modeled appropriately in AGI32 is to create new layers named as the material type. It is possible to change material types for surfaces once imported into AGI32, but the process becomes too tedious and time consuming with more complex models such as this student area. For the study area AGI32 model, most of the material types had already been exported to an appropriate layer by Revit, but components with multiple materials – such as particle board cabinets with wooden tops – had to be exploded and sorted by material type.

Once the .dwg export is organized by material type, it can be “cleaned-up” in AutoCAD. This part of the model sharing process is important when working with very detailed models. In the example of the study area export shown in Figure 1.34, very detailed items such as cabinet caster wheels, cabinet handles, computer screens, and office chairs must be changed in order for smooth import into AGI32. Such detailed components, when exploded in AutoCAD, cause the analysis software to produce an error stating that it cannot read or analyze the associated import layer. The clean-up process must target such components by changing wheels and other curved components into squares and meshes that are appropriately sized to run in AGI32. Some components are available in simplified forms within AGI32 – chairs, computer screens, and other furniture items.

It is important to note that Revit is a source for analysis geometry, but analysis cannot be taken back to Revit in the reverse order. For example, if the previously mentioned process results in an analysis that produced less than acceptable light levels, the designer cannot simply change the luminaires in AGI32 and reverse the process into Revit. The model in AGI32 must be re-worked to achieve design goals, and then the final design must be re-modeled in Revit. In conclusion, the advantage of BIM software for this lighting design application is the availability of accurate room geometry for analysis. The main drawback is that there is not a two-way communication between the two software platforms.

MODEL SHARING BETWEEN REVIT AND 3D STUDIO MAX

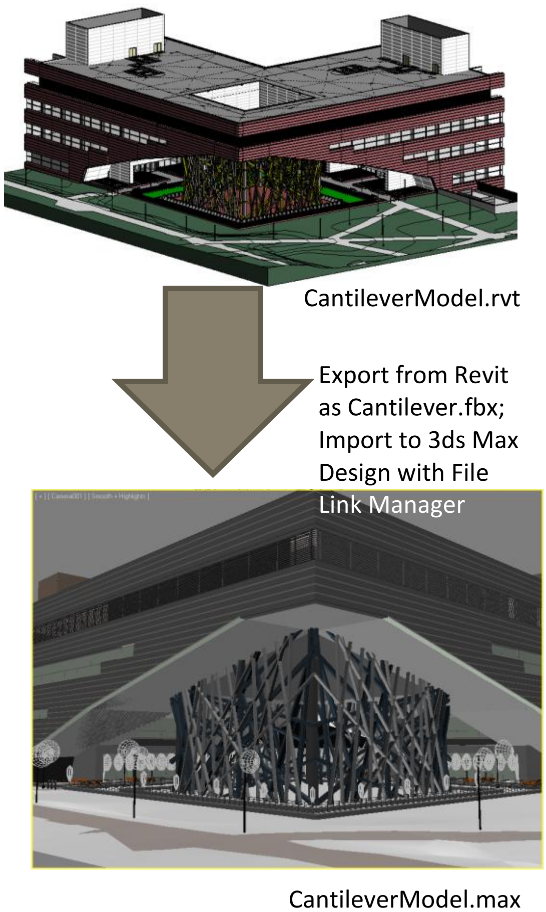


Figure 1.35: Simplified model sharing process Revit to 3ds Max

A second avenue for lighting design with Building Information Modeling software is the .fbx export from AutoDesk Revit Architecture. A simplified model flow is illustrated in Figure 1.35 shown here. AutoDesk 3D Studio Max Design is a great tool for rendering environments and using material properties to their fullest advantage. In this section of Unit 1, a discussion of possibilities using Revit and 3ds Max to achieve lighting design objectives will be examined.

As with the previous example of file sharing, the ultimate question that will need to be answered is “in what format does my final file need to be imported?” The answer to this question when using 3ds Max Design is the .fbx file extension. From Revit Architecture, this file format is easily accessible from the file menu. Benefits from using an .fbx file include no need to assign additional object parameters (as needed in the previous example) and the completeness of the information contained within the .fbx format. However, the latter advantage can also be a disadvantage.

The .fbx file extension exports the entire model and its parameters in the current 3D view. This means that every wall, button, knob, light fixture, photometric distribution, or any other entity within the model. This level of detail is great for composing nearly one-hundred percent accurate renderings, but drastically increases file size in the end file format (.max). For example, KGB Maser’s Revit model for the cantilever portion of the Millennium Science Complex has a file size of 236,448 kB. When the model is exported to an .fbx format, the file size decreases to 61,001 kB. Once the .fbx is imported into 3ds Max Design, the file size increases to 916,942 kB. This great jump has to do with the level of detail contained in the 3ds model capabilities. These capabilities include accurate daylight rendering through radiance plug-ins, highly accurate material properties, photometric lighting, and movie-making abilities among many other design features.

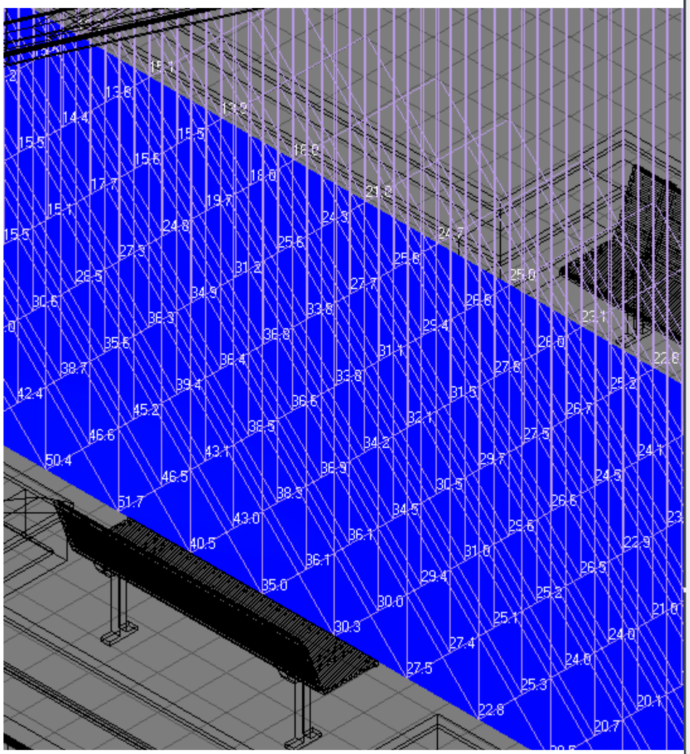
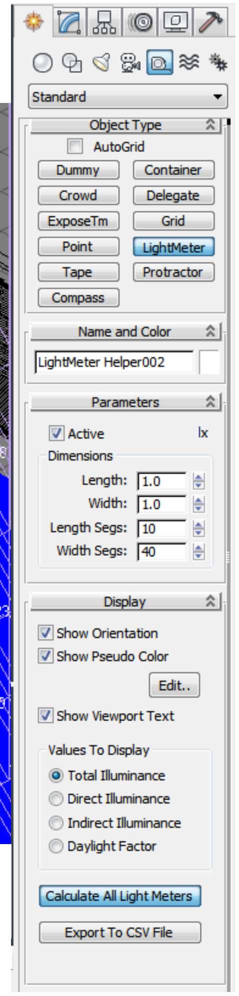


Figure 1.36: Calculation Grids in 3ds Max Design



In order to reduce rendering time, as with the previous example, the Revit model must be "cleaned-up" to reduce the number of problematic surfaces in the file share. In the case of KGB Maser's central model, all irrelevant lighting fixtures, interior walls, furniture, and other components had to be deleted. The final product to be exported as an .fbx file extension only contained the cantilever courtyard materials, building shell, floors, columns, and applicable luminaires. The rest of the model was not included by way of a section box around the rest of the building.

One specific feature that will be examined as part of the IPD/BIM section of this thesis is the ability of 3ds Max Design to perform light level estimations – more specifically the calculation of total illuminance. When modeling the calculation grid, its size can be determined by a click-and-drag method, followed by changing the number of segments along the grid's length (x-axis) and width (y-axis). The display options can be toggled depending on the clutter within the view. Figure 1.36 shown here illustrates an example calculation grid. Once all grids have been placed, the "Calculate All Light Meters" button will process the algorithms within 3ds Max to calculate the desired statistic. Once complete, each "LightMeter Helper" can be exported as a .csv file ("comma delimited" or "comma separated value") to be opened in Microsoft Excel. Once in Excel, the values from the light meters can be compiled in a pivot table, thus allowing the engineer/designer to visualize the minimum and maximum calculation points. *Note: 3ds Max has default settings to include a specific daylight condition.* If daylight is not being considered, as in the case of this thesis, the user will need to change the scene parameters to exclude sun and sky conditions. Additionally, the pseudo color image settings may be customized in the display settings of the light meter properties window. An example can be seen in Figure 1.37 below:

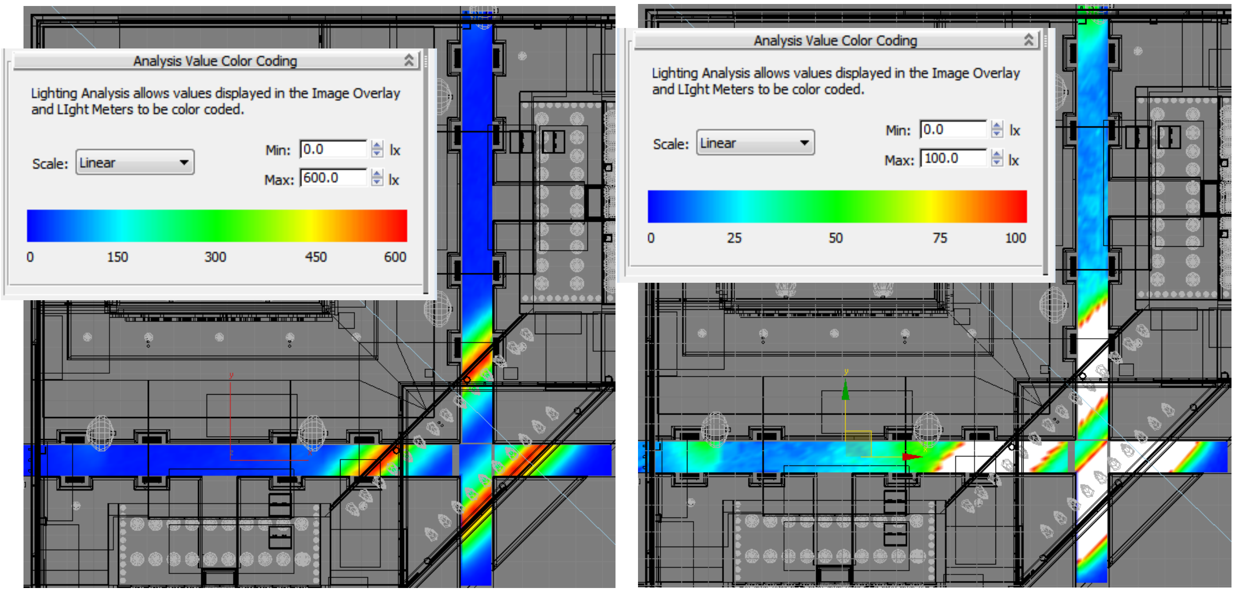


Figure 1.37: Pseudo Color Illuminance Settings in 3ds Max Design

In addition to the challenges of model size, there is a challenge when "turning on" luminaires within 3d Studio Max Design. Once imported, the .fbx file will contain all photometric data that has been compiled within the Revit model, but will import the fixtures as turned off. The "Light Lister" tool can only hold so many photometric files before the user must select the luminaires in smaller parts by selection box. Once these luminaires are turned on, the photometric patterns become white in color – as seen in Figure 1.37 above. Following analysis, the results from 3ds Max were compared to output values from AGI32.

Calculation Values: AGI32 vs. 3ds Max Design						
Calculation Grid	AGI Illuminance (fc)			3ds Illuminance (fc)		
	Min.	Avg.	Max.	Min.	Avg.	Max.
Paths	1.10	7.72	63.20	0.102	23.15	59.00

Each program handles lighting calculations in a different manner. AGI32 is a lumen-method-based calculation, whereas 3D Studio Max has a different calculation method.

MECHANICAL BIM PROCESSES

Building information modeling software has been used throughout mechanical redesign efforts for the Millennium Science Complex. BIM adds additional information to design documents that allow the engineers, architect, owner, and operator to more fully understand the components of design. Autodesk's Revit Architecture, Revit MEP, and Revit Structure were used to coordinate designs from all disciplines. For mechanical design, a Revit MEP central model was created. Revit Architecture and Revit Structure models were linked to the same coordinates of the Revit MEP to provide architectural and structure references during design.

MODEL SHARING BETWEEN REVIT ARCHITECTURE AND TRANE TRACE

The first step in mechanical analysis is to accurately predict the loads that will occur in the building. Once loads are obtained, the mechanical system can properly be sized. An energy modeling program can be used to obtain the proper loads. For the analysis of the Millennium Science Complex, Trane TRACE was chosen to model the loads. There are two ways that rooms and spaces can be modeled in Trane TRACE. The first method is to manually input each room's area, exterior walls, openings, and roof area. For a project as large as the Millennium Science Complex, this approach would not be feasible to be completed timely. Another method for importing rooms into Trane TRACE is to use the gbXML file import method. The process begins with a Revit Architecture model with room tags in it or a Revit MEP model with proper space tags. The Revit MEP of the Millennium Science Complex was supplied to KGB Maser for our analysis with proper space tags of each room and was used for gbXML export. After the model has been exported to gbXML format, it can be opened in Trane TRACE. The conversion process takes minimal time and afterwards, the spaces or rooms that were tagged in the Revit model show up as rooms in the Trane TRACE model. It is important to realize that there are corrections that need to be made within the Trane TRACE file after import. Occasionally, excess walls and openings show up in rooms. It is important to reference the main Revit model to determine if these walls and openings should factor into energy modeling or if they should be deleted.

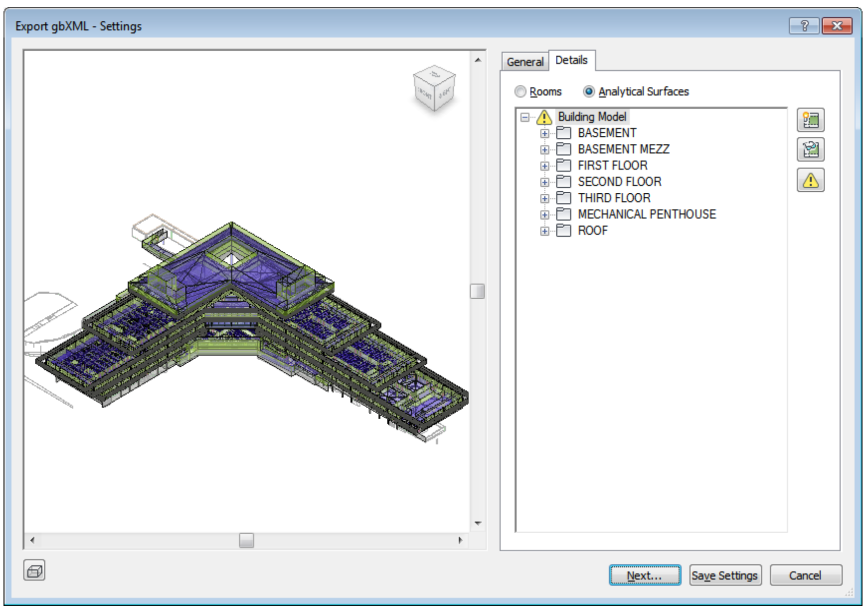


Figure 1.38: gbXML Export from Revit

Despite having relatively accurate space areas and openings in Trane TRACE, the existing conditions were not able to be replicated entirely. The façade of the existing design consists of a precast panel structure that overhangs the glazing of the interior spaces by roughly 2.5 feet. Additionally, the glazing is divided into two areas by a shading device. Within Trane TRACE, only one feature of the shading feature can be modeled per opening. Additionally, with the proposed use of interior shades, it was not possible to model the three shading aspects of the proposed façade conditions. In energy modeling calculations, the overhang by the existing precast panel and the shading depths for the proposed façade were modeled. This results in a seemingly conservative estimate, but do the the results of the energy simulations, it seems that additional shading will only have a small impact on operating cost savings.

Figure 1.39: Existing Facade

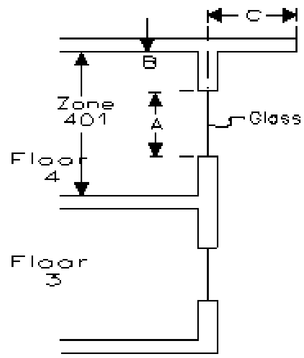


Figure 1.40: TRACE Help Description of Overhang Definition

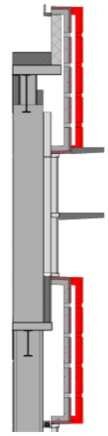


Figure 1.41: Proposed Facade

REVIT MEP LOAD CALCULATION CAPABILITIES

The existing Revit Architecture model provides an additional avenue for obtaining space loads. The architectural model can be opened within Revit MEP. Underneath the “Analyze” tab in Revit MEP is an selection called “Heating and Cooling Loads.” Building information such as the construction of various elements in the building, the infiltration class, the mechanical service, to the building, and the building type can be adjusted as necessary. In Figure 1.42 and Figure 1.43, a screenshot of the mentioned workspace in Revit MEP is shown. When attempted for the Millennium Science Complex’s architectural model, the accuracy of the output report was of concern. The Revit MEP list of available options did not include a laboratory related option. The closest option was a school/university classification. A school/university report showed greater loads than an identical report run as an office. Trane TRACE, despite difficulties during transition from Revit Architecture to gbXML import was preferred for accurate energy calculations. However, the downside of using Trane TRACE is that any changes made to the building Revit model cannot be synched. A Revit MEP heating and cooling load report can be created quickly after model changes have been made.

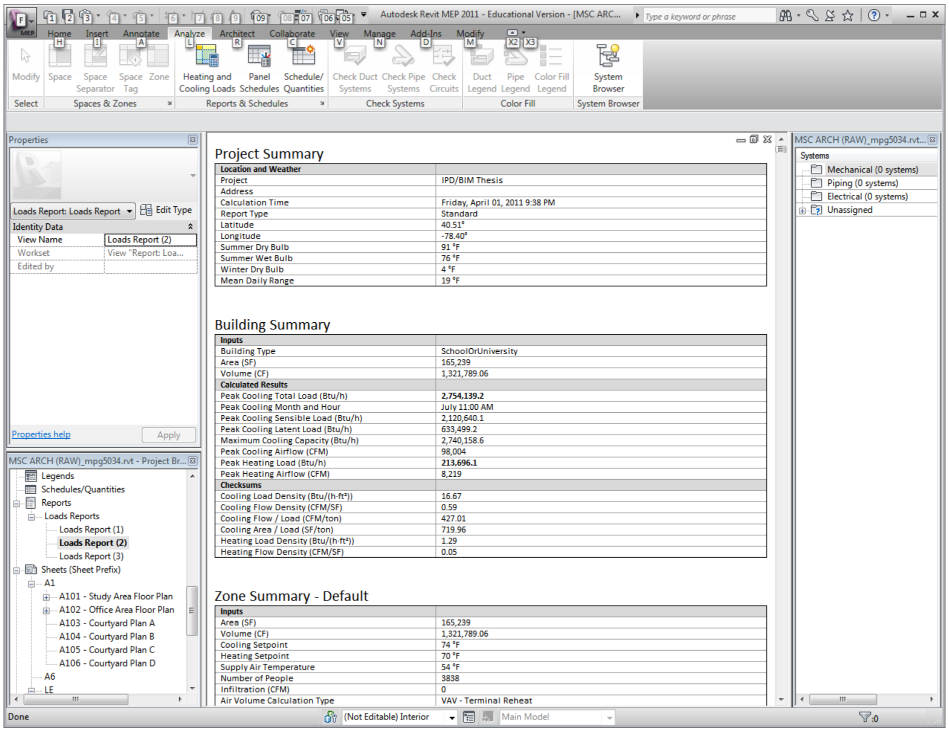


Figure 1.42: Heating and Cooling Load Calculations in Revit MEP

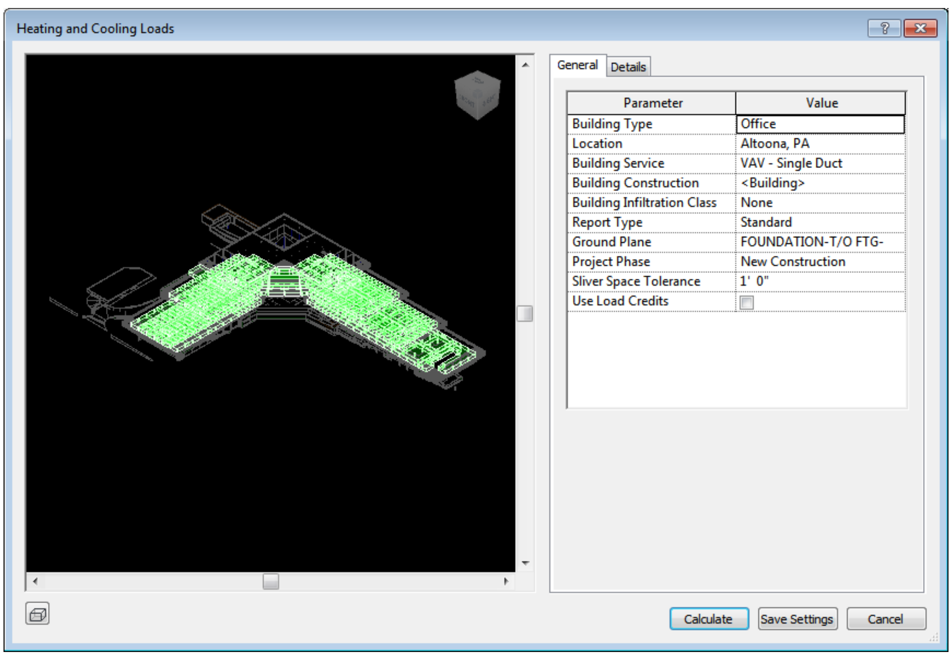


Figure 1.43: Space Heating and Cooling Loads from Revit MEP

CHILLED BEAM FAMILIES

Once the final façade strategy was finalized, the Trane TRACE model was ran to obtain the final loads that will drive the mechanical design. For the active chilled beam redesign, the space peak loads were exported to a Microsoft Excel workbook. The ventilation outputs were analyzed based on ASHRAE Standard 62.1, latent loads, and ventilation requirements. With both ventilation and peak loads obtained, chilled beams can be sized for each space. The Excel workbook tracked the impact of two different types of active chilled beams, Trox 2-way DID 632 high capacity beams and Price-HVAC ACBL one-way beams. One-way beams were located along the perimeter walls to handle envelope loads directly. Two-way beams were placed perpendicular to exterior walls to conveniently fit in the established reflected ceiling plan. The combination of the airflows from the two beams should result in effective mixing and a thermally comfortable space.

Often the ventilation requirements drove the need for the amount of chilled beams, especially in exterior lab zones requiring 6 air changes per hour. In order to avoid excess cooling, the flow rate of chilled water to each beam was tracked based off of manufacturer selection and sizing data. The combination of Revit MEP and downloaded manufacturer chilled beam files allows for this information to be included in the design model.

Price and Trox both made Revit files available of their chilled beam products, although the formatting of the two families varied. Figure 1.44 and Figure 1.45 demonstrate the differences in appearance and editable properties of the two types of chilled beams.

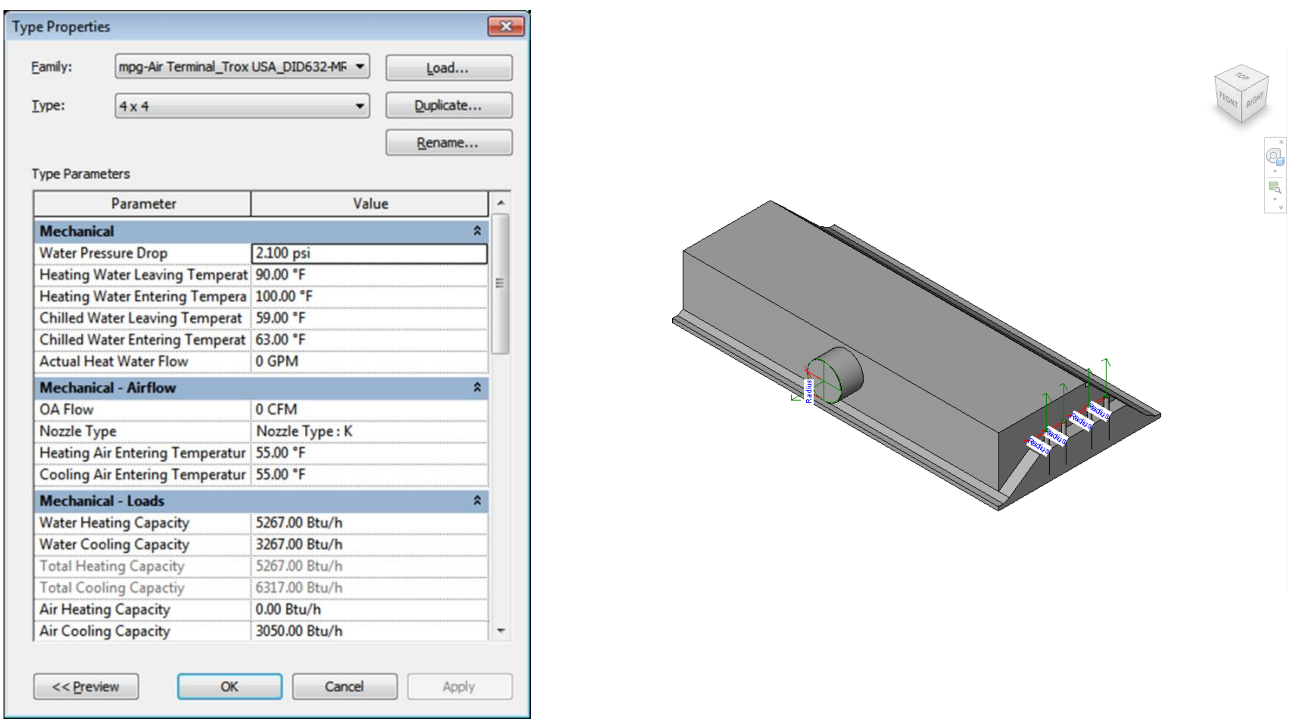


Figure 1.44: Type Properties and 3D view of TROX DID 632 Active Chilled Beam

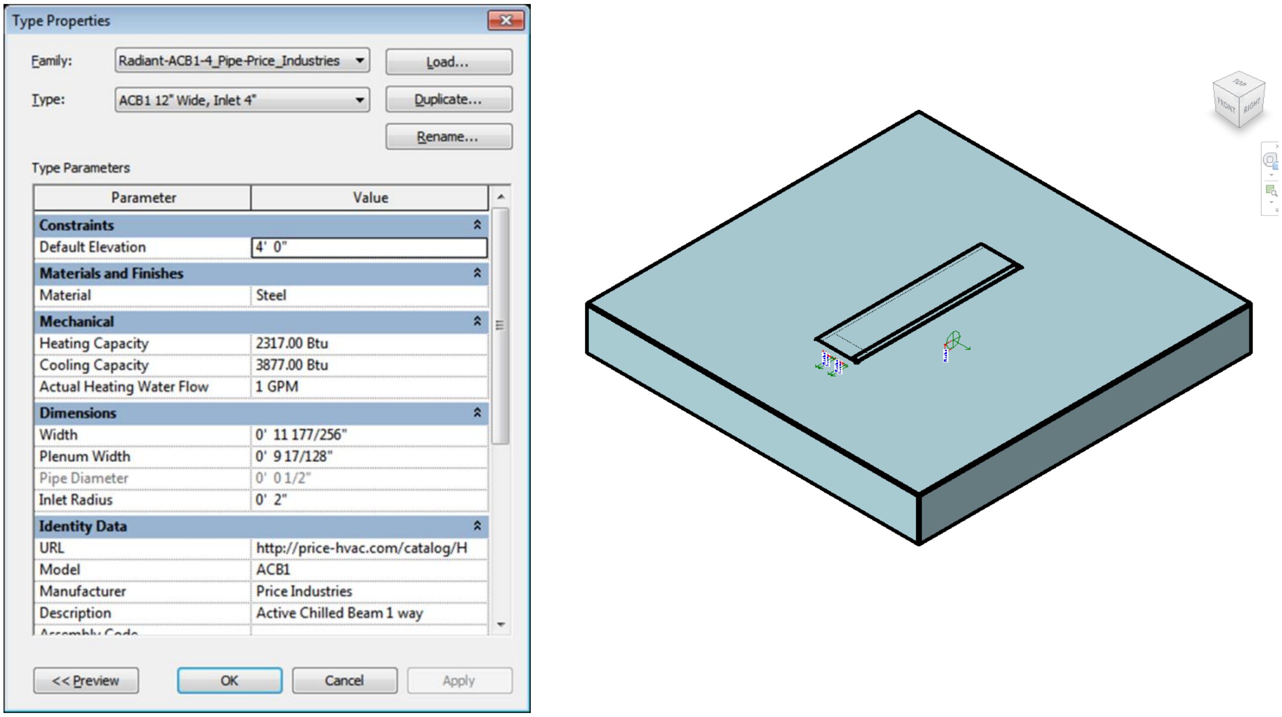


Figure 1.45: Type Properties and 3D view of Price-HVAC ACBL Chilled Beam

Despite the availability of manufacturer chilled beam models, providing a mechanical system redesign in Revit MEP with the downloaded chilled beams required some adjustments. Within Revit MEP, a typical diffuser can be assigned a specified CFM to supply to a space. A duct connected to this diffuser can then "read" the amount of airflow required by that diffuser and store the information in the ductwork's properties. Within Revit, the automatic sizing feature can be used to size ductwork based on the CFM of the diffuser. Essentially, ductwork can be sized efficiently without manually keep track of the airflow required by each branch of ductwork. However, coordination of ductwork within the available space in the ceiling plenum still needs to be done manually.

The TROX chilled beam family needed to be altered in several ways as outlined in the following table. The key alteration was changing the air flow parameter to allow for different CFM for each beam to be specified in the model instead of being constant. Since only 2' x 4' sized beams were used, it was beneficial to allow this parameter to be changed in the main model. The Price-HVAC ACBL chilled beam download only needed to be carefully place in the model since it was designed with the need for a host surface.

Summary of TROX Chilled Beam Adjustments		
Parameter	Downloaded Setting	Adjusted Setting
Flow Configuration	Calculated	Preset
Flow Direction	In	In
Family	Air Terminal	Mechanical Equipment
Location of Inlet	Side	Top (Cost Option)
Air Flow	Instance: Keeps CFM constant for the same family	Type: Allows different CFM for same family

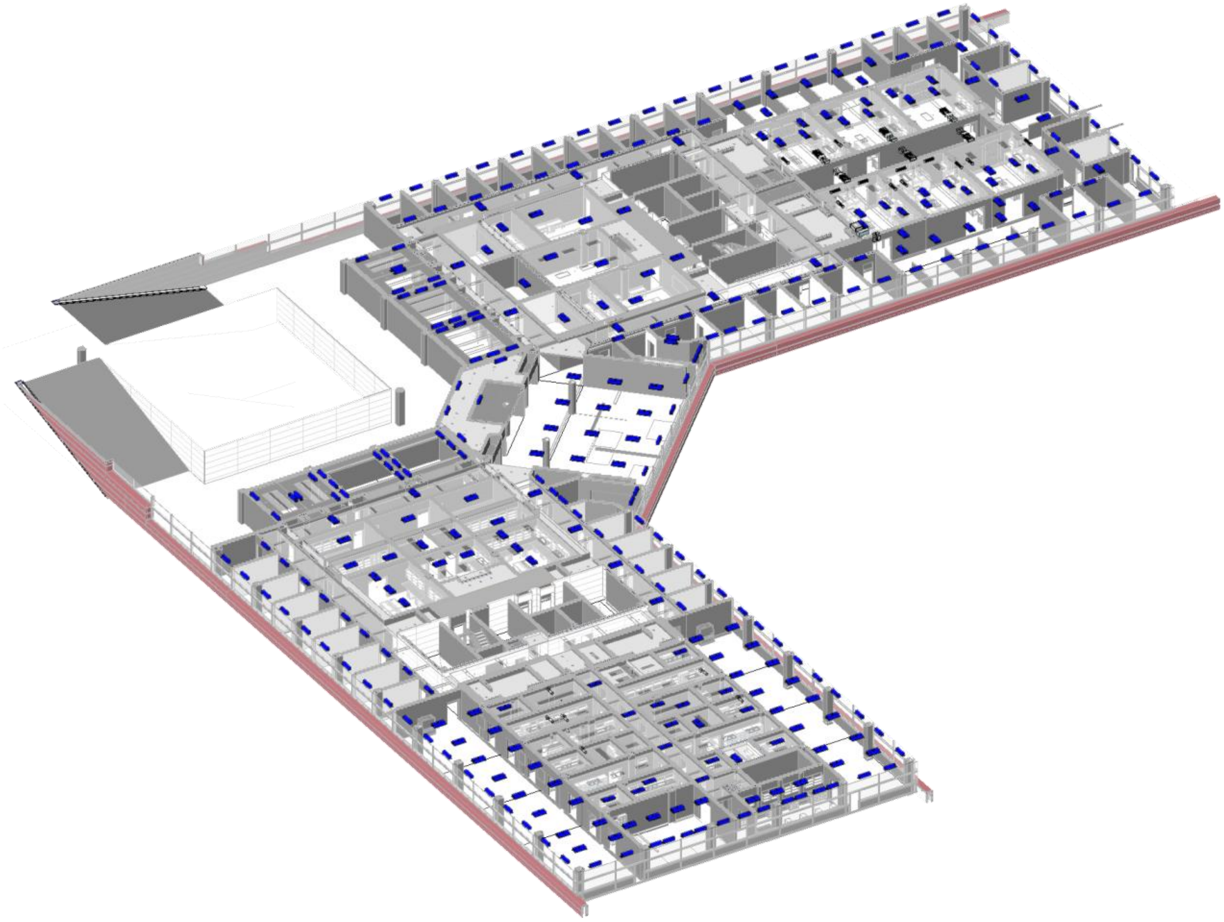


Figure 1.46: Chilled Beam Layout in 2D

Chilled beams were coordinated on paper with the reflected ceiling plan and the Excel Workbook that tracked compliance with ventilation and space loads. The next step was to transfer the schematic placement of beams into the Revit MEP central file. While placing beams, an error message arose that stated: “The default system "Default Supply Air (mpg5034)" is now over 50 elements. To improve performance, Revit is no longer calculating the critical path pressure drop and the more complex duct sizing has been disabled. If you want to use these features, you must define logical systems in the model instead of using the default system.” Therefore, in order to allow for Revit MEP to calculate ductwork sizing based on specified CFM to each chilled beam, an additional step was needed. After a chilled beam was placed, the beam needed to be selected and added to a duct system. Duct systems were defined based on location in the fined based on zoning. This step is not due to classifying chilled beams as mechanical equipment and is necessary if modeled as air terminals. The goal of designing in Revit is to supply information such as pressure drop or airflow needed within a duct. Embedding information into to the model’s elements and creating systems allow a design engineer in Revit MEP to quickly reference information.

OPPORTUNITIES FOR MODEL SHARING BETWEEN REVIT AND PHOENICS

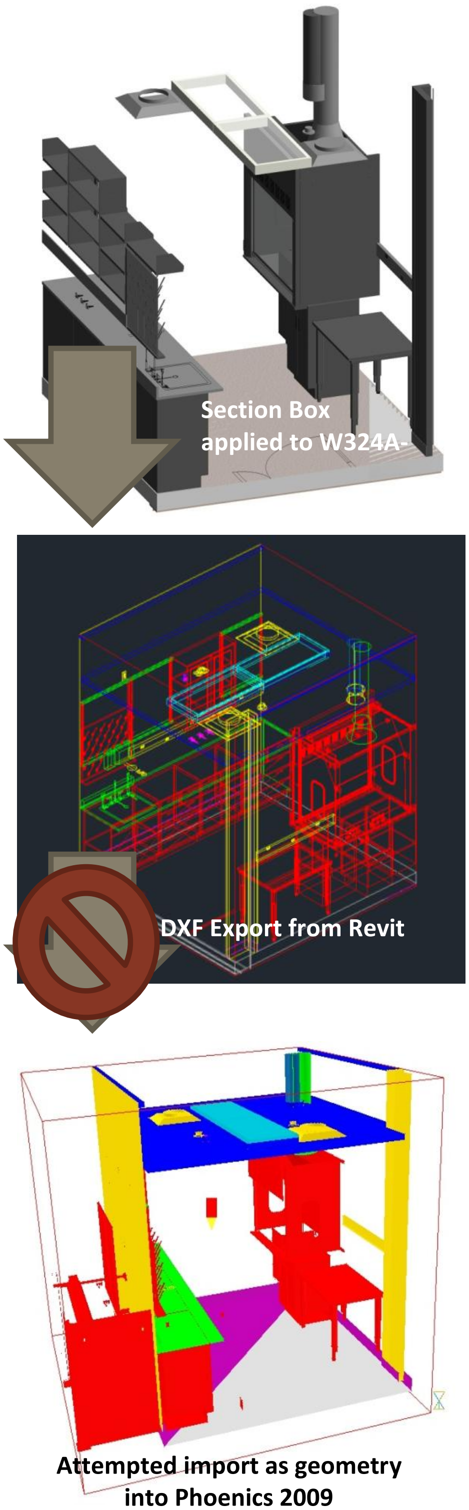


Figure 1.47: Attempted Revit to Phoenics 2009 Process

When creating a CFD model of a sample fume hood room for analysis, the model was created by taking dimensions from the Revit Architecture model, converting the dimensions into metric units, and building the room element by element.

To streamline the tedious process of creating elements, the possibility of exporting geometries from Revit Architecture into a CFD modeling program such as Phoenics 2009 was explored. From investigation within Phoenics 2009's help files, it was found that CAD files such as .stl, and .dxf could be imported as objects.

A section box narrowed around W324A-Hot room in a 3-D view isolated the elements that were desired for a CFD model. From this view, a CAD DXF file can be exported. Once, exported into DXF format, the file was reviewed to ensure the geometries that were needed showed up in the export. The import into Phoenics as a geometry shape did not occur smoothly. Multiple attempts were made to import the geometry in the correct form. The best attainable model is depicted as the last image in Figure 1.47: Attempted Revit to Phoenics 2009 Process.

The CAD geometry import process was not found to be effective for modeling indoor air flows. However, CAD geometries can be used to model exterior flows, such as wind through a neighborhood, more effectively. KGB-Maser believes that a great opportunity lies in completing the process from a Revit Architecture model to a CFD modeling platform. CFD modeling can produce accurate simulations of airflow in spaces and can be used to test designs and correct problems. If geometries can be effectively transferred, the opportunity exists for CFD to ensure the effectiveness of more areas of design. It should be noted that simulations and input of additional parameters take a reasonable about of time to complete. The immediate accurate modeling of space geometries would eliminate time spent building the elements and ensure accurate element representation within the CFD model.

COORDINATION BETWEEN STRUCTURAL, MECHANICAL, AND ARCHITECTURAL REVIT FILES

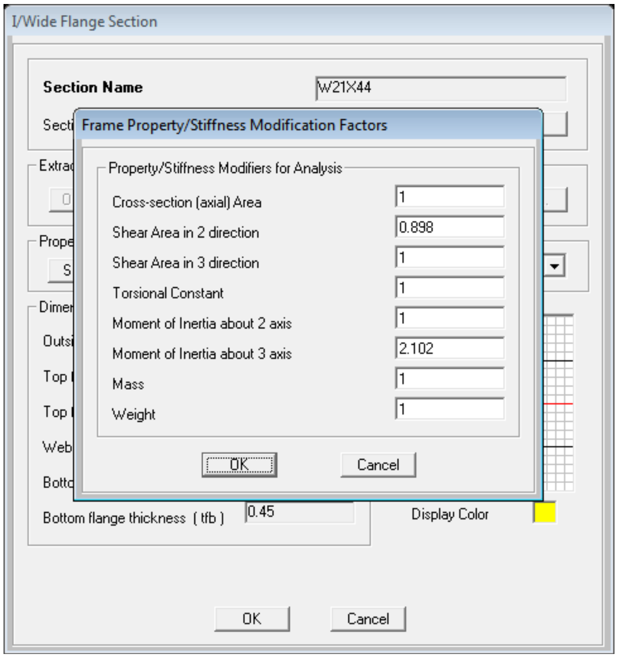


Figure 1.48: LB30X44 Property Modifiers

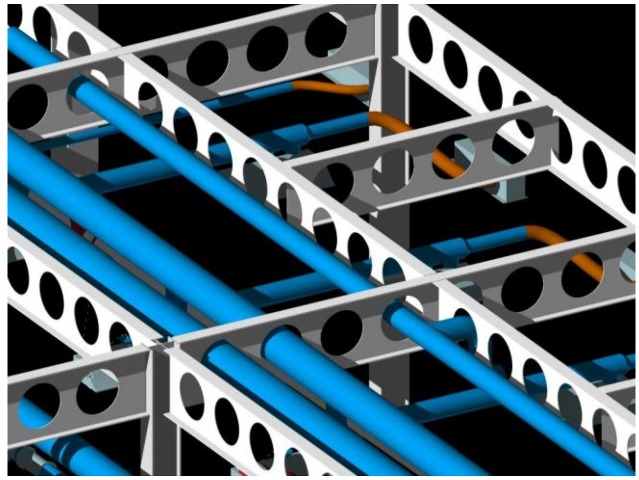


Figure 1.49: Mechanical and Structural Coordination

The use of cellular members with active chilled beam ductwork was a design goal of KGB Maser. The theory behind the initial idea was that main ductwork would run below the cellular members because they would be too large to fit through reasonably sized cellular beams. In order to achieve this design, the structural engineer required rough estimates of duct sizes that were to be run through the cellular member. The structural engineer then sized the cellular beam system according. During this time, the mechanical engineer devised a scheme to run ductwork through the cellular beams and reach the chilled beams previously placed.

The design of the mechanical system required coordination with the cellular members. The Revit Structure linked file was referenced when designing ductwork in the plenum space. Chilled beams were placed in the acoustic ceiling grid according to the Revit Architecture model. Distribution of chilled beams was accomplished without affecting the lighting scheme and with constant reference to the structural system.

STRUCTURAL BIM PROCESSES

FAÇADE

Throughout the entire process, depth of the panel was given special consideration. Not only does depth affect the shading of interior spaces, it limits the amount of insulation that can be inserted between the panel and the interior wall of the building. It was ideal to decrease the depth of the panel as much as could be afforded by the mechanical and lighting/electrical disciplines. Of course the controlling factor of the depth ended up being strength against wind. The depth of the panel decreased, as well as the depth and therefore inertia of the top flange.

It was anticipated that the panel could be modeled with the appropriate changes and applied to the entire Revit model we had been given at the start of the semester. There is no master panel that changes all of the façade simultaneously. Every panel, individually, would have needed to be changed in order to replicate the redesign in the model. This task would have been tedious and time consuming, so it was decided that only one panel, as a representative to the rest of the façade, would be modeled in Revit to illustrate the new design.

Dimensions were taken from an excel spreadsheet which was used to check the panel's strength. These measurements were then used to assemble the 3D extrusion, complete with brick face and perimeter flanges. The model then served as a source for quick takeoffs for the rest of the team.

FLOOR SYSTEM

The program used to analyze the existing conditions and redesign, was SAP2000, chosen for its versatility and ability to analyze virtually any 3D structure. SAP does not include cellular shapes in its library of frame types, so wide flanges had to be edited in order to emulate the behavior of a cellular beam; a W21X44 was chosen to represent an LB30X44 for example. Shear area was reduced by 20% and Inertia was increased twofold. The resulting modified w-shape gave a good approximation of the behavior an LB30X44 as the results were as expected, aligning with deflections previously calculated.

As mentioned before, using cellular beams in a laboratory setting isn't typical because the ducts required to ventilate the lab spaces are usually larger and more intricate. Reorganizing the plenum therefore required the 30-inch cellular beams to be modeled in Revit, so the mechanical engineer could model necessary ductwork and equipment in 3D to provide a proof of concept.

Revit allows the editing of certain member properties including those of cellular beams. Unfortunately, the shapes provided by AutoDesk were few in number and hard to edit. Inputting numbers manually into the properties menu of an LB20X14 yielded only problems. Even though the numbers were taken from a standard LB30X44, whose dimensions met all code requirements and limits, Revit was consistently incapable of extruding the new dimensional values, leading to voids that were mashed together. This extrusion was clearly inaccurate and of little use to the MEP engineer who was depending on the structural Revit model to use in laying out his mechanical equipment. Therefore a new family was created from scratch whose extrusion accurately reflected the appearance of a cellular shape. Replacing the existing frames in the central revit model, was as simple as changing beam properties from a menu. However, some frames were drawn beyond the extent of the boundary line when inserted into the model. These, shorter, beams were fixed by editing the family of the cellular beam in Revit.

Originally it was thought that the floor system modeled in SAP would simply be exported into Revit, serving as a base for the complete reconstruction of the building redesign. Even if SAP had been able to successfully model the correct extrusion, the link to export information from SAP to Revit does not exist for 2011 Autodesk applications. The link in question is provided by CSI, the software company behind SAP, which had not yet updated their link, which only worked with 2010 applications. An idea had been brought up to use the 2010 Revit software to enable the link, but the process would have downgraded the current software and disabled some of the features that the other disciplines may have needed. Using the 2010 software would have also prevented the use of the existing conditions Revit model, as it was created in Revit 2011. The older software would not have recognized the newer model, costing the team valuable time in recreating the building top to bottom with the appropriate structural, mechanical and lighting/electrical systems.

Since the redesign would focus mainly on the third floor, it was originally thought that only that floor would be modeled due to the complexity of each system. Fortunately, the BIM teams were provided with a complete model of the existing conditions, which saved us an enormous amount of time in modeling the information that was not changed.

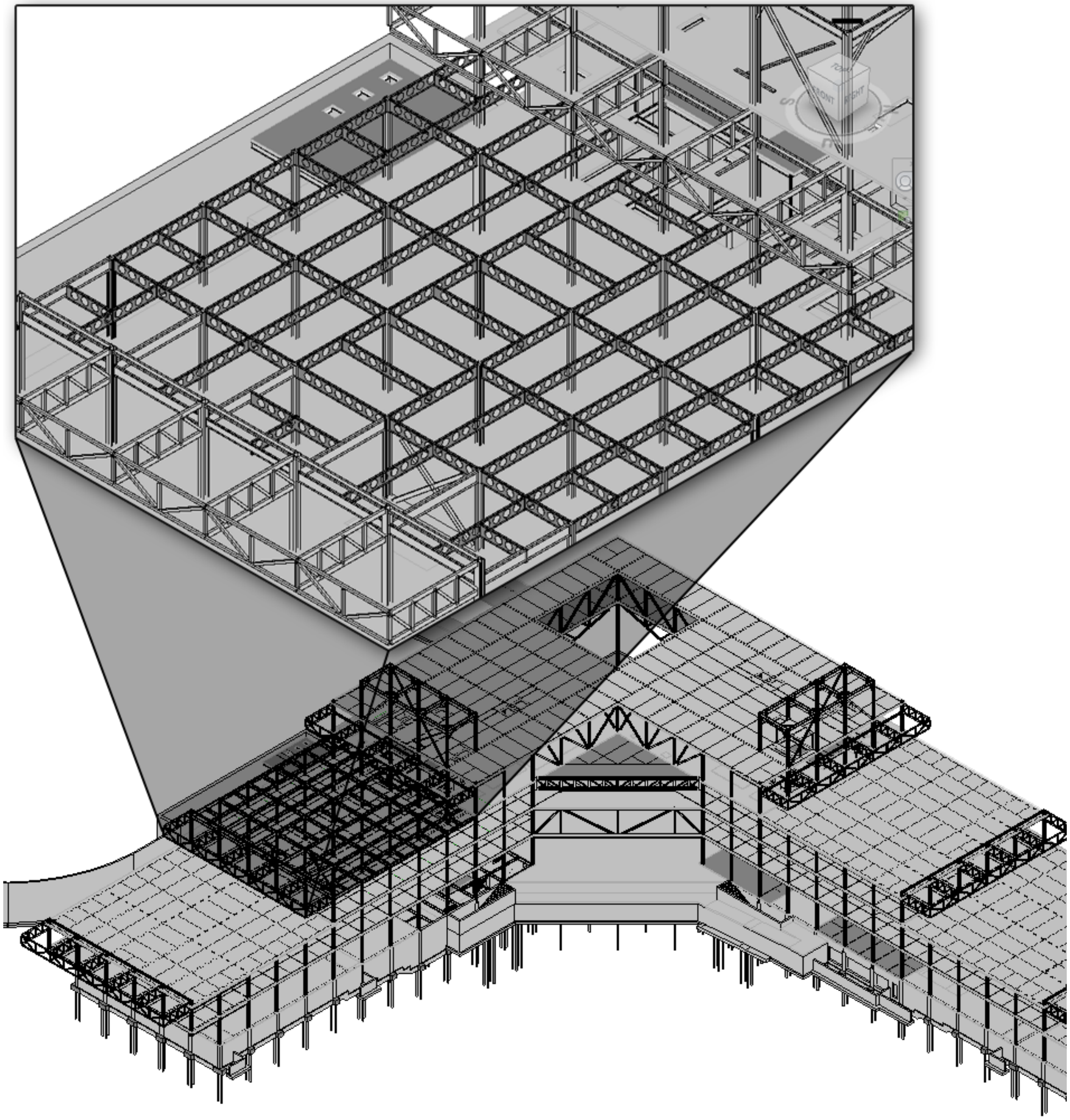


Figure 1.50: Cellular Beams Revit Model

The existing conditions Revit model provided each team with a wealth of information. If one needed to find the location of a certain member, rather than search through the construction documents and attempt to visualize its location relative to the overall building, the model could be searched for the same member and viewed in 3D. Its ability to provide context to an element where a 2D drawing could only give information about one plane, is invaluable to understanding and studying the building. Losing that information would have been an immeasurable disadvantage to the entire redesign process.

So rather than importing the redesigned floor system from SAP, a new member was created in Revit and used to replace the existing floor members. In a relatively short time, the structural floor model was complete and ready to be used for the mechanical layout. This provided the MEP engineer a 3D plan in which he could configure and model his system. Immediate feedback was available to alert him of the presence of collisions or of any unanticipated issue with the structural system.

The process of modeling did feature a few errors, which were brought into light by the mechanical engineer. Beam voids were not perfectly aligned due to Revit's default placement of members between columns. One end of the cellular beam would meet the flange of a column and the other would meet a column's web; this might have been vice versa with the next member, moving the voids one or two inches from the center of the beam before it. The mechanical engineer had to weave his equipment to and fro in order to avoid hitting the edges of each void in the beams. There were also smaller beams that exemplified this same issue, their voids lining up in completely the wrong place with the beam before or after it. This issue would have been completely looked over if it weren't for modeling it in 3D, where issues like this one could be discovered and resolved before being sent to final construction documents.

Since the lateral system was desired to remain unchanged, some members in the 3rd floor had to remain wide flanges. This was initially an issue, as it was planned to run all mechanical equipment through the structural system. The mechanical engineer was able to simply move his equipment below the level without any significant consequences.

CANTILEVER

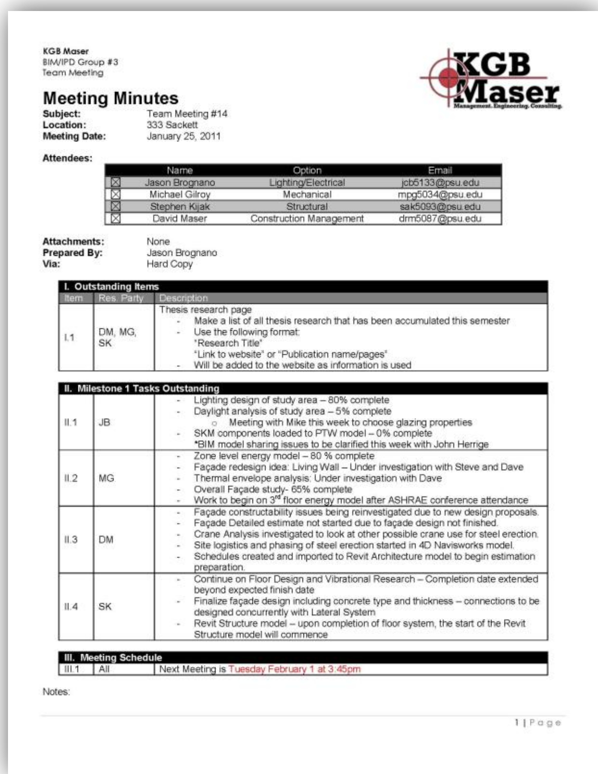
Analysis was done in SAP. An entire corner of the building was modeled for maximum accuracy. The model itself took around 12 hours to complete with the existing member sizes and loads. The trusses were then altered for the premeditated redesign and the model was run. Strength was checked in each member by exporting the results obtained from a SAP analysis into excel that was set up to read the results and use their values to check members in an interaction equation. Excel was able to immediately identify members that did not meet strength requirements, expediting the process of analytical iterations. The analytical model was then checked that it met deflection requirements of L/360. Strength ultimately controlled in all the redesigned trusses, whose web members were oriented for tension. Column size was based on an unbraced length of 32', a dimension taken from the birdcage sculpture; its mess of frame elements contains larger HSS tubes, which intersect at the columns' midpoints to provide bracing.

To visualize all these changes, the existing revit model was altered to accommodate the changes proposed. It was originally thought that the gravity model from SAP could simply be exported to Revit, so the same model did not have to be replicated twice in two different programs. This was not possible as explained above. Since all the redesign information was stored in SAP, the analytical model had to be referenced while changing members in the existing revit model.

First the superfluous bracing and web members were deleted from the existing revit model then the section properties of the existing members were changed from a pull down menu. The columns were inserted into the model by dragging down the existing truss member to the right base level. This process was seamless and did not cause any unforeseen problems or issues with the other systems. The resulting model made evident the space freed in the mechanical penthouse. Only two of the four main trusses use bracing on this level, and it is present in only two bays.

Before this model was completed, the lighting/electrical engineer had planned on lighting a space inside the building, not considering the plaza an especially interesting space as of that time. When the idea of a column was proposed, its architectural consequences made the plaza an even more undesirable location to light. The column intruded into the space completely destroying any subtlety that had been desired of its presence in the plaza. Once a proper architectural solution was suggested, it was modeled in Revit. Modeled in 3D, the lighting/electrical engineer saw potential for lighting and changed his proposal.

TEAM INTERACTION & BIM PROCESS



KGB Maser
BIM/IPD Group #3
Team Meeting

Meeting Minutes

Subject: Team Meeting #14
Location: 333 Sackett
Meeting Date: January 25, 2011

Attendees:

	Name	Option	Email
☒	Jason Brognano	Lighting/Electrical	jcb5133@psu.edu
☒	Michael Gilroy	Mechanical	mpg5034@psu.edu
☒	Stephen Kijak	Structural	sak5093@psu.edu
☒	David Maser	Construction Management	drm5087@psu.edu

Attachments: None
Prepared By: Jason Brognano
Via: Hard Copy

I. Outstanding Items		
Item	Res. Party	Description
I.1	DM, MG, SK	Thesis research page - Make a list of all thesis research that has been accumulated this semester - Use the following format: "Research Title" "Link to website" or "Publication name/pages" - Will be added to the website as information is used

II. Milestone 1 Tasks Outstanding		
II.1	JB	- Lighting design of study area – 80% complete - Daylight analysis of study area – 5% complete o Meeting with Mike this week to choose glazing properties - SKM components loaded to PTW model – 0% complete *BIM model sharing issues to be clarified this week with John Herrige
II.2	MG	- Zone level energy model – 80 % complete - Façade redesign idea: Living Wall – Under investigation with Steve and Dave - Thermal envelope analysis: Under investigation with Dave - Overall Façade study- 65% complete - Work to begin on 3rd floor energy model after ASHRAE conference attendance
II.3	DM	- Façade constructability issues being reinvestigated due to new design proposals. - Façade Detailed estimate not started due to façade design not finished. - Crane Analysis investigated to look at other possible crane use for steel erection. - Site logistics and phasing of steel erection started in 4D Navisworks model. - Schedules created and imported to Revit Architecture model to begin estimation preparation.
II.4	SK	- Continue on Floor Design and Vibrational Research – Completion date extended beyond expected finish date - Finalize façade design including concrete type and thickness – connections to be designed concurrently with Lateral System - Revit Structure model – upon completion of floor system, the start of the Revit Structure model will commence

III. Meeting Schedule		
III.1	All	Next Meeting is Tuesday February 1 at 3:45pm

Notes:

1 | Page

Figure 1.51: Sample Meeting Minutes Form

To maintain an accurate gauge of team progress and responsibilities, the team had weekly meetings to discuss upcoming due dates, project progress, and details regarding tasks and activities throughout the 2010-2011 academic year. These meeting minutes contained valuable information regarding team member analysis documentation, responsibilities for various stages of design, a rough estimate of lead and lag time, and team standards for formatting documents. Information exchange is key to facilitating an efficient team and the meeting minutes were a central piece of KGB Maser's chain of communication.

KGB Maser set out in the beginning with BIM goals as a team, and the potential BIM uses that could help achieve these goals. The BIM Mission Statement for KGB Maser is as follows:

KGB Maser will utilize BIM to streamline the design process, and effectively communicate building system designs to team members and advisors. BIM will be used as part of an integrated process to facilitate the investigation, coordination, and communication of the designs generated by our team. KGB Maser will use BIM to design, visualize, simulate, and analyze the designs that are developed for Millennium Science Complex.

This is a strong clear mission, and the goals we set as a team were to fulfill this mission statement. Throughout the entirety of the BIM/IPD Senior Thesis KGB Maser met at a minimum once a week to discuss progress and changes to the design. During these meetings, we were able to keep each other focused on our goals and mission. Below is a chart of the goals we set in the BIM Execution Plan.

PRIORITY (HIGH/ MED/ LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES
MED	WE WILL UTILIZE BIM TO INVESTIGATE AND DEVELOP POSSIBLE FAÇADE REDESIGNS FOR MILLENNIUM SCIENCE COMPLEX.	3D COORDINATION, STRUCTURAL ANALYSIS, LIGHTING ANALYSIS, ENERGY ANALYSIS, COST ESTIMATION
HIGH	WE WILL UTILIZE BIM TO EVALUATE AND DEVELOP METHODS TO REDUCE THE ENERGY CONSUMPTION OF MILLENNIUM SCIENCE COMPLEX.	MECHANICAL ANALYSIS, ENERGY ANALYSIS, LIGHTING ANALYSIS
HIGH	WE WILL UTILIZE BIM TO INVESTIGATE AND DEVELOP VALUE ENGINEERING EFFORTS FOR OTHER SYSTEMS OF MILLENNIUM SCIENCE COMPLEX.	3D COORDINATION, STRUCTURAL ANALYSIS, MECHANICAL ANALYSIS, LIGHTING ANALYSIS, ENERGY ANALYSIS, 4D MODELING, COST ESTIMATION.
HIGH	WE WILL UTILIZE BIM TO IDENTIFY CONCERNS ASSOCIATED WITH PHASING ON CAMPUS.	4D MODELING, SITE UTILIZATION PLANNING
HIGH	WE WILL UTILIZE BIM AND MODEL BASED ESTIMATION PROGRAMS TO QUICKLY ASSES COST ASSOCIATED WITH DESIGN CHANGES.	COST ESTIMATION, DESIGN REVIEWS
MED	WE WILL UTILIZE BIM TO EFFECTIVELY TRACK THE SCHEDULE IMPLICATIONS OF DESIGN CHANGES.	4D MODELING, DESIGN REVIEWS

Figure 1.52: BIM Execution Plan - BIM Goals

Keeping these goals in mind early on, KGB Maser was able to evaluate potential BIM Uses by qualifying each BIM use for its value to the project, value to the responsible party, and our team capability rating on the particular BIM Use. Below is the BIM Use Analysis Worksheet that was completed by KGB Maser to evaluate potential BIM Uses.

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating		
	High / Med / Low		High / Med / Low	Scale 1-3 (1 = Low)		
				Resources	Competency	Experience
Maintenance Scheduling	Med	Facility Manager	High	3	2	1
		Contractor	Low	2	1	1
		MEP Engineers	Med	2	1	1
Digital Fabrication	Low	Contractor	Low	1	1	1
		Subcontractors	Med	2	1	1
Record Modeling	Med	Contractor	Med	2	2	2
		Facility Manager	High	1	2	1
		Designer	Med	3	3	3
Cost Estimation	High	Contractor	High	2	1	1
4D Modeling	High	Contractor	High	3	2	2
Site Utilization Planning	High	Contractor	High	3	3	2
Layout Control & Planning	Med	Contractor	Med	2	2	1
		Facility Manager	High	1	3	3
3D Coordination	High	Contractor	High	3	3	3
		Subcontractors	High	1	3	3
		Architect	High	2	2	2

Figure 1.53: BIM Execution Plan - BIM Use Evaluation

Knowing what BIM Uses that the team would employ, KGB Maser completed the Information Exchange Worksheet of the BIM Execution Plan that specifically breaks down what each team member will need, and who is responsible for delivering that modeling content in each information exchange to complete the BIM Use. For example, a Cost Estimation BIM Use will have a file receiver of the CM-Student, but for a structural cost estimation, the Structural-student is responsible for delivering a 3D Revit Structural model that is to the highest level of detail. Each of the BIM Uses were evaluated with the Information Exchanges that needed to happen, and the Information Exchange Worksheet was completed.

INFORMATION EXCHANGE (IE)

Information	
A	Accurate Size & Location, include materials and object parameters
B	General Size & Location, include parameter data
C	Schematic Size & Location

Responsible Party	
ARCH	Architect
CON	Contractor
CE	Civil Engineer
FM	Facility Manager
MEP	MEP Engineer
SE	Structural Engineer
TC	Trade Contractors

BIM Use Title			Existing Conditions Modeling			Cost Estimation			3D Coordination		
Project Phase			Design			Design			Design		
Time of Exchange (SD, DD, CD, Construction)			DD			DD			DD		
Responsible Party (Information Receiver)						CM Student			CM Student		
Receiver File Format											
Application & Version											
Model Element Breakdown			**Info**	**Resp Party**	**Notes**	**Info**	**Resp Party**	**Notes**	**Info**	**Resp Party**	**Notes**
A	SUBSTRUCTURE										
	Foundations										
		Standard Foundations	B			A	SE		B	SE	
		Special Foundations	B			A	SE		C	SE	
		Slab on Grade	B			B	SE		A	SE	
	Basement Construction										
		Basement Excavation	C			B	SE		B	SE	
		Basement Walls	B			B	SE		A	SE	
B	SHELL										
	Superstructure										
		Floor Construction	A			A	SE		A	SE	
		Roof Construction	A			A	SE		A	SE	
	Exterior Enclosure										
		Exterior Walls	B			A	CM/S		A	CM/S	
		Exterior Windows	C			B	LE/M		A	LE/M	
		Exterior Doors	C			B	ARCH		B	ARCH	

Figure 1.54: BIM Execution Plan - Information Exchange

LESSONS LEARNED

CONSTRUCTION MANAGEMENT

The lessons learned during this senior thesis project involve Integrated Project Delivery and the use of Building Information Modeling to ease the sharing and possibilities of the information. The main lesson learned from integrated project delivery is the more open you are with your team, the more information you can get and receive from them. The biggest thing that I wish could have happened in an integrated approach is to know when each model was updated and what aspects of the model were updated. The ability to easily share information, could allow the modification of models by the architectural and engineering design firms, and could easily notify the construction management firm of what the changes were. Also learning more about sharing as much information as early as possible is vital to a successful integrated project delivery team. Last year in a previous integrated project delivery team, our communication was not sufficient and our progress suffered. This year our team was able to openly communicate about their own designs, and communicate with each other how all of the designs would affect their own. I look forward to taking what I have learned from working in an open, integrated team with me into my career.

As the construction industry moves more and more to the unanimous implementation of BIM, it is important to take the lessons learned in this thesis on BIM with me. The lessons I have learned with BIM is how to seamlessly make useful Revit Schedules to export to Microsoft Excel or other model based estimation programs. I have learned how to create detailed families for unique project components. I have learned that 4D modeling is not simply a video to show the entire project duration. 4D modeling can be used to show explicit details of certain processes and how they will occur. IPD/BIM Thesis has taught me to remain open minded and to share as much information with my team as possible. I have learned how to evaluate and effectively incorporate different BIM Uses. I have learned a lot this year to take on with me to my career.

LIGHTING AND ELECTRICAL

Major lessons learned from participating in IPD/BIM thesis revolve around two main ideas – model sharing abilities and full-service design. More companies are shifting to BIM related software platforms such as Revit, even in the lighting and electrical sector of engineering. MEP design firms are beginning to utilize Revit MEP in conjunction with traditional computer aided drafting and annotation software to streamline designs. One of the advantages of BIM software, such as Revit, is the ability to only change a datum once and it will cascade through the model and be changed in all other instances within the project. This saves design time and reduces the number of type mismatches when documents are sent to be published. Additionally, I have gained much needed knowledge about lighting and electrical specific model sharing processes and programs (as seen in this unit). The tools I will be able to take from this academic exercise pushes my abilities farther into the future of engineering design.

Secondly, this program has further prepared me for work in a full-service environment. The company that will be employing me to start my career is a full-service architectural and engineering firm. Through working with a member of each architectural engineering discipline, I have gained valuable knowledge related to other areas of study that both impact my designs and other disciplines. I have further learned the importance of team values such as respect, responsibility, and punctuality. I am thankful for participating in this program and hope that it has continued success at Penn State and in other academic institutions.

MECHANICAL

Mechanical design during the IPD/BIM thesis seemed to play a part in every decision that was made. The active chilled beam system impacted reflected ceiling plans, equipment power requirements, coordination with structure for plenum space, and impacts on cost and schedule. Often times, it seemed the load information contained by the chilled beams in the model was less valuable than their total quantity, placement, or ductwork requirements. As the mechanical engineer, much time was spent to ensure the chilled beams were accurately sized especially due to a more complex design for a laboratory facility.

While each discipline is undoubtedly equally important, the goal of improving operating costs put a lot of pressure on the mechanical design. Early estimates of ductwork sizes were provided for the structural engineer's cellular beams before deep analysis of distribution systems was completed. While analyzing chilled beams, a concurrent shading study was done to keep pace with the lighting engineer's façade study. Time constraints limited the amount of system Revit modeling that could be achieved. However, per the construction manager's request, chilled beams were sized and placed in the Revit MEP model for easier chilled beam estimation.

Some opportunities have also been identified for enhancement of BIM interfacing. CFD modeling can be an extremely effective tool to model indoor airflow conditions. However, the construction of a CFD model is more difficult than a Revit model. Revit models cannot be imported into CFD models for indoor airflow modeling purposes. If a better link can be obtained between the architectural models and CFD interfaces, CFD's role in HVAC design could drastically increase.

Overall, the team performed well together. Information was distributed at weekly meetings to update team members on discipline specific progress. To further enhance the analysis of the Millennium Science Complex, I feel that a room with all four disciplines working concurrently on models and analyses would be better served to facilitate communication. Often times I desired an answer to a quick question, but different schedules or work stations prohibited pertinent questions from getting prompt answers.

Entering the MEP design industry upon graduation, I feel the knowledge gained in BIM Thesis and BIM Studio relates to the capabilities and frustrations of using BIM software. More detailed information about a mechanical design can be input into a model, but the importance of the end use of such information must be wagered versus the time spent incorporating the additional data.

STRUCTURAL

Coming into the pilot BIM/IPD program, I had little knowledge of the BIM process. I was under the impression that BIM was simply the use of computer modeling to analyze and convey information more easily. I had no idea of the integration that was involved. The things that once annoyed me about Revit (central models had always caused more frustration than it helped) were now essential to integrated project delivery and the process of communication. To me, communication was the most intriguing part of BIM. Developing ideas to fit a range of functions rather than just the structural objective was more realistic than the traditional thesis. It was through communication that these ideas could be solidified into tangible concepts that were more realistic than simply the most "cost effective" solution. Those considerations that were taken when compromising with the Gil about cellular void size, or when deciding what depth was most efficient for the façade panel with Jay, made this pilot thesis a worthwhile experience. To have learned the general process of communication and information sharing before entering into the field of engineering is invaluable.

CONCLUSION

KGB Maser has worked hard throughout the 2010-2011 academic year to achieve goals set in the fall semester. Through integrated project delivery and building information modeling platforms, we can say with confidence that our goals for this capstone project have been achieved.

The first team goal undertaken was reducing energy consumption for the Millennium Science Complex. Main measures of success in this section are a lowered operating cost and a lower net present value of 30 year life cycle cost analysis. As seen in the "Energy Consumption Reduction" section of this unit, the engineering team redesigns produced a 14.1% energy savings annually with respect to the existing VAV design. In life cycle cost analyses, the existing system was favored if coal remains the main source for the campus power plant and inflation is not considered. With inflation and either natural gas or coal as a primary fuel source for the campus plant, the new design is favorable. By saving in energy consumption annually, this design goal can be considered to be achieved.

The façade redesign is intertwined with KGB Maser's energy consumption reduction goal. The new façade panels and the addition of 3'-0" overhangs contribute to decreasing the indoor environment load on the mechanical system and decreasing dependency on electric lighting in perimeter spaces. The latter portion of the energy savings produced an average of 6.97% energy savings in the perimeter zones controlled by team lighting redesign. With the application of vacancy sensors, this savings has opportunity to further increase savings. Additionally, reducing façade panel thickness can conceivably reduce prime energy in manufacturing the panels. As with the previous team goal, these savings in cost and energy have allowed this goal to be achieved.

The structural redesign by KGB Maser for the Millennium Science Complex is an integral part to our team's success and funding for other long term investments. The structural redesign is considered a success in the fact that the upfront cost of the structural steel package was reduced in cost by close to $2,300,000. The upfront savings comes primarily from the addition of the W14X550 columns under the cantilever. Another success of KGB Maser's structural redesign is the addition of castellated beams. The castellated beams in an integrated design approach are able to be used for mechanical duct, electric conduit, and other trades to flow through the open spaces. This is an advantage over the existing design that had a very congested, and complicated plenum coordination. KGB Maser's structural redesign is a success in saving upfront costs and reducing the complications for plenum coordination.

TEAM ACKNOWLEDGEMENTS

This capstone project was a challenging academic experience and our research has shown us the high standards and abilities of the Millennium Science Project team. We are thankful to have been a part of the IPD/BIM thesis program and would like to express our gratitude to all of those who have supported our efforts throughout the year:

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- Britt Ellis

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April 7th, 2011

UNIT 2: CONSTRUCTION REPORT

KGB Maser
Management. Engineering. Consulting.

IPD/BIM TEAM #3

JASON BROGNANO | MICHAEL GILROY | DAVID MASER | STEPHEN KIJAK

Dr. Mistrick | Dr. Jelena Srebric | Dr. John Messner | Dr. Andres Lepage

CONSTRUCTION EXECUTIVE SUMMARY

The Unit 2: Construction Report of KGB Maser's team report will cover the findings and the conclusions on the design analyses completed by KGB Maser on Millennium Science Complex. The Millennium Science Complex is a 275,000 SF Materials and Life Sciences Research Facility that contains 40,000 SF of quiet labs and 9,500 SF of nano-clean room lab space. This unit will cover existing conditions and evaluate the redesigns of KGB Maser in terms of upfront cost, architecture, and the implications to the schedule.

Structural Redesign:

The structural redesign of Millennium Science Complex utilized the placement of two W14X550 columns under the 150 FT signature cantilever and the utilization of castellated beams in the wings that are a separate system of the structure. The effect of the structural redesign is reflected in a significant savings of close to $2,300,000 between an existing conditions detailed structural system estimate and a redesign estimate. The two estimates were completed for the same floor plan, and the cost was applied per square foot to the entire building. The structural redesign will have minimal changes on the duration of the scheduling, but could change the phasing of the structure or the entire project significantly.

Architectural Redesign:

The architectural redesign of the courtyard beneath the cantilever involved the creation of a signature structure and a public gathering space. The existing courtyard plan consisted of an organic, curvaceous design that did not fit the rectilinear design of the rest of the building. The courtyard was redesigned to mask the cascading columns supporting the cantilever, and to also create an interesting public space that matched the buildings architecture. The existing courtyard and redesigned courtyard were estimated in detail; however a price for fabrication of the cage structure could not be acquired from Zahner Architectural Metals. The existing courtyard was estimated to cost $271,700 and the redesigned courtyard was estimated at $604,900 with an allowance built in for the cage structure.

Mechanical/Energy Savings Redesign:

The existing mechanical system and the façade system were both altered in this redesign and both had to be investigated. The existing mechanical system consisting of eight major AHU's was bid by the Farfield Company for $19,188,000, and the redesign of the mechanical system was estimated to be $21,040,000. This increase in upfront costs is funded from the savings on the structural system, and the mechanical system net present value analysis can be found in Unit 4: Mechanical Report. The mechanical system will also require a double crew for the installation of the chilled beams to remain on track with the original durations of the schedule.

The façade pre-cast paneling system was estimated in detail for the entire building to be $3,300,000, while the redesigned pre-cast paneling system was estimated to be $3,052,000 which is a savings of close to $248,000. This savings results from the reduction of the materials used in the façade panels, warranted by a structural study in Unit 5: Structural Report. The redesign of the panels will also have a minimal effect on the schedule due to the fact that the number of panels is not reduced.

TABLE OF CONTENTS

EXISTING CONDITIONS SUMMARY

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. Preconstruction for this project began in March 2008 and moved to primary coordination meetings by May 2009. By November 2010 the commissioning process will have begun and the building will be turned over to The Pennsylvania State University in July 2011.

The full summary schedule can be found in Appendix 2A. Below is a short summary made of several key construction activities, their durations, and the corresponding dates.

Construction Phase	Duration (Days)	Start	Finish
Notice to Proceed	1	8-12-2008	8-12-2008
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
Construction Duration	758	8-12-08	7-7-11
Substantial Completion	1	7-7-11	7-7-11

Figure 2.1: Summary of Construction Scheduling

PROJECT COST EVALUATION

Considering the magnitude and complex nature of this project, 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

Figure 2.2: Total Cost Analysis

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

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

Figure 2.3: Construction Cost Analysis

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

Figure 2.4: Building Systems Cost Analysis

BUILDING & CONSTRUCTION SYSTEMS SUMMARY

ARCHITECTURE

Figure 2.5: Existing Architecture Rendering

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

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

STRUCTURAL SYSTEM

The sub structure is a cast in place reinforced concrete system consisting of localized groups of 7 in. diameter micro-piles, of ranging depths, under individual pile caps ranging from 36 to 72 inches in thickness and located at the intersection of the column grid lines. 24 and 36 in thick grade beams connect these pile caps along the grid lines.

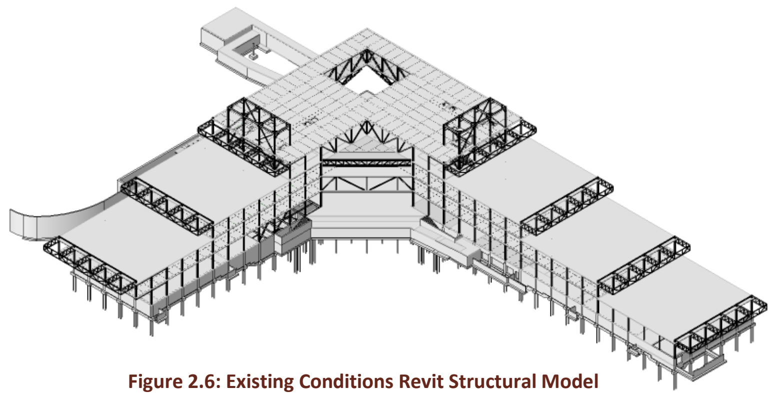

Figure 2.6: Existing Conditions Revit Structural Model

The super structure consists of a typical steel framed building with regular 22 feet square bays. The average floor to floor height is 19 feet. The typical construction for the two wings consists of steel wide flange columns and a concrete on metal deck floor system supported by steel wide flange beams and girders. Column and beam sizes range from W14X43 to W14X233 and W21X44 to W44X593, respectively. The typical floor system consists of 3 inch metal deck with 3 ¼ inch concrete topping.

The structure has to support the 150 foot cantilever at the intersection of the two wings. This is done through the use of a truss system consisting of wide flange members ranging from W14X90 to W14X283. This system is integral with a concrete shear wall extending from the foundation to the fourth floor level. This large c-shaped shear wall also contributes to the lateral force resisting system along with two moment frames and two smaller concrete shear walls at the stair wells.

The structural steel bid package for Millennium Science Complex has a contract value of $18,389,000.

MECHANICAL SYSTEM

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

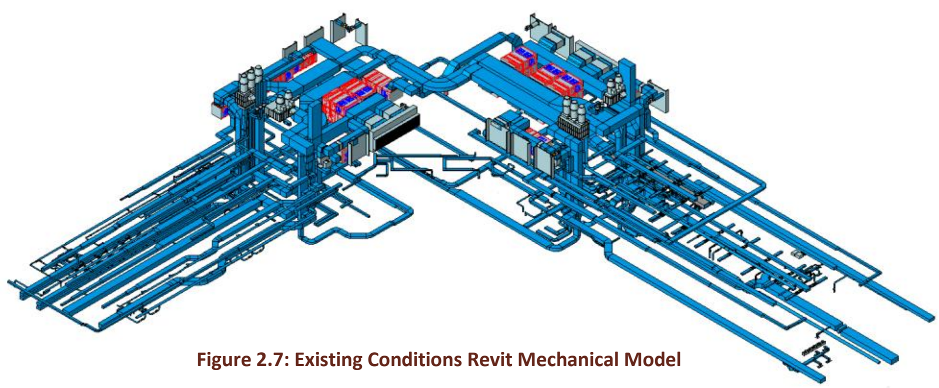

Figure 2.7: Existing Conditions Revit Mechanical Model

The laboratory areas of the building are served by five (5) 50,000 CFM VAV AHUs. Each of these AHUs contains a supply fan, cooling coils, heating coils, humidification equipment, and MERV-14 filters. All laboratory AHUs deliver 100% outside air. In an effort to save operating cost and energy in the DOAS systems, general laboratory exhaust air enters an enthalpy wheel with the incoming supply air. The laboratory fume hood exhaust is not included in the enthalpy wheel due to the potential contaminants within the exhausted fume hood air.

The office, lobbies, and common areas are served by three (3) 40,000 CFM VAV AHUs. These AHUs do not provide 100% outdoor air and instead contain a mixing box with CO2 sensors in the outdoor air, return air, and all conference rooms to ensure that the CO2 concentrations in these areas is maintained at appropriate levels by supplying enough outdoor air.

In addition to the main AHUs, cabinet unit heaters, electric heaters, fan coil units, and supplemental air conditioning units, other local equipment is 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.

LIGHTING & ELECTRICAL

Power/Distribution

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

Lighting

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

ENCLOSURE

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

PROJECT SITE LOGISTICS

Figure 2.8: Bing Maps View of Millennium Science Complex Site

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 Testing Center. Figure 2.8 above 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 is Nittany Apartments, to the South is the Pollock Testing Center, and to the West is the existing Life Sciences building.

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. To the East, across Bigler Road, is Nittany Apartments, where students must be easily able to arrive from and depart for class safely. To the North of the site, along Eisenhower Parking Deck, is a main artery of student travel in which safety is a main concern. On the South edge of the Life Sciences Wing, the building cantilevers over the pedestrian walkway, in which case a temporary structure has to be built in order to protect pedestrian safety.

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, and the Blue Loop also comes up Bigler Rd and turns onto Pollock Rd to continue its campus loop. Vehicle and pedestrian traffic are 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 would cover from site preparation through the foundation being complete. The second phase site logistics plan would cover from steel erection to interior finishes. Both Site Logistics plans are shown on the next page.

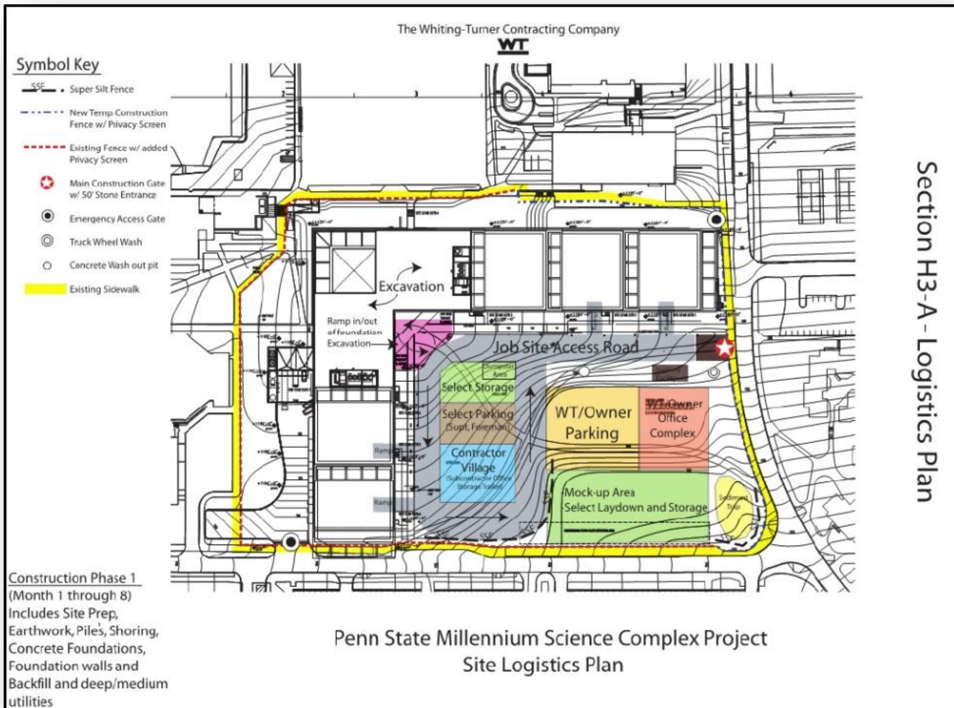

Figure 2.9: Phase 1 Site Logistics Planning

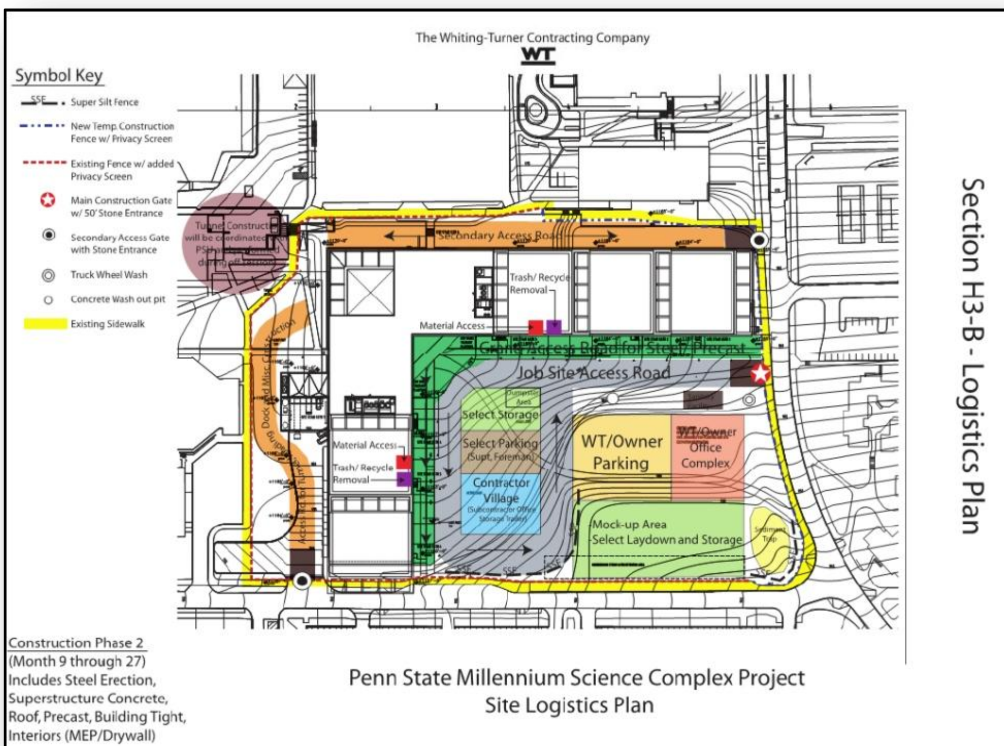

Figure 2.10: Phase 2 Site Logistics Planning

While the existing 2D site logistics plans from Whiting-Turner were beneficial, we were able to model the site logistics plans in 3D to get a better understanding of how project phasing would go, and how design changes could affect project phasing and delivery. Below is an image from the site logistics model that was created consisting of the various crane sizes and types that were used.

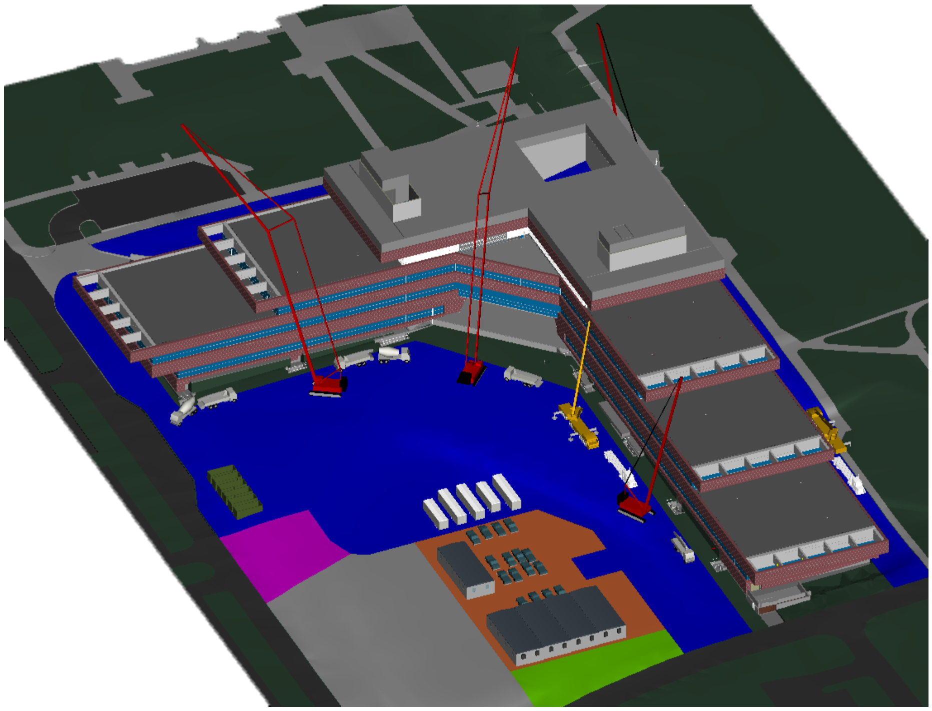

Figure 2.11: 3D Site Logistics Model in Navisworks Manage

PROJECT STAFFING & DELIVERY METHOD

PROJECT STAFFING

Whiting-Turner is staffing the project based on the project size and complexity. A simplified staffing plan is shown on the next page, and a full staffing plan is attached in Appendix 2.B. This particular project has two Sr. Project Managers, four Project Managers, a Sr. Superintendent, two Superintendents, and five Project Engineers. The project is overseen by Dick Tennant, an owner's representative Construction Manager. 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 will handle all project submittals, most of the RFI's, and review the payment requisitions from the subcontractors. As for the Superintendents and their assistant, they 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.

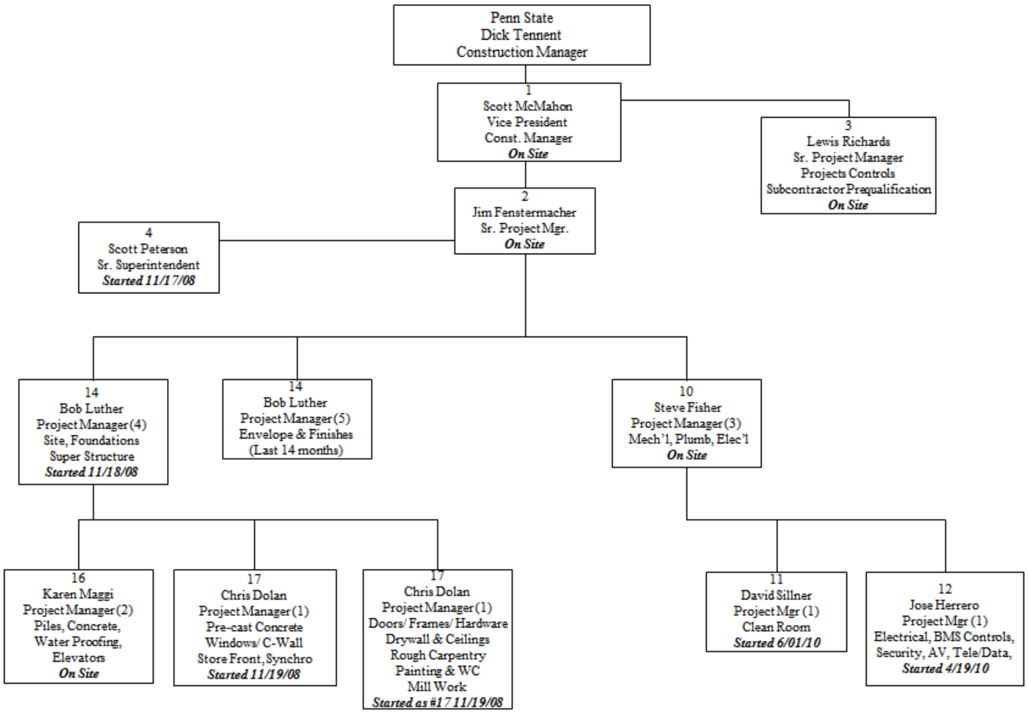

Figure 2.12: Simplified Project Staffing Plan

PROJECT DELIVERY

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 has Department General Services (DGS) funding, Penn State University is required to hold the contracts which are publicly funded directly. These contracts include site demolition, underground utilities, micro-piles, structural steel, mechanical, and other early on activities. 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-Turning maintains contracts will 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.

ARCHITECTURAL REDESIGN STUDY

The architectural redesign of the cantilever courtyard was a multiple step process in which there were numerous iterations on the design. The existing design can be seen in the rendering to the right. Large open spaces and sweeping paths fill the courtyard. The ground cover consists of decorative grasses, stones, and plants. This design of the courtyard seemed to contrast the rigidity and linear design of the rest of the building. A free flowing layout of the courtyard was an organic design that could have reflected the Life Sciences aspect of the building, but contrasted with the strong lines of linearity of the rest of the building.

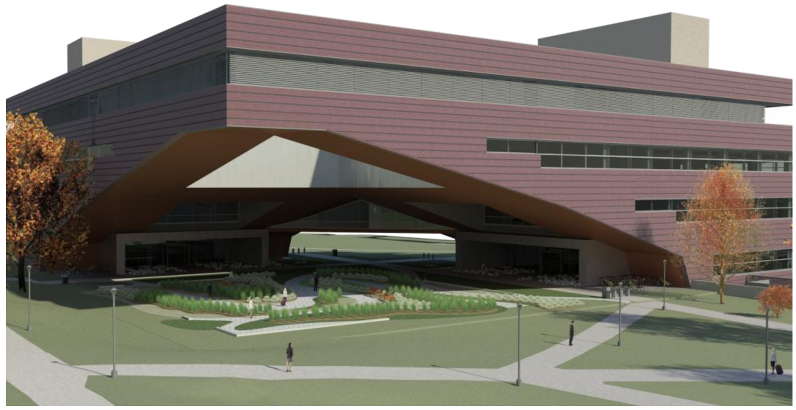

Figure 2.13: Existing Conditions Cantilever Courtyard Rendering

The first attempt at designing an architectural and structural column that would aid in supporting the cantilever was a single column placed at the North-West corner of the light well in the cantilever. For structural purposes, the column was placed at the intersections of grid lines B and 2. While this design worked well in terms of simplicity, structural capabilities, and had a minimal interference with the floor plan, it did not blend well with the design of the building and simply looked like an afterthought.

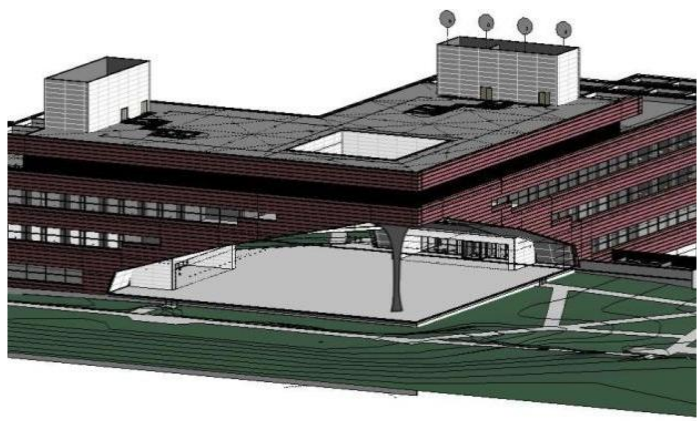

Figure 2.14: Cantilever Support Design #1

After going to the construction site and sketching other possible designs, KGB Maser began to develop a strong rigid design that utilized a cage structure to reduce the unbraced length of the column supporting the cantilever. To the right is one of the first renditions of the final design.

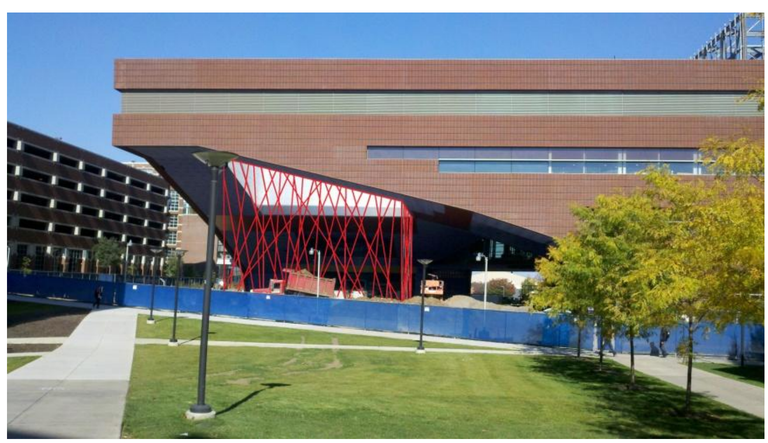

Figure 2.15: Preliminary Cage Structure Sketch

The first model with this design scheme consisted of a light, airy cage structure that didn't create a strong enough statement to still look like a featured aspect of a signature building like Millennium Science Complex. The cage structure was made much more significant with the increase in the size of each stick of the structure. Also to give the cage structure some depth and multiple aspects, a second layer was added with sticks ranging in size from six inches wide and a foot deep to one and a half feet wide and one and a half feet deep. The sticks are wrapped in two materials consisting of a blue brushed aluminum and a semi polished aluminum. The final design pictured to the left required significant coordination with the structural engineer to determine were cross bracing had to be placed for the columns supporting the cantilever, and also added a second column at the intersection of column lines E and 5. The final design is shown below in a rendering and the columns are shown in a basement floor plan to show the minimal effect that they will have on the floor plan of the lab spaces.

Figure 2.16: Final Cage Structure Design Rendering

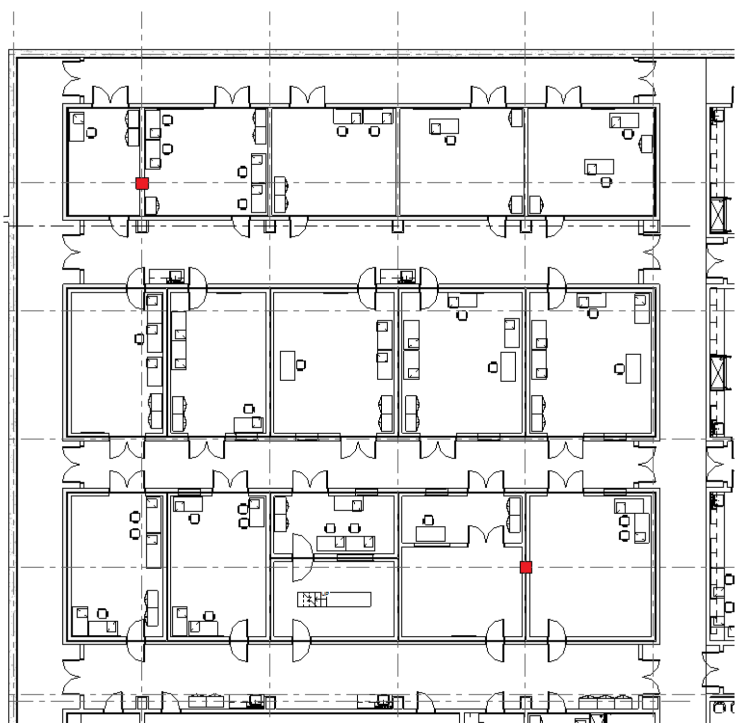

Figure 2.17: Basement Floor Plan with Cantilever Support Columns

FAÇADE REDESIGN COST IMPACTS

FAÇADE CONSTRUCTABILITY CONCERNS

A change to the existing design of the pre-cast panel façade will have to be investigated while taking multiple things into consideration. Initial cost, maintenance scheduling, and the constructability of the façade redesign will all have to be considered while selecting a façade system.

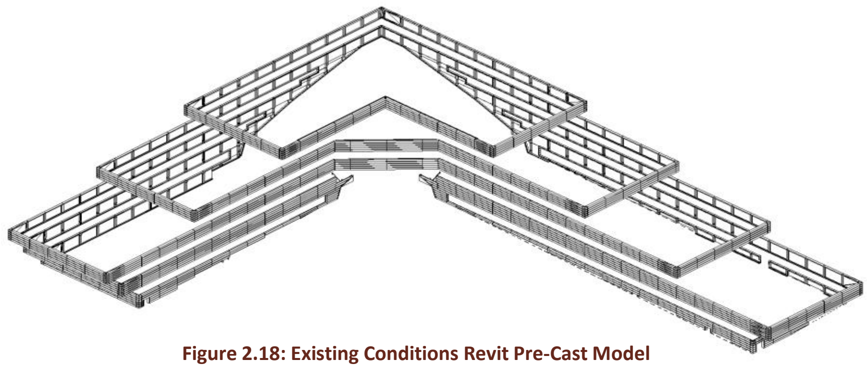

Figure 2.18: Existing Conditions Revit Pre-Cast Model

The precast panels of Millennium Science Complex cost $5.6 million, according to the bid packages available from Penn State's Office of Physical Plant, and are currently a substantial load on the structural system. The cost can easily be reduced by researching other cost effective designs and erection time of the building enclosure can be reduced by further prefabricating connections, or making each panel lighter. It will certainly be more of a challenge to achieve a redesign of the façade system that both performs better with respect to energy and daylighting while maintaining the architectural theme desired by Rafael Vinoly Architects and The Pennsylvania State University.

KGB Maser's main constructability concerns and possible benefits for our proposed façade redesign include the fact that decreasing the weight of each panel could result in being able to ship more than one panel to the site at a time, however a lighter panel may be more prone to cracking during delivery. Another constructability issue being looked at is the size of each panel. If the panels can be lengthened, and made to a bigger nominal size of up to 60' in length, the number of deliveries and picks for the façade will be reduced.

DETAILED ESTIMATE

The pre-cast panels of the façade consists of over 330 brick faced "C" shape panels with 6" of concrete backing. RS Means had pricing information for a 20'X10' architectural panel with a 6" thickness. This panel pricing information was used for a baseline, but the volume of this panel was compared to the volume of the nominal pre-cast panels at Millennium Science Complex. The increased percent of volume was relayed to the material pricing that would be used for our detailed estimate. The total square feet of precast for the entire building was exported from Revit Architecture to Microsoft Excel, and the estimate was completed.

The total square feet of pre-cast panels will not change, but for each square foot of the panel, there will be less material used. The reduction in material is not enough to warrant a reduction in crane size or reduction of crew so the labor and equipment pricing will stay the same for the redesigned panel.

Existing Pre-Cast							
Total (SF)	Material	Labor	Equipment	Total	Cost	Time	O & P
72319.11	27.3	1.74	1.63	30.67	$2,218,027	$2,816,894	$3,295,766
		TOTAL COST =		$3,295,766.47			
Redesign Pre-Cast							
Total (SF)	Material	Labor	Equipment	Total	Cost	Time	O & P
72319.11	25.03	1.74	1.63	28.4	$2,053,862	$2,608,405	$3,051,834
		TOTAL COST =		$3,051,834.62			

Figure 2.19: Existing and Redesign Pre-Cast Estimate

MECHANICAL REDESIGN COST IMPACTS

EXISTING CONDITIONS COST BREAKDOWN

The mechanical system was going to be estimated from the mechanical Revit MEP model, which did not include everything to its entirety as a coordination model. Figures 2.20 and 2.21 below show the difference in detail from the coordination model to the Revit Mechanical Existing model.

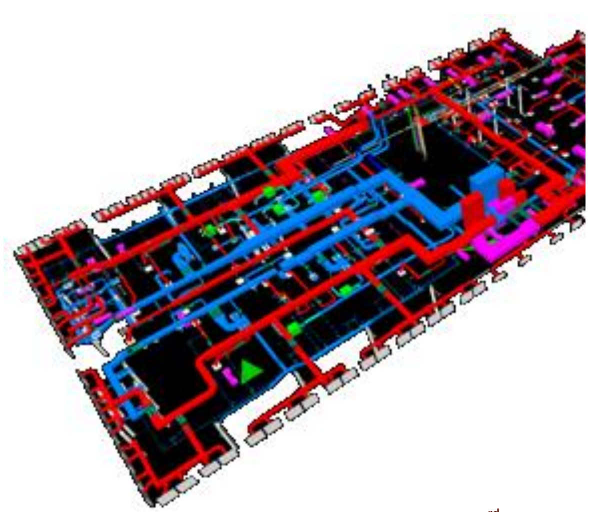

Figure 2.20: Mechanical Coordination Model – 3rd Floor LS

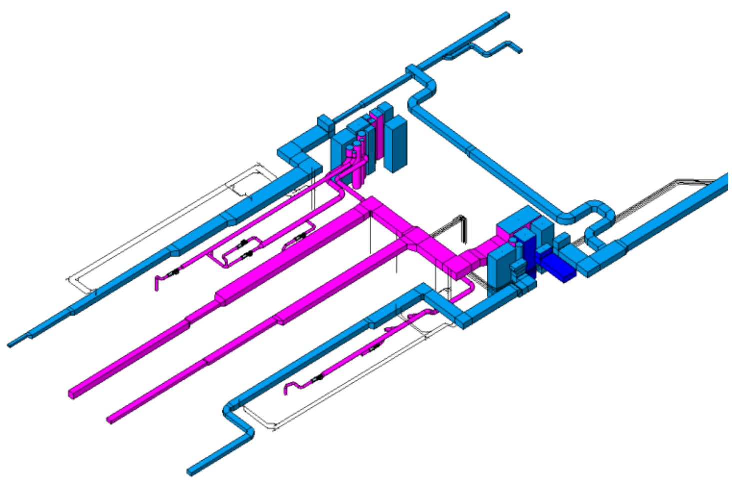

Figure 2.21: Revit Mechanical Existing Conditions Model – 3rd Floor LS

This lack of detail in the Revit Mechanical model required that assumptions be made for the estimate, which reduces the detail and precision of the estimate. Instead of doing a detailed estimate existing conditions estimate of the third floor for comparison, the entire building mechanical system had to be compared for the analysis. The Farfield Company was awarded the mechanical system, for the bid value of $19,188,000. This cost breaks downs to a cost per square foot of $78.38/SF.

COST IMPLICATIONS OF REDESIGN

The redesign of the mechanical system will include the use of two different types of chilled beams, each with extensive copper piping to be priced for the connections. Chilled beam prices have come from calling suppliers and researching labor output and labor pay rates. The redesigned system will have a cost reduction in AHU's of $452,924. Below is a summary of the cost of chilled beams, piping, and ductwork for the entire redesigned mechanical system. This cost is derived from a SF based estimate of the mechanical system, with the equipment and pumps being added.

The methodology behind this estimate is a detailed estimate of a predetermined area of the building. This predetermined area was modeled and estimated in detail, and the cost per SF was applied to the rest of the building. After the cost of these main categories was calculated, the pricing of the pumps was found through RS Means Mechanical Cost Data, and the AHU's were priced on a quote from SEMCO HVAC. The quote for this equipment is attached in appendix 2.C.

Chilled Beams	Ductwork	Piping	Pumps	AHU's	Total with GC & Crane Cost
$9,608,006.00	$2,966,422.00	$377,840.00	$165,484.00	$2,274,046.00	**$21,035,567.00**

Figure 2.22: Mechanical Estimate Breakdown Summary

The total cost of the redesigned mechanical system is expected to be around $21,040,000 based on a detailed square foot based estimate. This final cost includes general conditions and any crane costs for lifting mechanical equipment to the mechanical penthouse on the fourth floor. Detailed schedules are also attached in Appendix 2.D for the area that was detail estimated from the third floor.

ARCHITECTURAL REDESIGN OF COURTYARD

EXISTING CONDITIONS DETAILED ESTIMATE

The current design of the courtyard consists of sweeping paths with varying types of decorative grasses and gravels. Figure 2.23 to the right shows the existing design of the courtyard. This design was estimated in a detailed manner with takeoffs of major ground coverings, plantings, park benches, and bicycle racks. Pricing information was gathered from both RS Means and contacting vendors for specific plants.

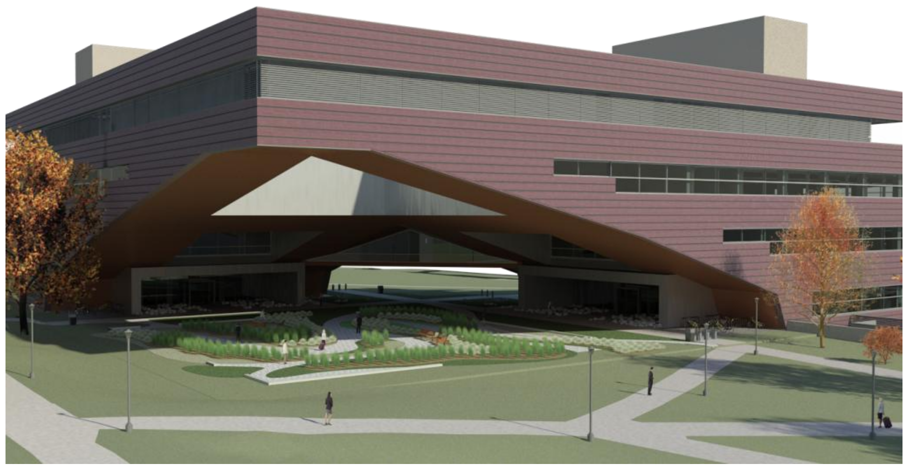

Figure 2.23: Existing Courtyard Rendering

Type	Total	Unit	Cost Total	Cost Unit	Cost
RPC Shrub: Century 1'-10"	244	EA	22	EA	$5,368.00
RPC Shrub: Switchgrass (2) 4'-0"	327	EA	17.1	EA	$5,591.70
Basic Wall: Concrete Panel Wall	214.5	FT	11.45	LF	$2,456.03
Custom Park Bench 6'-0"	5	EA	526.5	EA	$2,632.50
Bicycle Racks	8	EA	649	EA	$5,192.00
Stamped Stone Path	4271.75	SF	17.05	SF	$72,833.34
Mulch	4624.63	SF	2.91	SY	$498.43
Bermuda Ornamental Grass	1298.57	SF	50	SY	$2,404.76
Ground Cover Grass	8487.97	SF	220	MSF	$ 1,867.35
Fern/Boulder Area	1926.43	SF	46.3	SY	$3,303.47
Exposed Aggregate Concrete	1451.47	SF	18.18	SF	$26,387.72
Decorative Pea Gravel	4337.69	SF	7.1	SF	$30,797.60
Decorative Boulders	240	EA	28.85	EA	$6,924.00
					$166,256.90

Figure 2.24: Existing Courtyard Breakdown Summary

Total Including O & P, Waste, Delivery, & Time Modifications = **$271,745.24**

REDESIGN DETAILED ESTIMATE

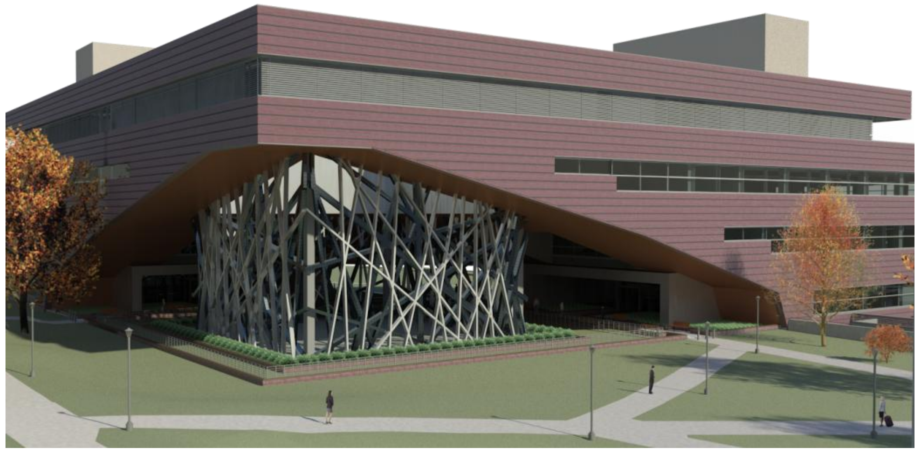

Figure 2.25: Redesign Courtyard Rendering

KGB Maser's redesign of the courtyard was necessitated by the integration of the W14X550 columns beneath the cantilever. The redesigned courtyard wraps the columns and the opening of the 66'X66' light well in the cantilever. This cage structure consists of two primary materials, brushed blue aluminum and a semi-polished aluminum. Due to the complex nature of estimating an artistic structure of this nature, Zahner was consulted for pricing information of a fabrication estimate of the cage structure. Zahner is experienced for over 110 years in working in an architectural metal industry.

The redesigned courtyard was estimated in the same manner as the existing courtyard. Ground covering, planting, site accessories, outstanding items were considered in the estimate.

Type	Total	Unit	Total	Unit	Cost
RPC Shrub: Acacia 3'-6"	101	EA	63.8	EA	$6,443.80
RPC Shrub: Fountain Grass 1'-6"	733	EA	21.01	EA	$15,400.33
Basic Wall: Courtyard Path Wall	1617.89	LF	12.34	LF	$19,964.76
Park Bench 6'-0"	16	EA	448.5	EA	$7,176.00
Courtyard Railing	486.5	LF	22.92	LF	$11,150.58
Mulch	14492.05	SF	2.91	SY	$1,561.92
Cage Structure(ALLOWANCE)	1	EA	0	EA	$ 1,000,000
Courtyard Sod	9356.29	SF	265.95	MSF	$2,488.31
					$ 64,185.70

Figure 2.26: Redesign Courtyard Breakdown Summary

Total Including O & P, Delivery, Waste, & Time Modifications =	**$1,104,910.88**

STRUCTURAL REDESIGN COST IMPACTS

STRUCTURAL CONSTRUCTABILITY CONCERNS

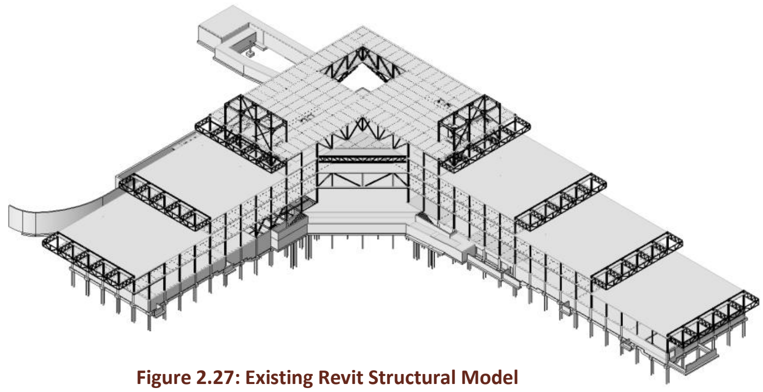

Figure 2.27: Existing Revit Structural Model

The current structural system for Millennium Science Complex costs $24,559,974 or $90.06/SF. This cost is from the bid packages found Office of Physical Plant's website. The structural redesign of the cantilever and floor systems will benefit the constructability and cost of Millennium Science Complex. The cost of the structure could have a significant decrease with the columns being placed underneath the cantilever. The use of other supporting systems will also help eliminate some on the truss bracing that is a concern for coordination on the 4th floor mechanical penthouse.

Extensive resources were also allocated by Whiting-Turner and Thornton Tomasetti to the in depth sequencing and erection process planning that was necessary to construct the cantilever. With a column being placed for support under the 150-ft cantilever, the construction sequencing becomes much simpler and easier to plan.

The use of columns under the cantilever should reduce the current truss system, and will benefit the constructability by allowing more space for coordination, specifically on the 4th floor penthouse, and to reduce the total tons of steel for Millennium Science Complex. The cost of the structural system and the amount of planning and sequencing are both expected to be reduced, due to the reduction in the complex nature of the structural system, specifically the 150-ft cantilever.

A smaller crane size is not a likely possibility due to the fact that the crane will still have to be placed between the two wings to erect the courtyard/cantilevered area. Furthermore, the addition of the W14X550 columns under the cantilever will have to be placed from this location as well.

EXISTING DETAILED ESTIMATE

The existing structural steel was estimated in detail for both the entire building and the third floor with RS Means cost information. Autodesk Revit Architecture was used to create structural framing and structural column schedules for the entire existing structural steel, the existing and redesigned 3rd floor structural steel. Due to the irregularity of some of the W shapes used in the structure, linear extrapolation was used to determine pricing for some of the larger beam sizes that needed to be priced.

Existing Entire Structure				
	Framing Tons	Column Tons	Framing Cost	Column Cost
	3058.7 Tons	953.84 Tons	$8,179,891.34	$2,386,659.20
		Total =	$10,566,550.54	
Existing 3rd Floor Structure				
	Framing Tons	Column Tons	Framing Cost	Column Cost
	595.72 Tons	231.47 Tons	$1,848,680.85	$434,508.19
		Total =	$2,283,189.04	

Figure 2.28: Existing Conditions Structural Cost Breakdown Summary

REDESIGN DETAILED ESTIMATE

Our redesign for the floor system consists of castellated beams for the wings, and including W14X550 columns with bracing to support the cantilever. These changes to the structural system were estimated in detail for the third floor. With a cost for the third floor both in an existing conditions and a redesigned state, costs were compared and the savings per square foot was calculated. With a savings per square foot, we were able to apply the savings of our redesign to the entire building.

Redesign 3rd Floor Structure				
	Framing Tons	Column Tons	Framing Cost	Column Cost
	459.79 Tons	202.92 Tons	$1,310,896.61	$539,218.72
		Total =	$1,850,115.33	
Cost Implications to Entire Structure				
	Savings/SF	Total SF	Total Savings	Total Cost
	$8.3326/SF	274,922 SF	$2,290,815.05	**$8,275,735.48**

Figure 2.29: Redesign Structural Cost Breakdown Summary

It is estimated that the structural system redesign will save close to $2.3 million. The savings was taken off of the detailed structural steel estimate that was completed with cost information from RS Means, so that the savings was compared to an estimate that was constructed from the same manner and assumptions rather than comparing our savings and our detailed estimates to the structural steel package contract value of $18,389,000 for

Kinsley Construction. Attached in Appendix 2.E are the detailed take offs of the entire structure, existing third floor structural steel, and the redesigned third floor structural steel.

SCHEDULE IMPLICATIONS

FAÇADE REDESIGN

The façade redesign is very important to analyze with respect to the schedule because it could affect the duration until the building cane become water tight. However, the schedule implications due to the redesign of the pre-cast architectural panels are very minimal due to the fact that the number of panels and total square feet of the panels will not change. It is understood that also the redesign of the panels will not warrant a reduction in crane size. This may allow for a quicker pick time for each panel, with each panel being reduced in weight, but will reasonably take the same amount of time to set each connection for the panel.

MECHANICAL REDESIGN

The original duration of the mechanical system installation is 303 days from 12/24/09 to 2/9/11. This sequence of activities is an integral part of the critical path so it is necessary to try to maintain at the most this same duration. Chilled beams are very labor intensive and require a lot of field fabrication of connections. It is estimated based on our design that Millennium Science Complex will house roughly 3300 chilled beams to install. The installation of the chilled beam is what will change the schedule the most. From conversations and research through mechanical contractors, it has been found that a typical crew can install 5-6 chilled beams per day. This production rate would mean that the installation duration for the 3300 chilled beams would be around 600 days. With this extended duration, it would be necessary to add another crew to keep track with the original schedule duration of 300 days.

The mechanical penthouse will also have less equipment to be installed which will also lower the duration of the installation for the mechanical system. With less equipment and cross bracing in the mechanical penthouse as well, the installation of the ductwork and piping will take less time to coordinate and install. The mechanical system installation of the equipment and the chilled beams is expected to remain close to the existing duration through the use of a double crew to install the chilled beams.

STRUCTURAL REDESIGN

The erection of the structural steel is a critical task to analyze with respect to scheduling. The original structural steel erection duration was 274 days. It is believed that our redesign will have an erection duration of the same expected time, with a minor possibility to reduce this duration do to a reduction in the complex nature of the structural design, and a change in sequencing.

The existing structural sequencing begins steel erection with the East side of the Material Sciences wing works west through the wing, secondly moving to the South of the Life Sciences wing and working North. Finally the erection of the cantilever could be completed after the shear walls and moment connections were completed. With the reduction in moment connections and less detailed sequencing and coordination need for our redesign cantilever, the erection process can work from the East of Material Sciences to the West, construct the cantilever, and move on to the Life Sciences wing working from North to South.

While the structural redesign maintained the same number of pieces for structural framing, the additional two W14X550 columns will have to be set. This is again a minimal impact to the schedule. A standard steel erection crew (E-2) can set over 900 LF of columns per day. This makes a maximum to set the columns at half a day, which can be recovered by the reduction in complexness.

The Manitowoc 999 and 16000 cranes used for steel erection will primarily still be used, and will not be reduced in size due to the fact that there are still very large member sizes that need to be set for the vibration labs. (W40X593) These picks along with the enlarged W14X550 columns necessitate that the crane size can't be reduced.

SUMMARY AND CONCLUSION

The original interpretation of the team goals was to save money in some areas to provide for the upfront cost of the life cycle saving options. The cantilever, structural, and architectural redesign studies seemed to be areas to save money to fund higher efficient lighting fixtures and the mechanical redesign for energy savings.

The cantilever study of the structural system was a successful study in finding that there would be a savings of close to $2,300,000. This savings however covers the entire structural system, and not the percentage saved by simply placing the columns into the cantilever and seeing the savings from this redesign. KGB Maser believes that the cantilever is a successful option that could have been considered early in the design as another viable option to the cantilever. Along with the columns being placed for support KGB Maser was able to create an architectural study and believe that we have created an interesting courtyard space and a significant signature structure of the campus.

The chilled beam implementation for the mechanical system redesign will increase the current $19,188,000 mechanical system package by $1,852,000 or for a total new mechanical system with chilled beams of $21,040,000. This is a substantial increase in the upfront cost, but will have a lower net present value if inflation is considered. Reference Unit 4: Mechanical for further investigation on the net present value. KGB Maser believes that chilled beams are a viable option that can have an upfront cost increase, and will affect the schedule due to the labor intensive connections.

The façade was another area of improvement for KGB Maser's redesign as we saved $244,000 in the pre-cast paneling system by lessening the materials used. This results in a final pre-cast paneling contract value of $3,005,000 instead of close to $3,300,000 that was estimated for the existing conditions design.

KGB Maser believes that the designs and proposals that have been developed should have been strongly considered in the early stages of design. We have presented the results of our designs, and believe that as a whole our designs can still save close to $350,000 in upfront costs. This total analysis of savings is completed in Unit 1: IPD/BIM DISCUSSIONS.

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April 7th, 2011

UNIT 3:
LIGHTING/ELECTRICAL REPORT

KGB Maser
Management. Engineering. Consulting.

IPD/BIM TEAM #3

JASON BROGNANO | MICHAEL GILROY | DAVID MASER | STEPHEN KIJAK

Dr. Mistrick | Dr. Jelena Srebric | Dr. John Messner | Dr. Andres Lepage

EXECUTIVE SUMMARY

The following unit of KGB Maser's report includes lighting- and electrical-specific requirements for Architectural Engineering senior capstone thesis. The subject building is scheduled for completion in the summer of 2011. The Millennium Science Complex will be both a signature building and house state-of-the-art research facilities to further Penn State's reputation for science excellence. The existing power system is a double-ended, main-tie-main configuration being supplied by Penn State campus power. Within the building, there are two distribution voltages – 480Y/277V for lighting and mechanical equipment and 208Y120V for receptacle and small loads. Lighting delivery consists of recessed lay-in-grid luminaires. Portions of the perimeter spaces are controlled using daylight sensors and the Lutron EcoSystem digitally addressable lighting interface. There will be three spaces considered for lighting and power system redesign.

The first space in the redesign exercise is a third floor perimeter student study area. The lighting redesign includes reducing the number of fixtures per row of luminaires, creating a pseudo ceiling by suspending luminaires, adding task lighting for the desks, and integrating automatic shading with a larger overhang applied to glazing. The cost changes can be seen in Unit 1 of KGB Maser's report. The operating cost is estimated to save $46.48 for the third floor of the Millennium Science Complex. Following lighting delivery redesign, the panelboard feeding the space will be resized according to the National Electrical Code.

The second space in the redesign exercise is a third floor office for distinguished personnel. The lighting redesign for this space includes an aesthetic change in luminaire delivery to accommodate the visual environment created by chilled beam application. There are three applications of lighting design in this space – wall washing, overhead lighting, and grazing. Fixtures with aesthetics similar to chilled beams have been applied to the overhead lighting, chalkboard-type fixtures graze shelving in a recessed alcove, and linear T5 wall washers balance luminance on the interior wall with surfaces near the large glazing. Additionally, as with the previous space, the controls and panelboards will be designed to accommodate the new lighting application.

The final redesign space is KGB Maser's signature design for the Millennium Science Complex – the cantilever courtyard and steel sculpture. The ironic nature of this space makes it unique for lighting design. It is located at the main entrances of the building wings, yet foot traffic over its center trespasses upon the vibration requirements of the nanotechnology laboratories below. Utilizing mostly floodlighting, the courtyard will be emanating its grand nature through a soft glow. Two main applications of lighting will be used in this space – grazing the support members of the structure and floodlighting the soffit and light well of the cantilever. The control of this space is achieved through state-of-the-art lighting control panels.

In addition to the aforementioned lighting redesign, two electrical-specific depth topics will be examined. Through mechanical redesign, water pumps will be consolidated into a motor control center. This distribution center will then be located within the Millennium Science Complex in an appropriate space, given what space is available for reconfiguration. The second topic includes a short circuit analysis in SKM Power Tools for Windows of major equipment supplying the third floor of the complex.

TABLE OF CONTENTS

LIGHTING OVERVIEW

The following section presents lighting requirements for AE482. There are three spaces to be redesigned along with integration between daylighting, shading, and the mechanical system design. The three spaces include a third floor student study area, third floor office for distinguished personnel, and architectural lighting for the structural redesign of the cantilever courtyard.

Student study areas appear around the perimeter of the second and third floor of the Millennium Science Complex. The existing lighting delivery utilizes linear sets of 1x4 recessed luminaires over the aisles of each set of workstations. These rows of luminaires are currently dimmable and will continue to be dimmable in redesign. The corridor utilizes the same linear recessed fixture, but is only controlled by periodic occupancy sensors and is non-dimming. All luminaires in both the corridor and the student study area perform with T8 lamps. The redesign will be governed by the following goals:

a. Visual separation of corridor and study area through luminaire applications
b. Daylight integration in both dimming and automatic shading
c. Energy responsibility by complying with appropriate energy codes

Offices appear throughout the Millennium Science Complex around the perimeter of each wing. The specific office being examined for redesign is a “Distinguished Office” on the third floor located on the south side of the Material Science wing. The existing lighting delivery system is the same as the student study areas – 1x4 recessed luminaires through the center of the room. The redesign was originally intended to utilize integrated chilled beam lamping, but was abandoned when lighting integrated chilled beams were found to be non-ideal for KGB Maser’s mechanical system design goals. The redesign now involves new recessed fixtures to blend with chilled beam aesthetics. Secondary to overhead lighting is the addition of washing luminance balance between the window wall and corridor wall and book shelf task lighting delivery.

The final space that will be redesigned for lighting has two major purposes for the Millennium Science Complex – an architectural statement and pedestrian control. The over 150-foot cantilever provides a unique architectural interest and is designed to help isolate the nanotechnology labs below from the building vibrations. To achieve the latter design goal, the structure of the building had to be oversized three-fold to absorb vibrations. The structural redesign involves adding support to the cantilever and wrapping the structure in a steel sculpture. By boxing out the cantilever light well, the courtyard landscape becomes inaccessible to pedestrians and protects the nano-technology labs below. The lighting redesign for this space has been limited to the steel sculpture and pathways outside the entrance canopies that fall in the building footprint. To emphasize the grand nature of the sculpture, recessed lighting along the perimeter of the sculpture will both graze the steel and wash the underside of the cantilever.

Each design section hereafter will include applicable design criteria, space properties, a discussion of lighting gear used, and a discussion on the space’s ultimate performance in the redesign.

EXISTING CONDITIONS REVIEW

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

Perimeter study areas are controlled by EcoSystem ballasts, daylight sensors, and occupancy sensors. There is currently no task lighting within these spaces. The rows of computer desks are open to the corridor and all overhead lighting is recessed 1x4 fluorescent luminaires.

Offices contain the same recessed 1x4 luminaires as the corridors and student study areas, but are not connected to a smart dimming system. With the exception of few “distinguished” offices, additional task lighting will be up to the end user to provide.

The space beneath the cantilever houses a serpentine pathway that is lighted by various heights and styles of landscape and area lighting. The luminaires include the Penn State campus standard Louis Poulsen Kipp Post design for surrounding pathways. All existing light delivery within this space is high intensity discharge metal halide lamping ranging from 39W to 100W depending upon mounting height within the cantilever soffit.

SPACE 1: STUDENT STUDY AREA

Study areas are located throughout the perimeter of each floor in the Millennium Science Complex. These areas are workstations for occupants of the building and can be accessed directly from perimeter corridors. Primary tasks in these areas include computer usage, reading, and writing tasks. Additionally, study areas interact with large windows perpendicular to workstations. Sunlight penetration is both beneficial and detrimental to occupants. Psychological benefits and reduced energy usage are available; however, too much daylight will cause occupants to become uncomfortable within the space.

Located in the study area are five rows of computer work stations. The stations are divided by partitions that have been redesigned to reach 4’-0” above finished floor to allow for less shading between rows of computers. As part of KGB Maser’s IPD/BIM initiative, plans shown will be from the team central modeling file.

FLOOR PLAN

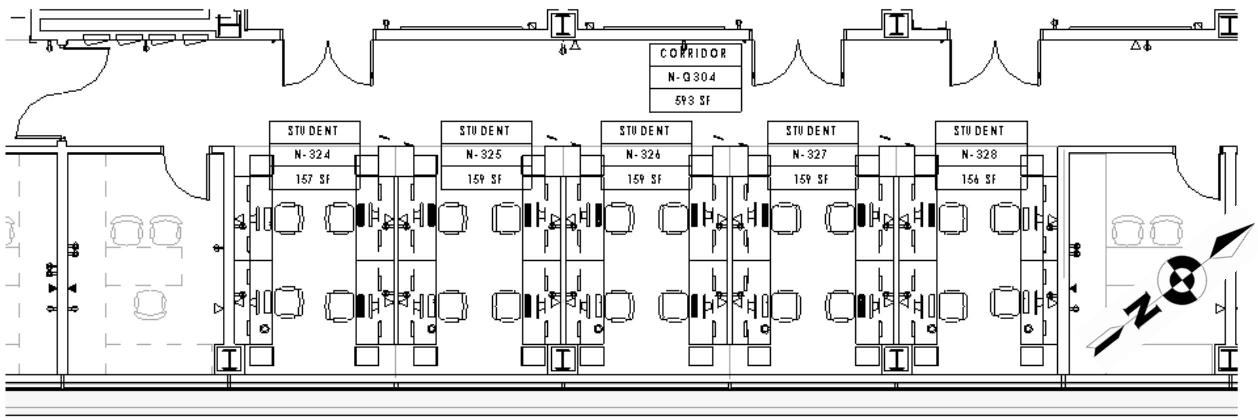


Figure 3.1: Student Study Area Floor Plan, NTS, from KGB Maser Central Revit model

ROOM SURFACE MATERIALS

The table below lists the various reflectances in use in this space.

Surface	Material Description	Reflectance	Specification
East Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
West Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
North Wall	Painted GWB – Benjamin Moore 2111-60 Barren Plain, eggshell (Corridor)	0.60	09900
South Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
Ceiling	Armstrong ACT Ultima HRC Beveled Tegular	0.74	09500
Floor	Mannington Solidpoint VCT 12"x12" in 341 Cameo White (Corridor) J&J Commercial/Invision Altered Elements Weathered Steel Modular 333 Iron Carpet (Student Study)	0.70 0.16	09685
Glazing Redesign	Viracon VNE 13-63 insulating laminated glass with low-e coating on surface #2 VLT = 0.66 Uwinter= 0.29 UVT < 0.01 Usummer= 0.26 SHGC = 0.29 SC = 0.33 LSG = 2.24	0.10	N/A
Desk Partitions	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
Desk Surfaces	Oak table – assumed	0.22	N/A

FURNITURE DESCRIPTION

The furniture in the student study area is comprised of various elements producing a two-shelf system to support computer stations. Figures 3.2 and 3.3 below illustrate the geometry of the workstations.

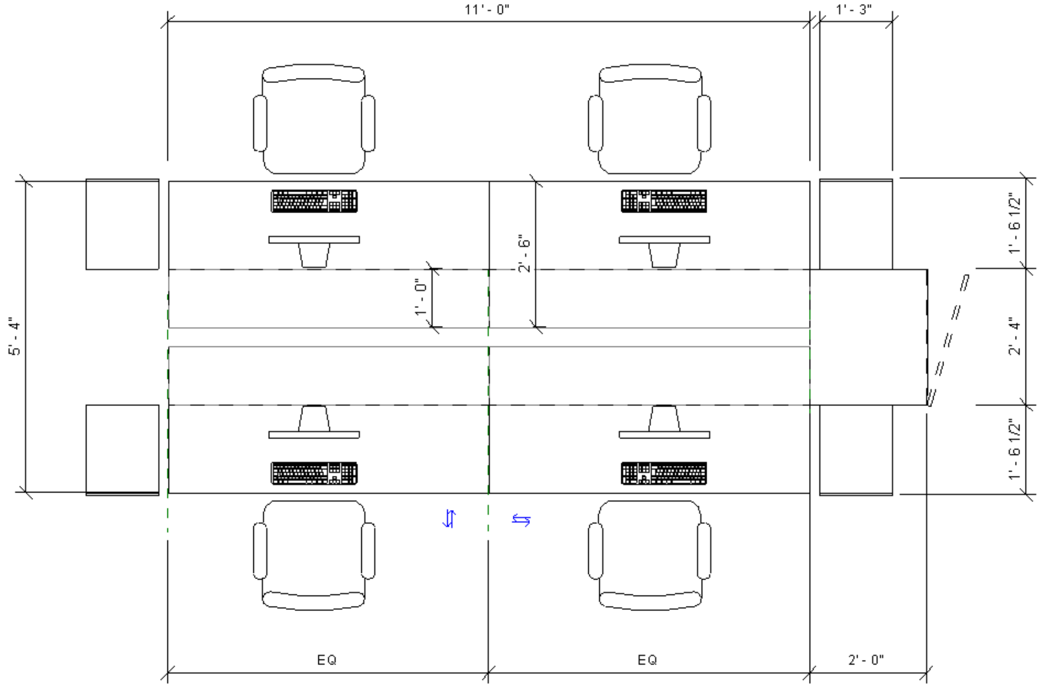


Figure 3.2: Typical Workstation in Plan View, NTS, from KGB Maser Revit Desk Family

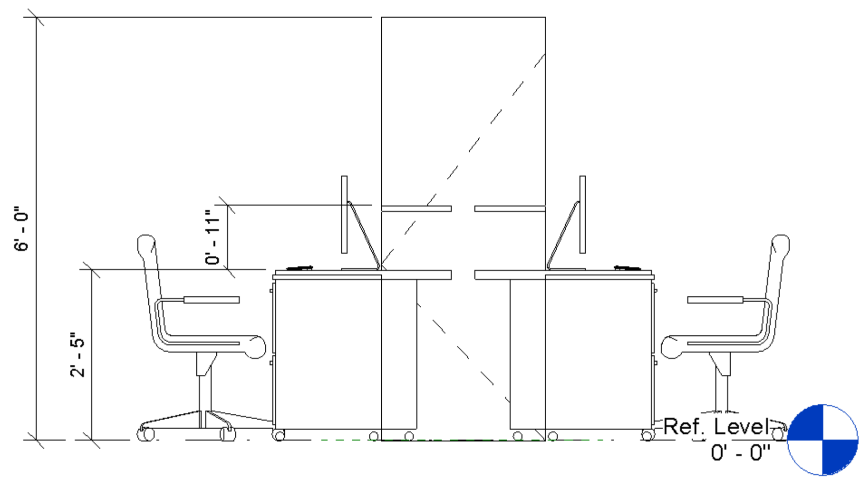


Figure 3.3: Typical Workstation in Elevation View, NTS, from KGB Maser Revit Desk Family

TASKS AND ACTIVITIES

This particular area of the Millennium Science Complex is unique in that there are two distinct areas that share a "wall," but there is no physical barrier. Therefore, tasks in this area are dual natured. At any given time, an occupant may be working at a computer station transferring notes from his or her laboratory report to a word processing engine while researchers are walking by in the corridor. Though this space is mostly computer work, the latter activity must be addressed due to the absence of a physical barrier between the two spaces.

DESIGN CRITERIA

Corridors and study areas individually are relatively straight forward to design, but when they are coupled without a barrier, the design is more complicated. Corridor spaces only require five footcandles of illuminance, yet in this application they are adjacent to study spaces requiring thirty to fifty footcandles for various tasks. Light falling on the corridor from the study areas will easily meet this illuminance. Design criteria in this section have been researched in the IESNA Lighting Handbook.

Corridor Design Criteria

Shadow Avoidance — 5fc horizontal illuminance

Navigating corridors is a simple task. Occupants only need to know if they will come into contact with any obstructions in their path. Visually, shadows cast across the floor – in this case from workstations and cabinetry – will cause pedestrians to take notice of the lighting in the space. To be considered successful, a lighting design must be uniform.

Study Area Design Criteria

Reading Tasks — 30-50fc horizontal illuminance

Reading tasks in the study area vary depending on the task medium. Users may be reading from notes written in #2 pencils, pens, or printed on a variety of colored papers. Higher illuminance values allow for faster and more accurate deciphering of reading material. Increased illuminance values may be provided by a task-ambient design in which overhead lighting provides minimum light to the task plane while task-specific lighting boosts illuminance on the task surface.

Lobbies, Lounges, and Reception Areas — 10fc horizontal illuminance

In the office section of the IESNA Lighting Handbook design guide, a specific line is devoted to lounges. The largest concern in these types of spaces is the appearance of the space and the luminaires. The design should be uniform, even a repeating pattern, so as to not distract users of the space.

Visual Display Terminals (VDT) — 3fc horizontal illuminance

In older interpretations of design criteria, direct and reflected glare are large concerns when dealing with computer screens. With the advent of flat screen monitors – usually with plasma or liquid crystal display – glare is no longer a large concern.

Luminance Ratios

Paper to VDT:	3:1 / 1:3
Task to Adjacent Surroundings:	3:1 / 1:3
Task to Remote Surfaces:	10:1 / 1:10

REDESIGN PLANS, SECTIONS, ELEVATIONS

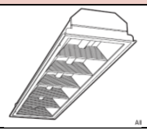
For the following plans, sections, and elevations, see Appendix 3.B:

A101 – Student Area Floor Plan and Section

LE101 – Student Area Lighting Layout and Section

LUMINAIRE SCHEDULE

For luminaire, lamps, and ballast manufacturer cut sheets, see Appendix 3.C.

Student Study Area and Corridor Luminaire Schedule									
Tag	Image	Manufac.	Product	Catalog No.	Description	Lamp	Input Watts	Voltage	Ballast
C-1		Lithonia Lighting	ES8	ES8P-132-277-(Ballast)-L841HT8	Recessed linear fluorescent troffer luminaire with specular baffles; sized to fit within 1'x4' acoustical ceiling grid	(1) FO32/841/XP/ECO Osram Sylvania	32	277	VEL-1P32-SC Philips Advance
S-1		LiteControl	SD^{X}	P-S/D-1824T8-BW-CWM-(Ballast)-277	Semi-direct pendant fixture mounted 2'-0" below ceiling surface; matte white finish with baffles; total linear system 8'-0" nominal; additional end cap to allow for occupancy sensor mount	(2) FO32/841/XP/ECO Osram Sylvania	65.7	277	H3D-T832-C-U-2-10 Lutron
T-1		Philips Alkco	Aris	ARIS-11-40-120-PRL-DWC	Low profile LED surface mounted luminaire; integral switch; 4000K; mounting under top shelf of desk	4000K LED integral to fixture	6	120	N/A

CONTROL EQUIPMENT SCHEDULE

For control equipment cut sheets, see Appendix 3.C. For wiring diagrams, see "Dimming and Wiring Diagrams" in the electrical portion of this document. The Lutron EcoSystem lighting control option allows for integration of both daylight and occupancy sensors. The existing perimeter spaces utilize this system and the redesign would most benefit from using the system also. The corridor lighting will be connected to the existing sensors.

Study Area and Corridor Control Equipment Schedule					
Tag	Image	Manufac.	Product	Catalog No.	Description
DS		Lutron	Wired Daylight Sensor	C-SR-M1-WH	Wired daylight sensor compatible with Lutron Ecosystem; ceiling mounted between rows of pendant luminaires
ES		Lutron	EcoSystem EnergiSavr Node	QSN-4S16-S	Addressable lighting control unit to setup at least three lighting zones, three occupancy/vacancy sensors, and two daylight sensors; 277V control operating capability

Study Area and Corridor Control Equipment Schedule (Continued)					
Tag	Image	Manufac.	Product	Catalog No.	Description
LOSH		Lutron	Infrared Wall-Mount Occupancy Sensor	LOS-WIR-WH	Wall-mounted passive infrared occupancy/vacancy sensor with 90-110° coverage mounted to view into the study area; apply enough sensors to control entire study area pendant fixtures at 277V
LOSL		Lutron	Infrared Wall-Mount Occupancy Sensor	LOS-WIR-WH	Wall-mounted passive infrared occupancy/vacancy sensor with 90-110° coverage mounted to view into the study area from back of cabinets; apply enough sensors to cover study area for switching task lighting at 120V
PPH		Lutron	PP Series Power Pack	PP-277H	24V power pack to power occupancy sensors at 277V
PPL		Lutron	PP Series Power Pack	PP-120H	24V power pack to power occupancy sensors at 120V
SM		Lutron	QS Sensor Module	QSMX-4W-C	EcoSystem compatible sensor module; non-radio frequency

The coverage areas of the occupancy sensors can be seen in the figures below:

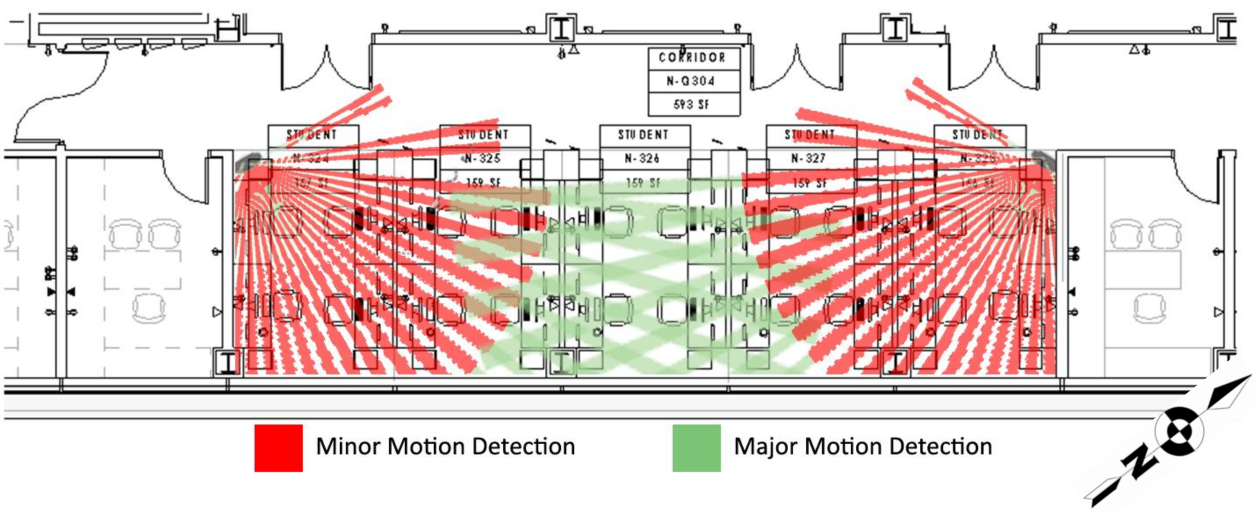


Figure 3.4: Study Area Overhead Lighting Occupancy Sensor Coverage, NTS

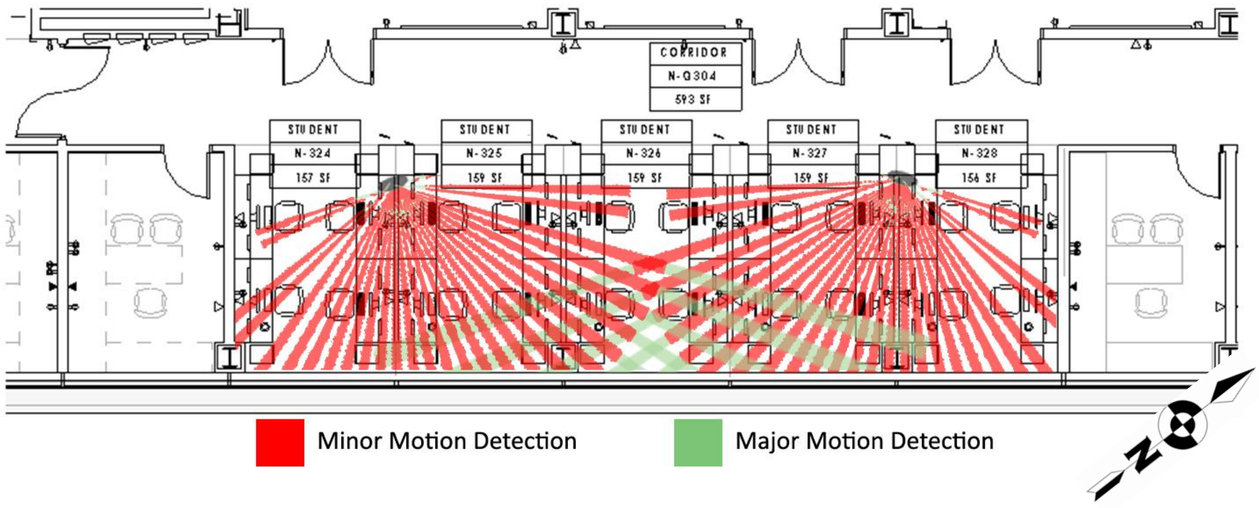


Figure 3.5: Study Area Task Light Occupancy Sensor Coverage, NTS

For a detailed discussion on how the presented control equipment will operate within the space, see the "Control Descriptions" section of the electrical portion of this document.

SHADING DEVICES AND DELIVERY

For a more in-depth description of the overhang selection, see Unit 1 of this document. Normally, roller shades are operated in a top-down configuration. As discussed in said section of this document, bottom-up roller shades allow for more ambient light and ground reflectance to enter the space. With an appropriate openness factor and interior shade color, occupants are able to see out of the space without blinding sunlight entering the space.

Study Area Shading Equipment Schedule				
Tag	Manufac.	Product	Catalog No.	Description
MS	MechoShade	FTS Electro Bottom-Up Shade	Unavailable	Bottom-up, sill-mounted shading system; 11'-0" nominal length of units; two motors; modified guide cable to allow for two shade roller mounts; top pulley recessed into ceiling cavity; two hembar attachments; second shade mounting half distance to ceiling with non-motor return roll; 10% openness factor shade cloth; light gray color
SSC	MechoShade	SolarTrac Automation System	Unavailable	Integrated roof-mounted radiometers to override shade position when in absence of daylight; minimum 5 shade positions; programmable computer simulation program and interface

The overall goal of the shading delivery is to block direct sunlight in both upper glazing and lower glazing. To accomplish this goal, the overhang delivery discussed in Unit 1 of this document must bisect the exterior glazing. By dividing the glazing in two sections with the same height, only one motor is needed to control two levels of shades. Each section then has the same path distance to cover the same profile angle penetrations. As specified in the table above, the shading automation system will be programmed to handle ranges of profile angles according to the façade orientation. The associated profile angles by façade can be seen in Figure 3.6 below. The MechoShade SolarTrac system can be programmed to account for each façade individually with sensor override for overcast conditions. In cloudy scenarios, the shades will be returned to the "off" position. When the sensor is active, then each façade can be programmed to the appropriate shade height according to the computer.

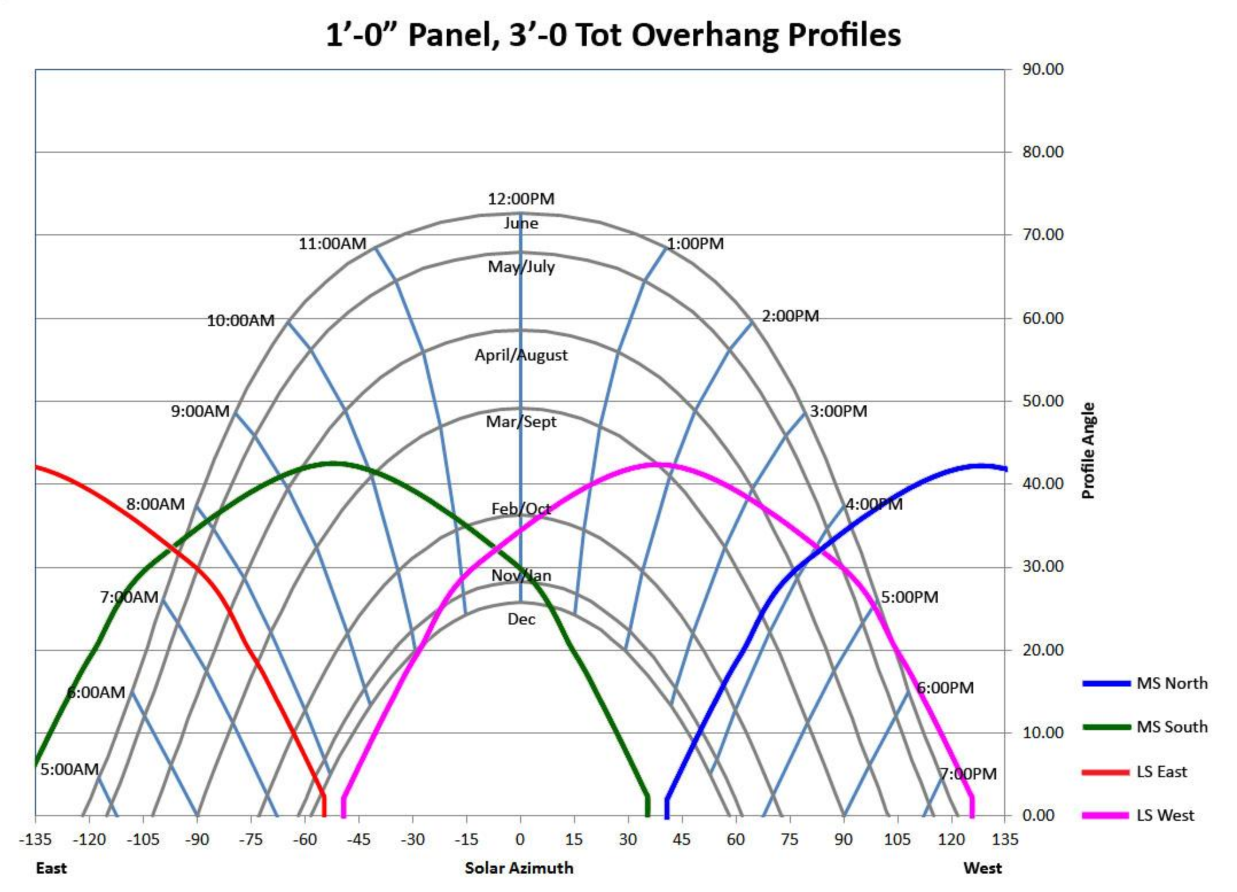


Figure 3.6: Profile Angles by Façade

PERFORMANCE DATA

The table below summarizes light loss factors used in illuminance calculations for the student study area. The Millennium Science Complex is assumed to be a clean environment, yet luminaires will not be actively cleaned very often (maximum allowable by IES standards).

Student Area Light Loss Factors				
Mark	Ballast Factor	Lamp Lumen Depreciation	Luminaire Dirt Depreciation	Total Light Loss Factor
C-1	0.92	0.95	0.88	0.77
S-1	1.0	0.95	0.88	0.84
T-1	1.0	1.0	0.88	0.88

The following figures illustrate light distribution compliance for student area design criteria discussed previously. Models for analysis were exported from AutoDesk Revit Architecture in drawing formats associated with acceptable geometry import into AGI32. For a further discussion on the BIM related model sharing, see Unit 1 of this document.

Figure 3.7: Student Area Rendering (top) and Exterior Render into Study Area (bottom)

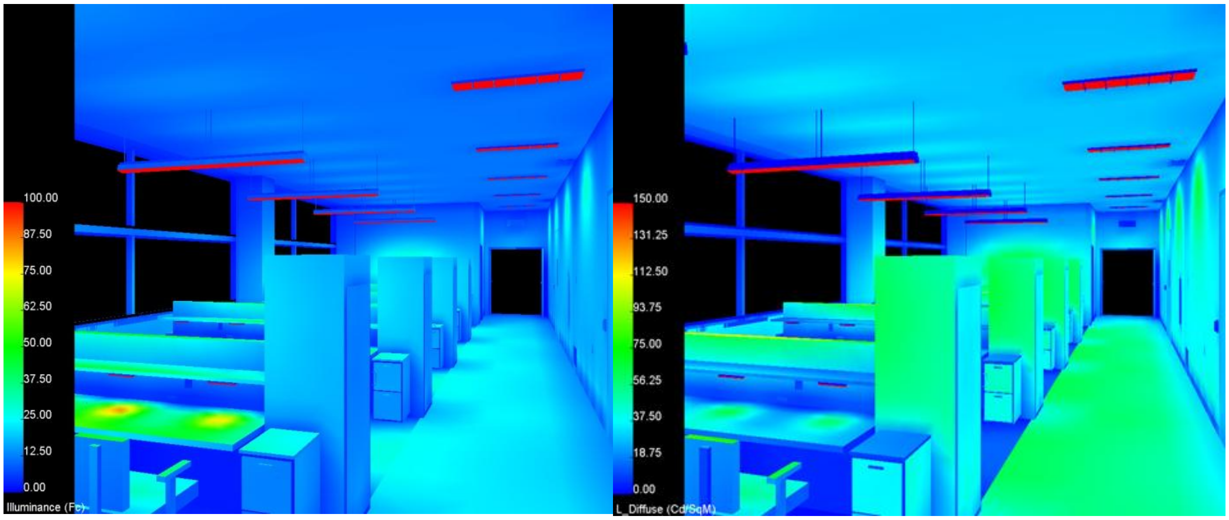


Figure 3.8: Illuminance, fc, Pseudo Color Image (left) and Luminance, cd/m^2, Pseudo Color Image (right)

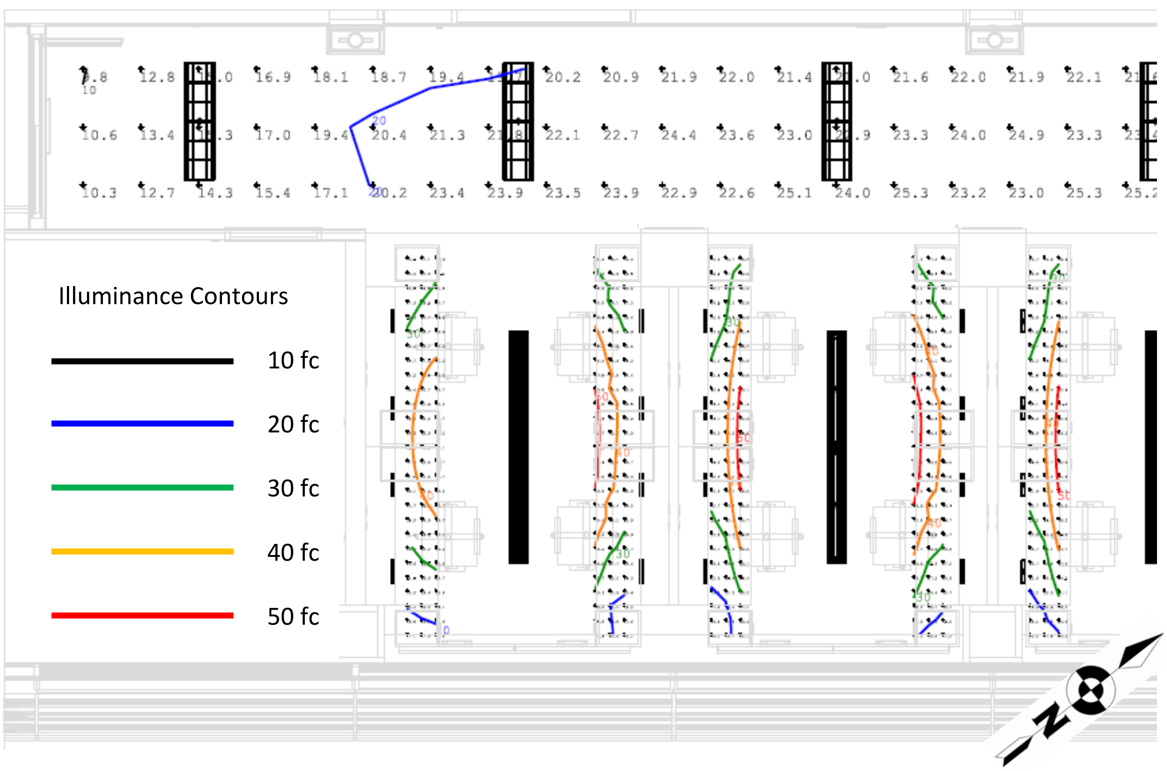


Figure 3.9: West Portion of Student Study Area Illuminance Contours (fc), plan NTS

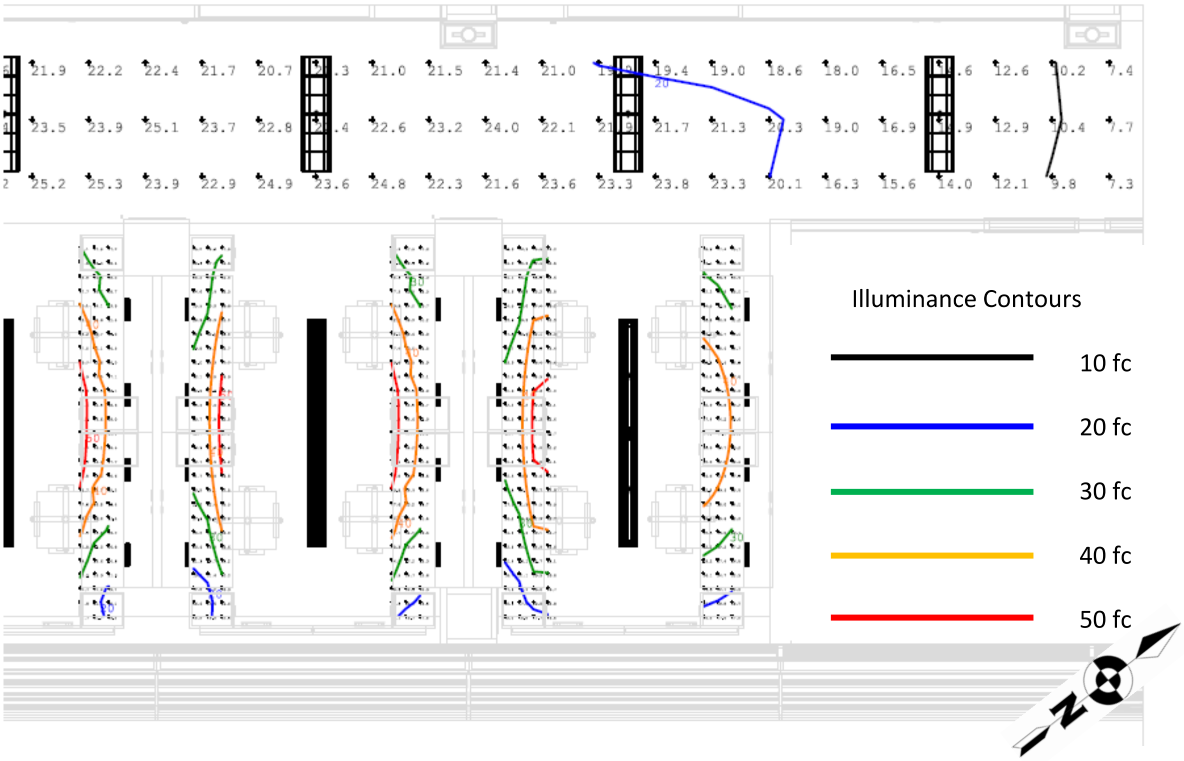


Figure 3.10: East Portion of Student Area Illuminance Contours (fc), plan NTS

ASHRAE Standard 90.1 Compliance

Space	Area (ft^2)	Allowable LPD (W/ft^2)	Allowable Power (W)	Total Power Used (W)	Actual LPD (W/ft^2)
Study Area	825.0	1.2	990.0	657.0	0.796
Corridor	657.9	0.5	329.0	224.0	0.681*

Illuminance Summary Table

Study Area Illuminance Summary						
Space	Illuminance (fc)			Max./Min.	Coeff. Of Variation	Uniformity Gradient
	Min.	Avg.	Max.			
Study Area Only	9.0	36.5	106.0*	11.73	0.47	2.47
Corridor Only	4.5	9.36	10.8	2.40	0.15	1.31
Student Area Combined	15.0	34.3	55.0	3.67	0.27	1.42
Corridor Combined	7.3	20.0	25.3	3.47	0.23	1.38

General ambient light for the tasks in both the student study area and the corridor are provided by the overhead luminaires. Examining each of the aforementioned design criteria and Figures 3.7 and 3.8 above, the performance of the design can be qualitatively and quantitatively judged:

Corridor Area

Shadow Avoidance

The linear recessed corridor lights in conjunction with the pendant luminaires in the study area diminish shadowing from tall cabinets. There is only a few footcandles difference in illuminance between the center of the hallway and at the cabinet's base.

Student Study Areas

Reading Tasks

All tasks related to paper and pencil are most likely to be occurring at the desk plane. The combination of pendant fixtures and under-shelf task lights provides between 15 and 55 footcandles of illuminance. The former value may be dismissed as it is beyond the usable area under the upper shelf of the workstations. The design criteria called for 30 to 50 footcandles and with an average of 34.3 footcandles on the desk plane, this application can be considered a success.

Lobbies, Lounges and Reception Areas

The illuminance value in this design criteria section applies to only lobbies, lounges, and reception areas. Of the most importance with respect to this section of design criteria is the appearance of the space and luminaires. The redesign achieves this goal on two levels – it separates to different open spaces with an imagined ceiling and keeps uniform layout and illuminance between rows of workstations. By suspending study area luminaires 2'-0" from the ceiling finish, a second "ceiling" is created in the visual environment. Occupants walking by the student area can see from down the hall that a peripheral, lower zone is in the area. The redesign achieves appropriate appearance of luminaires by keeping uniform spacing and alignment of luminaires between the corridor and study area. Though mounted below the ceiling height, the study area luminaires appear on the same sight line as corridor lights as viewed from the exterior of the building.

Visual Display Terminals (VDT)

As discussed in the design criteria section of this space, computer screens have advanced to be a non-issue with respect to light interaction. The user is able to tilt screens that may experience blurring of screen images due to overhead lighting. Given the nature of screen materials themselves, VDTs are of no concern in the redesign.

Luminance Ratios

The luminance pseudo color image in Figure 3.5 illustrates brightness that users will experience within the redesigned space. Task areas beneath shelving – illuminated by the LED strip luminaires – is approximately 50 to 70 candelas per square meter. Near surfaces such as cabinet tops and upper shelves are in the 15 to 20 candelas per square meter range. The remote surfaces within the space that are visible to occupants, such as far walls, are near or below 10 candelas per square meter. These scenarios satisfy the initial design criteria presented.

In conclusion, this space has achieved its design goals. Automatic shading in perimeter public spaces, such as the student area, provides daylight control without user interference. The automatic shading system in combination with dimming control systems allows for decreased energy usage. Task and ambient applications give users flexibility with light levels at the desk plane. The space is noticeably separated from the corridor due to the application of suspended luminaires over the student area, thus showing occupants that there are two distinct spaces present.

SPACE 2: DISTINGUISHED PERSONNEL OFFICE

Also located throughout the perimeter of the Millennium Science Complex, the offices provide occupants with a connection to the exterior environment through daylighting. Primary tasks in these areas include computer usage, reading, and writing tasks. As with study areas, the offices interact with large windows, but the orientation of the room puts the windows at the back of the occupant. This orientation may be a nuisance when working with computers. Sunlight penetration is both beneficial and detrimental to occupants. Psychological benefits and reduced energy usage are available; however, too much daylight will cause occupants to become uncomfortable within the space. The shading delivery will be user-controlled to allow for occupant-specific daylighting.

Also located within the perimeter offices are desks, tables, and shelves. The shelves will be lighted to accommodate reading tasks in the vertical plane. With the available daylight, the wall opposite the windows may need to be washed to balance luminance levels of surfaces in the room. As part of KGB Maser's IPD/BIM initiative, plans shown will be from the team central modeling file.

FLOOR PLAN

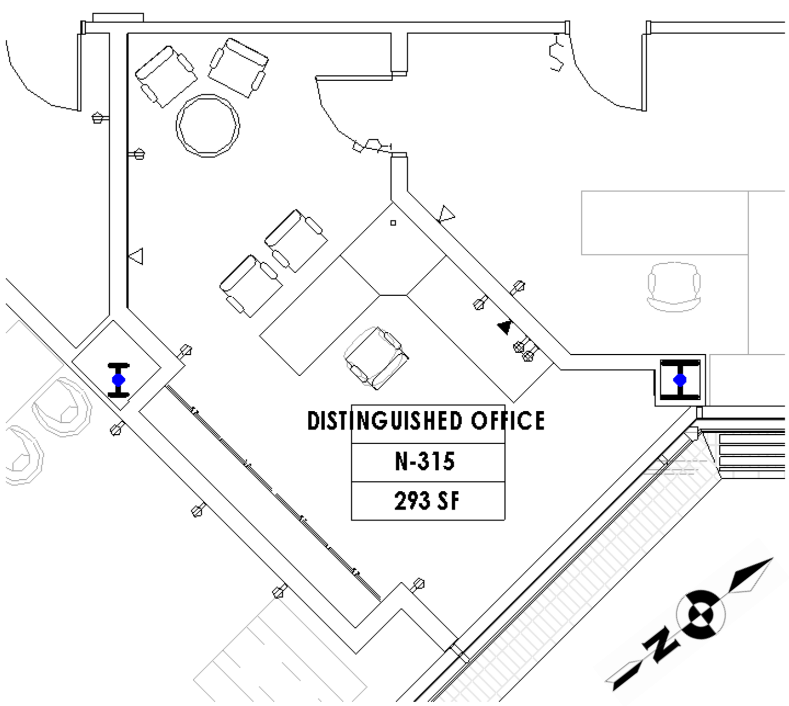


Figure 3.11: Distinguished Office Floor Plan, NTS, from KGB Maser Central Revit Model

ROOM SURFACE MATERIALS

The table below lists the various reflectances in use in this space.

Surface	Material Description	Reflectance	Specification
East Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
West Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
North Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
South Wall	Painted GWB – Benjamin Moore OC-26 Silver Satin, eggshell	0.76	09900
Ceiling	Armstrong ACT Ultima HRC Beveled Tegular	0.74	09500
Floor	J&J Commercial/Invision Altered Elements Weathered Steel Modular 337 Ore Carpet	0.35	09685
Glazing Redesign	Viracon VNE 13-63 insulating laminated glass with low-e coating on surface #2 VLT = 0.66 Uwinter= 0.29 UVT < 0.01 Usummer= 0.26 SHGC = 0.29 SC = 0.33 LSG = 2.24	0.10	N/A
Cove Base	Johnsonite 4" vinyl base color 179 steel	0.75	09900
Desk Surfaces	Oak table – assumed	0.22	N/A
Shelving	Oak finish – assumed	0.22	N/A

FURNITURE DESCRIPTION

Furniture within the space includes a large cornered desk that orients the occupant with his or her back to the large window wall. There may be up to five office chairs within the space – one for the room "owner," two for meetings with the owner, and two for users waiting around the small table in the corner. Located within a wall nook is a set of shelves and cabinets. Books, binders, and objects may be stored on these shelves at any time. Overall, the furniture layout and use is very simple, thus the lighting will be simple to address the tasks within the space.

TASKS AND ACTIVITIES

The tasks and activities within the offices are very straight forward. Occupants will be reading, writing, and using computers to communicate their research. Since this is a graduate level research building, there may be professors grading assignments, lab notebooks, and exams within their offices. Other than these reading specific tasks and activities, offices may be used for meetings with students. The professors within the office must be able to see their guests with appropriate facial coloring and with little shadowing of facial features.

DESIGN CRITERIA

General Office Criteria

Filing 10 fc vertical

Filing activities in the office will be confined mostly to the recessed shelving area. The occupant will be storing books, binders, and other reading material on shelving above cabinets in this area. There are no cabinet tops that would benefit from higher light levels for reading tasks. The vertical task plane is at the face of the shelving. The user must be able to discern which material he or she is looking for before pulling it out to read. Thus the vertical face of the shelving will need to be at the suggested 10 fc illuminance.

Private Offices 30-50 fc horizontal, 5 fc vertical

Of utmost importance within the office is the ability to integrate and control the room light in reaction to daylight. The personnel in the distinguished office have the most interaction with daylight due to the room's location on the perimeter. As these offices are private in nature, an automatic shading and dimming system may not be the best solution since different people tolerate different levels of daylight. The second concern is of glare. Although the use of flat screen monitors has diminished the worry of glare on screens, the large window wall may cause screens to be washed out if too much light falls on the screen. The user will need to be able to control both the electric lighting and daylight delivery to account for the possibility of the screen being washed by too much light. This control aspect also plays into the importance of luminance on various room surfaces. As in the description above, wall washing or grazing will be applied to the wall opposite the window wall. This will balance luminance levels within the space and to keep the occupant's eyes from being drawn away from the task at hand.

Reading Tasks

Paper Tasks 30-50fc horizontal illuminance

Reading tasks in the study area vary depending on the task medium. Users may be reading from notes written in #2 pencils, pens, or printed on a variety of colored papers. Higher illuminance values allow for faster and more accurate deciphering of reading material. Increased illuminance values may be provided by a task-ambient design in which overhead lighting provides minimum light to the task plane while task-specific lighting boosts illuminance on the task surface.

Visual Display Terminals (VDT) 3fc horizontal illuminance

In older interpretations of design criteria, direct and reflected glare are large concerns when dealing with computer screens. With the advent of flat screen monitors – usually with plasma or liquid crystal display – glare is no longer a large concern.

Luminance Ratios

Paper to VDT:	3:1 / 1:3
Task to Adjacent Surroundings:	3:1 / 1:3
Task to Remote Surfaces:	10:1 / 1:10

REDESIGN PLANS, SECTIONS, AND ELEVATIONS

For the following plans, sections, and elevations, see Appendix 3.B:

A102 – Office Area Floor Plan and Section
LE102 – Office Area Lighting Layout Plan and Section

LUMINAIRE SCHEDULE

For luminaire, lamps, and ballast manufacturer cut sheets, see Appendix 3.C.

Office Luminaire Schedule									
Tag	Image	Manufac.	Product	Catalog No.	Description	Lamp	Input Watts	Voltage	Ballast
O-1		LiteControl	Mod-66	LG-D-66N-2-4-T8-FP-CWM-IND-ECO/ELB-277	Lay-in grid recessed luminaire to be combined with custom edges to mimic chilled beams; manual dimming capabilities; total assembly to occupy one 1x4 section of ACT grid	(2) F032/841 /XP/ECO Osram Sylvania	65.7	277	H3D T832 C U 2 10 Lutron
OS-1		LiteControl	Mod-66 Chalkboard	W-ADW-66N-1-8-T8-6044-CWM - -ELB--277	Chalkboard luminaire mounted on interior of shelf nook bulkhead; mounted to throw light on shelves; space evenly on bulkhead	(1) F096/841 /XP/ECO Osram Sylvania	70	277	VEL-2P59-SC Philips Advance
WW-1		LiteControl	Mod^2 Recessed Wall Wash	LG-WWD-44-1-8-T5HO--CWM-IND-LP/ELB-277	Linear recessed wall wash luminaire; mounted 3'-0" from face of wall	(1) FP54/841 /HO/ECO Osram Sylvania	62	277	ICN4S5490C2LS@277 Philips Advance

CONTROL EQUIPMENT

For control equipment cut sheets, see Appendix 3.C. For wiring diagrams, see "Dimming and Wiring Diagrams" in the electrical portion of this document.

Office Control Equipment Schedule					
Tag	Image	Manufac.	Product	Catalog No.	Description
ODS		Lutron	Skylark dimmer switch	SF-12P-277-3-GR	Three-way combination on/off/dim switch; located near office desk for occupant to dim lighting while at desk; gray finish to match OOS switch; mounted 3'-6" AFF
OOS		Watt Stopper	DW-200 Wall Switch Sensor	DW-200-G	Multi-load wall box mounted combination PIR and ultrasonic vacancy sensor with two-level switching; must be able to switch two loads – overhead lighting and shelf lighting; located at 4'-0" AFF at office entry door

For a detailed discussion on how the presented control equipment will operate within the space, see the "Control Descriptions" section of the electrical portion of this document.

Occupancy passive infrared sensor coverage can be seen in the figures below:

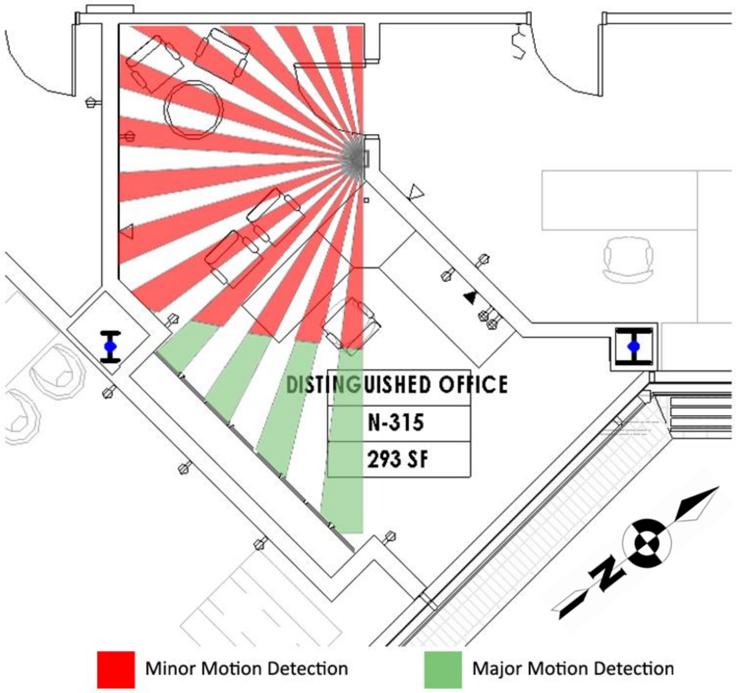


Figure 3.12: Office Lighting Occupancy Sensor Coverage

SHADING DEVICES

The shading devices for office areas throughout the Millennium Science Complex utilize the same equipment as seen in "Space 1: Student Study Area" of this unit. There is one change to the design – the office shading system will be controlled by the occupant. The change in equipment can be seen in the table below:

Office Shading Equipment Schedule				
Tag	Manufac.	Product	Catalog No.	Description
MS	MechoShade	FTS Electro Bottom-Up Shade	Unavailable	Bottom-up, sill-mounted shading system; 11'-0" nominal length of units; two motors; modified guide cable to allow for two shade roller mounts; top pulley recessed into ceiling cavity; two hembar attachments; second shade mounting half distance to ceiling with non-motor return roll; 10% openness factor shade cloth; light gray color
MC	Unknown	Unknown	Unavailable	Wall-mounted switch hard-wired to the shade motor; controls include "up," "center off," and "down"; mounted within 5'-0" laterally from exterior window and 3'-6" AFF

PERFORMANCE DATA

The table below summarizes light loss factors used in illuminance calculations for the offices. The Millennium Science Complex is assumed to be a clean environment, yet luminaires will not be actively cleaned very often (maximum allowable by IES standards).

Office Light Loss Factors				
Mark	Ballast Factor	Lamp Lumen Depreciation	Luminaire Dirt Depreciation	Total Light Loss Factor
O-1	1.0	0.95	0.88	0.84
OS-1	1.10	0.95	0.88	0.74
WW-1L(R)	0.99	0.93	0.88	0.81

The following figures illustrate light distribution compliance for office design criteria discussed previously. Models for analysis were exported from AutoDesk Revit Architecture in drawing formats associated with acceptable geometry import into AGI32. The renderings were completed using file sharing between AutoDesk Revit Architecture and AutoDesk 3D Studio Max Design as discussed in “Model Sharing Between Revit and 3D Studio Max” of Unit 1 of this document.

Figure 3.13: Office Rendering from Revit Architecture (left) and AGI32 (right)

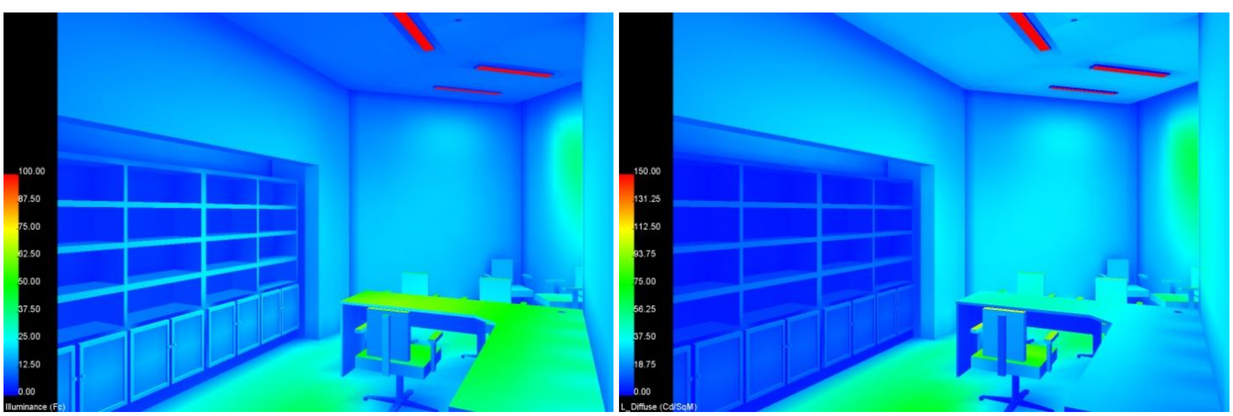


Figure 3.14: Office Illuminance, fc, Pseudo Color Image (left) and Luminance, cd/m2, Pseudo Color Image (right)

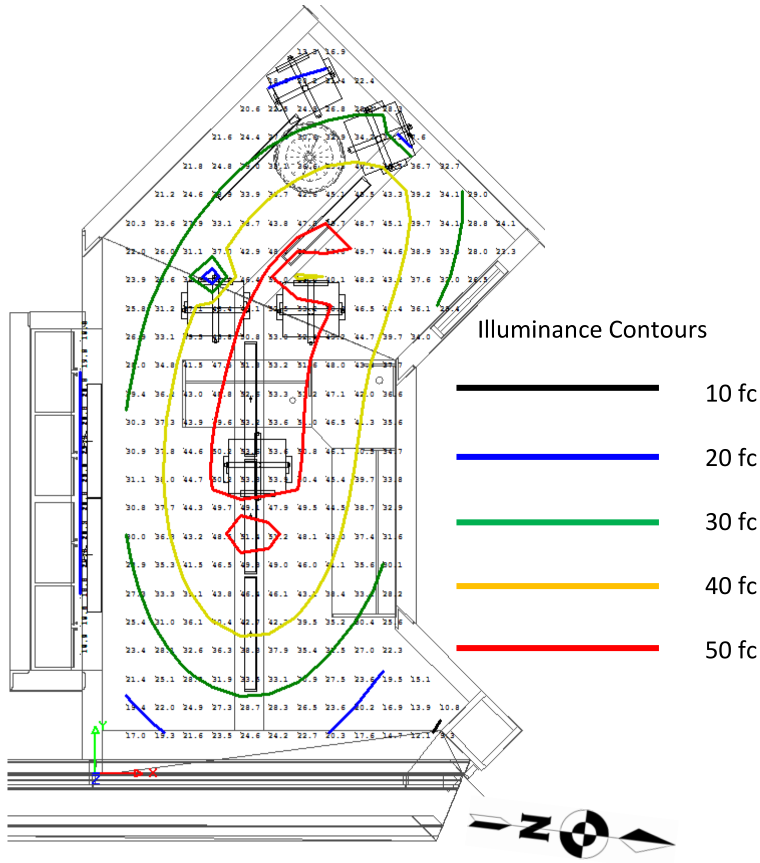


Figure 3.15: Office Plan Illuminance Contours, plan NTS

ASHRAE Standard 90.1 Compliance

Lighting Type	Area (ft^2)	Allowable LPD (W/ft^2)	Allowable Power (W)	Total Power Used (W)	Actual LPD (W/ft^2)
Office General	262.38	1.1	288.61	262.8	1.00
Decorative	262.38	1.0	262.38	132	0.50

Illuminance Summary Table

Office Illuminance Summary						
Calculation Grid	Illuminance (fc)			Max./Min.	Coeff. Of Variation	Uniformity Gradient
	Min.	Avg.	Max.			
Horizontal Task	7.60	35.75	53.90	7.09	0.31	4.83
Vertical at Shelves	14.9	19.36	22.10	1.48	0.10	1.17

General ambient light for the desk tasks is provided by the lay-in-grid overhead luminaires. Examining each of the aforementioned design criteria and Figures 3.13, 3.14 and 3.15 above, the performance of the design can be qualitatively and quantitatively judged:

General Office Criteria

Filing — 10 fc vertical

Filing activities receive plenty of light from the "chalkboard" luminaire – 19.36 fc average. This illuminance level is plenty to perform the simple tasks associated with the shelving. With the shelf illuminance up to its current level and the load being considered decorative lighting by ASHRAE Standard 90.1, the application of the chalkboard luminaire for grazing the shelving is considered a successful design.

Private Offices — 30-50 fc horizontal, 5 fc vertical

As mentioned previously, high importance within the office is placed on the ability to integrate and control the room light in reaction to daylight. For a more in-depth description on the lighting and daylight controls in the office, see the "Control Descriptions" section of the electrical section in this unit. The wall washing that has been applied to the wall opposite the window wall has proven to be both uniform and sufficient in the 20 fc range as seen in Figure 3.15. This has balanced luminance levels within the space well, seen in Figure 3.14. The private office design can be considered successful.

Reading Tasks

Paper Tasks — 30-50fc horizontal illuminance

The paper-related tasks will be occurring at the professor's desk. The recessed overhead luminaires supply between 7 and 54 footcandles of illuminance. Looking closer at the illuminance spread for the horizontal task plane, the bulk of the usable calculation points are between 30 and 54 footcandles. The lower values occur around the perimeter and corners of the space. The design criteria called for 30 to 50 footcandles and with an average of 35.75 footcandles on the desk plane, this application can be considered a success.

Visual Display Terminals (VDT) — 3fc horizontal illuminance

As discussed in the design criteria section of this space, computer screens have advanced to be a non-issue with respect to light interaction. The user is able to tilt screens that may experience blurring of screen images due to overhead lighting. Given the nature of screen materials themselves, VDTs are of no concern in the redesign.

In conclusion, the office lighting design has passed all design criteria tests presented. The overhead lights provide sufficient and uniform light to the desk task plane, the wall washing application balances luminance on the blank wall opposite the window wall, and the chalkboard luminaire provides ample visibility for the shelving unit. The control of electric light and daylight delivery, which will be seen in the electrical portion of this unit, will provide control to suit the occupant's need.

SPACE 3: CANTILEVER COURTYARD

A very large and important feature of the Millennium Science Complex is the 150-foot-plus cantilever that combines the Material Science and Life Science wings. In both the existing design and KGB Maser's redesign, the cantilever courtyard area is a focal point for pedestrians and for a statement of the building's architecture. The primary focus will be the newly designed steel support and sculpture that rises into the light well of the cantilever. The lobby and entry lighting will remain as existing design.

The structural redesign holds three purposes – to keep foot traffic off of the vibration-sensitive laboratories below, reduce the need of very oversized members in the wings, and to add an artistic interest to the exterior of the building. The lighting design for this space is intended to highlight the courtyard for user navigation and display the steel sculpture as a piece of art, not just as support structure.

The primary tasks in this area are very simple. Occupants of this space will be entering and exiting the Millennium Science Complex through the main lobby doors, passing by on the way to class, or viewing the structural sculpture. Illuminance levels need not be very high as outdoor navigation is the main concern and problem times of the day will be after operating hours most of the year. No outdoor furniture will be located within this area of the grounds because of the nature of spaces below grade. The original courtyard design was a serpentine of paths that led visitors in no aimed direction. This was done to deter mass quantities of people from sending unwanted vibrations into the nanotechnology labs below. In continuing the importance of vibration control, pedestrians will not have the opportunity to enter the courtyard area – small walls, shrubbery, and lack of paths will restrain pedestrians from passing over the nanotechnology labs.

The lighting design goal in this space is to combine bottom-up grazing of the steel structure with floodlighting of the underside of the building. Having a soft glow on the red-orange panels beneath the cantilever will create an illusion of a graceful engine keeping the building afloat. Grazing the structure will cause extreme high and low luminance areas that will stress the long lines associated with its components.

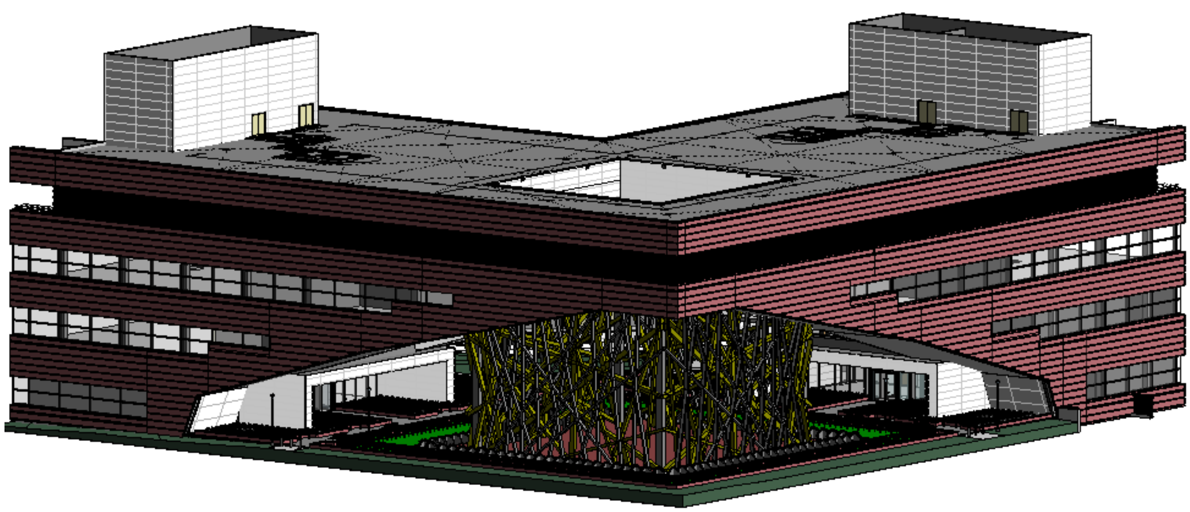


Figure 3.16: Cantilever Courtyard 3D Representation

FLOOR PLAN

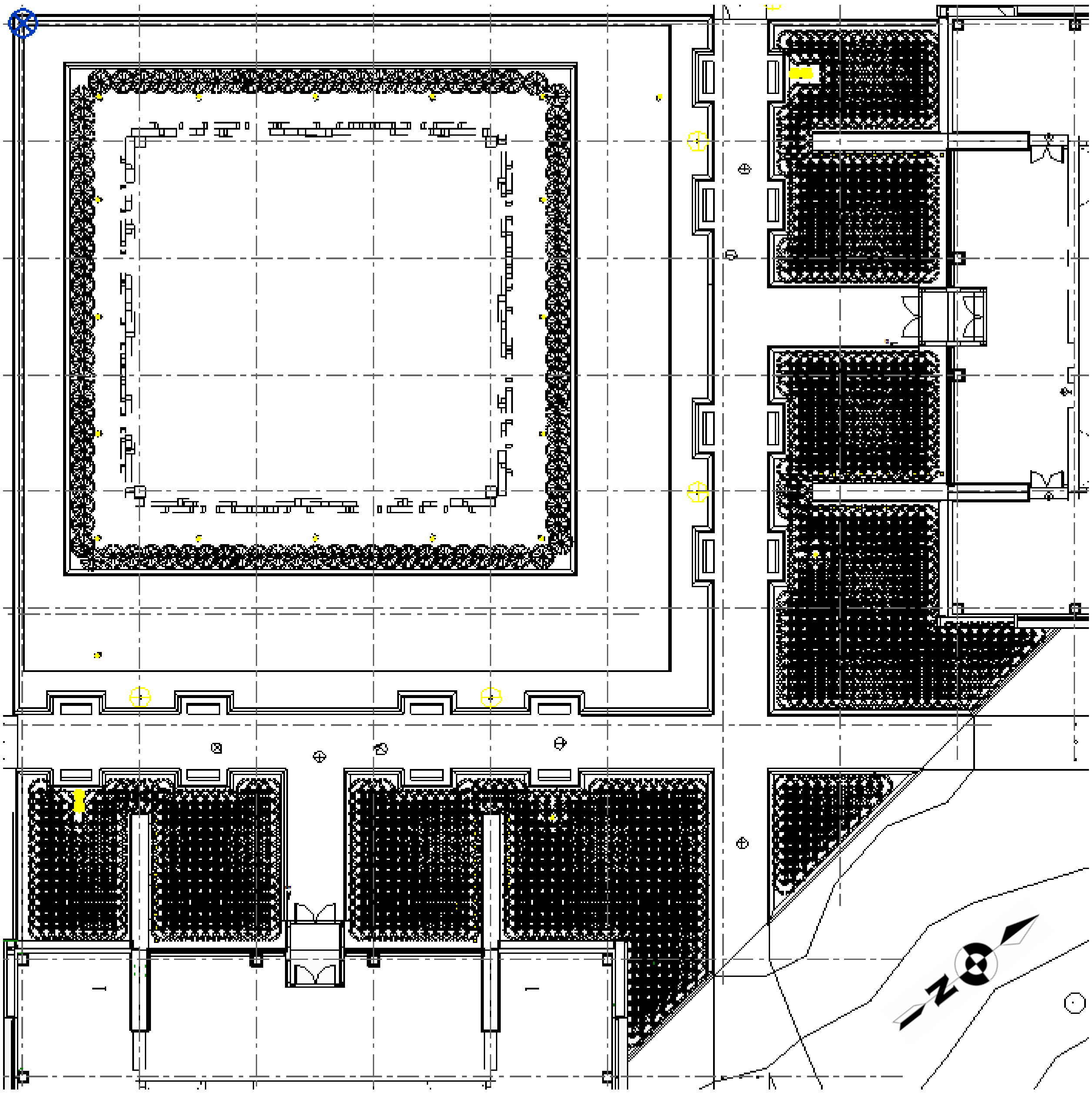


Figure 3.17: Cantilever Courtyard Plan from KGB Maser Central Revit Model

APPLICABLE MATERIALS

There is a wide variety of materials that are present within this space, more so than an interior space. Occupants are able to visualize the exterior of the building – brick and two different metal panels – as well as landscaping from mulch to grass, river rock to shrubs, and finally the steel sculpture at the center of the courtyard. The table below lists the applicable materials for the lighting design of the courtyard:

Surface	Material Description	Reflectance	Specification
Entryway Panels	Steel panel assembly consisting of two panels sandwiched around extruded plastic core. Stainless steel finish.	0.34	05730
Entryway Glazing	Various acceptable manufacturers with the following properties: VLT = 70% SHGC = 0.38 Winter U = 0.29 Shading Coeff. = 0.44 LSG = 1.85 Summer U = 0.26	0.11	08800
Cantilever Soffit	Steel panel assembly consisting of two panels sandwiched around extruded plastic core. Red-orange finish.	0.34	05730
Façade Panels	Pre-cast concrete "C" panels with Norman-sized burgundy brick embedded within the face of the concrete. Redesign includes an overall panel thickness of 1'-0" from exterior face to interior face of panel.	0.26	Unknown
Ground Cover	Including, but not limited to rocks, grass, mulch, and other plantings	0.15 or 0.26	N/A
Sidewalks	Cast-in-place site concrete	0.22	02515
Decorative Steel	HSS steel tubing wrapped with one of two finishes – brushed aluminum or blue aluminum	0.24	05730*
Structural Steel	Nominal 2'x2' wide flange columns	0.34	05100/05120**
Light Well Panels	Steel panel assembly consisting of two panels sandwiched around extruded plastic core. Stainless steel finish.	0.34	05730

*The redesign decorative steel falls under this specification and would need to be added to the specification section
**Structural specification only, no information given for architectural interest

TASKS AND ACTIVITIES

Occupants of the courtyard will not be participating in a wide variety of tasks as someone in a conference or multi-purpose room would. Users will mostly be navigating the grounds by foot into and out of the Millennium Science Complex. Secondary activities may include congregating around the courtyard, sitting on the low level boundary wall around the space, or holding discussions outside. Many of these activities are most likely to occur during the daytime hours, so the electric lighting will not be addressing these activities. What activities will be taking place are essentially secondary when compared to the main goal of the space – discouraging pedestrian traffic over the nanotechnology labs.

DESIGN CRITERIA

Building Exteriors

Active Entrances — 5 fc horizontal, 3 fc vertical

Entrances are the first impression when approaching any building. Nearly every aspect of lighting design can be considered important in these types of spaces. Occupants are introduced to the building at this juncture, so the lighting design must show consideration for aesthetics. The appearance of the entry area must dictate that, without a doubt, this is the point where one will enter the building. The luminaires themselves must show that careful consideration was taken to comfort the visitor by showing quality of products. Visitors may be meeting other occupants in the entrances before passing into the building, so there must be ample light for modeling of faces, detecting others in one's peripheral vision, and knowing points of interest (such as announcements, sculptures, or other information). The scope of this space redesign does not include the entry ways. The existing design will be modeled and reported on for its compliance with these design criteria.

Prominent Structures 5 fc horizontal, 3 fc vertical

The structural redesign of the cantilever will fall into this category of design criteria. Appearance is paramount in this design – every aspect of the design must be as appealing as the sculpture itself. The luminaires must fit the aesthetics of the structure, or be hidden from the view of onlookers. Uniform distribution must be kept across the structure to ensure that, in this case, all sides of the structure are illuminated evenly so as to not cause too much focus on one side of the structure. Having hidden or properly mounted luminaires will also aid in keeping the geometric relationship between the light source and the occupant eye from causing glare and shadows.

Buildings and Monuments, Floodlighted

Light and Dark Surroundings 3-10 fc vertical

The courtyard application for the Millennium Science Complex has two goals as discussed in the introduction to this space. The first goal is to graze the structure; the second is to floodlight the underside of the building. To keep luminance levels tolerable for visitors to the space, the ideal scenario would include lower illuminance levels on lighter surfaces and higher illuminance on darker surfaces. This range of illuminance holds true for lighter surroundings. For darker surroundings, a uniform illuminance of three footcandles is deemed sufficient.

Parks, Plazas, and Pedestrian Malls 5 fc horizontal, 3 fc vertical

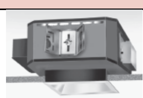
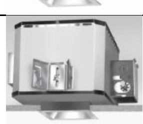
As discussed in other criteria sections, occupants must be able to navigate the space without hindrance and lack of light. This specific design scenario will be applied to the areas immediately surrounding the structure. For simplicity and uniformity, this criterion will include walkways.

REDESIGN PLANS, SECTIONS, AND ELEVATIONS

For the following plans, sections, and elevations, see Appendix 3.B:

A103A – Courtyard Plan Area A
A103B – Courtyard Plan Area B
LE401A – Enlarged Courtyard Lighting Plan Area A
LE401B – Enlarged Courtyard Lighting Plan Area B
LE401C – Enlarged Courtyard Lighting Plan Area C
LE401D – Enlarged Courtyard Lighting Plan Area D

LUMINAIRE SCHEDULE

Courtyard Luminaire Schedule									
Tag	Image	Manufac.	Product	Catalog No.	Description	Lamp	Input Watts	Voltage	Ballast
New Design Luminaires (including two existing)									
FL-1		Deco Lighting	D457 Wall Pack	D457-250-M-MT-CG-BL	Wall-mounted flood light to wash interior of cantilever light well; black housing; clear lens; adjustable height; mounted within reach from roof platform	(1) MCP250/PS/BU-ONLY/940PB Osram Sylvania	272	277	71A5737 BPEE Philips Advance
UL-1		Philips AllScape	SL-23	SL-23-70MH-T6-277-MFLD-F-BK	In-ground medium flood distribution; fixture must be able to graze structure and wash cantilever at same time; black housing; clear lens; minimum CRI of 80; color temperature must match all courtyard fixtures; 277V	(1) MC70T6/ U/G12/ 830PB Osram Sylvania	85	277	71A5237BP Philips Advance
UL-2		Kim Lighting	ALF10 Series	AFL11/70PMH 277/ BL/HDS/FH/BL/ SM18BL	Wide distribution flood luminaire; mounted at 1'-0" above grade; oriented with lamps along cantilever direction; must match CCT with other courtyard fixtures; minimum 80 CRI	(1) MC70T6/ U/G12/ 830PB Osram Sylvania	85	277	71A5237BP Philips Advance
XAM-1		Lightolier	Calculite HID	C6P30 MHACLW/ C6A39P30E2	Recessed adjustable flood light; specular reflector; adjust coverage after installation to uniformly light surface below	(1) MCP39PAR30LN /U/830/FL/ ECO PB Osram Sylvania	48	277	71A5037BP Philips Advance
XPO-1		Louis Poulsen	Kipp Post Cutoff	KIP/1/100W/ MH/ED-17 medium/ 277V/BLK/ CUTOFF	PSU standard existing metal halide post lantern	(1) 100W/MH/ED-17/4000K/Min. 92 CRI	118	277	71A5337BP Philips Advance
Existing Luminiares – No manufacturer data will be given									
DC-5		Kurt Versen	Square Aperture	H8643-SY-LP	6"x6"square aperture ceiling recessed compact fluorescent down lights with regressed lens	(1) 42W Triple Tube CFL	48	277	Unspecified
XDM-1		Kurt Versen	Square Aperture	H8406-SW-LP	4.5"x4.5" square aperture damp rated metal halide recessed downlights with prismatic lens	(1) 39W T6 metal halide / 4000K	48	277	Unspecified
XWM-1		Kurt Versen	Square Aperture	H8452-SY-LP	4.5" square aperture ceiling recessed mount metal halide wall washers with lens	(1) 39W PAR20 metal halide / 4000K	48	277	Unspecified

CONTROL EQUIPMENT

For control equipment cut sheets, see Appendix 3.C. For wiring diagrams, see “Dimming and Wiring Diagrams” in the electrical portion of this document.

Courtyard Control Equipment Schedule					
Tag	Image	Manufac.	Product	Catalog No.	Description
Z-5C		Eaton Corporation	Pow-R-Command 1000 Lighting Control System	Unknown	Provide with Pow-R-Command 1000 Lighting Optimization Software to allow for at least one central workstation and one lighting optimization work station
Z-5P		Eaton Corporation	Pow-R-Command 1000 Panelboard	Unknown	Line-voltage 277V operation; LCD display and keypad; 225A main bus with ability to override lighting circuits by daylight sensor – off during daylight conditions, on selected night conditions; up to (7) expansion panel outputs to control other exterior lighting zones; consult with manufacturer for additional specific component requirements

For a detailed discussion on how the presented control equipment will operate within the space, see the “Control Descriptions” section of the electrical portion of this document.

PERFORMANCE DATA

The table below summarizes light loss factors used in illuminance calculations for the courtyard. The cantilever area consists of all indirect lighting with the maximum allowable cleaning cycle by IES standards.

Courtyard Light Loss Factors					
	Mark	Ballast Factor	Lamp Lumen Depreciation	Luminaire Dirt Depreciation	Total Light Loss Factor
New Design	FL-1*	1.00	0.80	0.77	0.62
	LP-1	1.00	0.75	0.77	0.58
	UL-1	1.00	0.80	0.625	0.50
	UL-2	1.00	0.80	0.625	0.50
	XAM-1	1.00	0.80	0.875	0.70
Exist. *	DC-5	0.98	0.86	0.875	0.74
	XDM-1	1.00	0.80	0.875	0.70
	XWM-1	1.00	0.80	0.875	0.70
	*Same specification as existing conditions **Existing luminaires, lamps, etc. will not be included in the manufacturer pages of this report.				

The following figures illustrate the lighting redesign for the cantilever courtyard in several different media – AGI32, AutoDesk 3D Studio Max Design, and AutoDesk Revit Architecture. To see a further discussion on the model sharing process for lighting design in this space, refer to Unit 1 of this document.

Figure 3.18: Courtyard 3D Studio Max Design Render

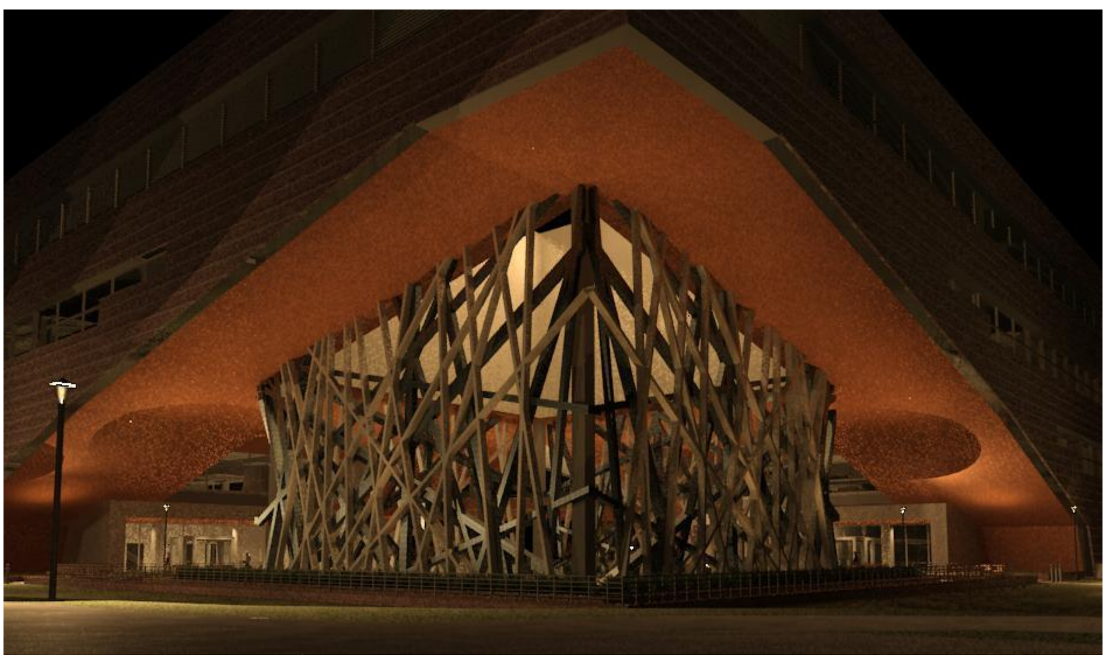


Figure 3.19: Courtyard Rendering in Revit Architecture

Figure 3.20: Courtyard AGI32 Render *Steel redesign omitted due to surface complexity

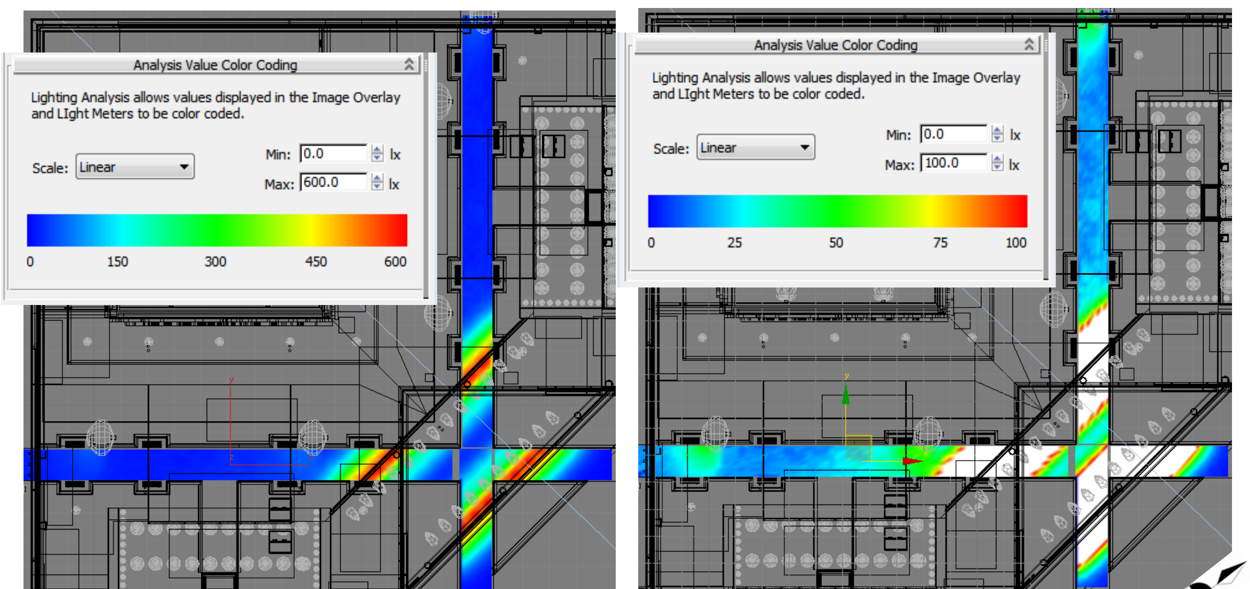


Figure 3.21: Courtyard 3D Studio Max Design Illuminance Pseudo Color 10 fc Max (left), 60 fc Max (right)

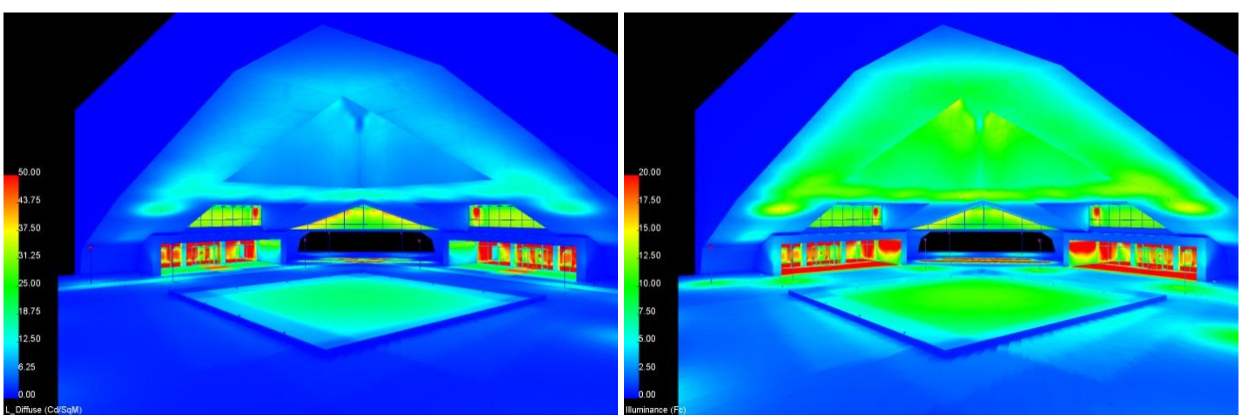


Figure 3.22: Courtyard AGI32 Pseudo Color Images – Luminance in cd/m^2 (left) and Illuminance in fc (right)

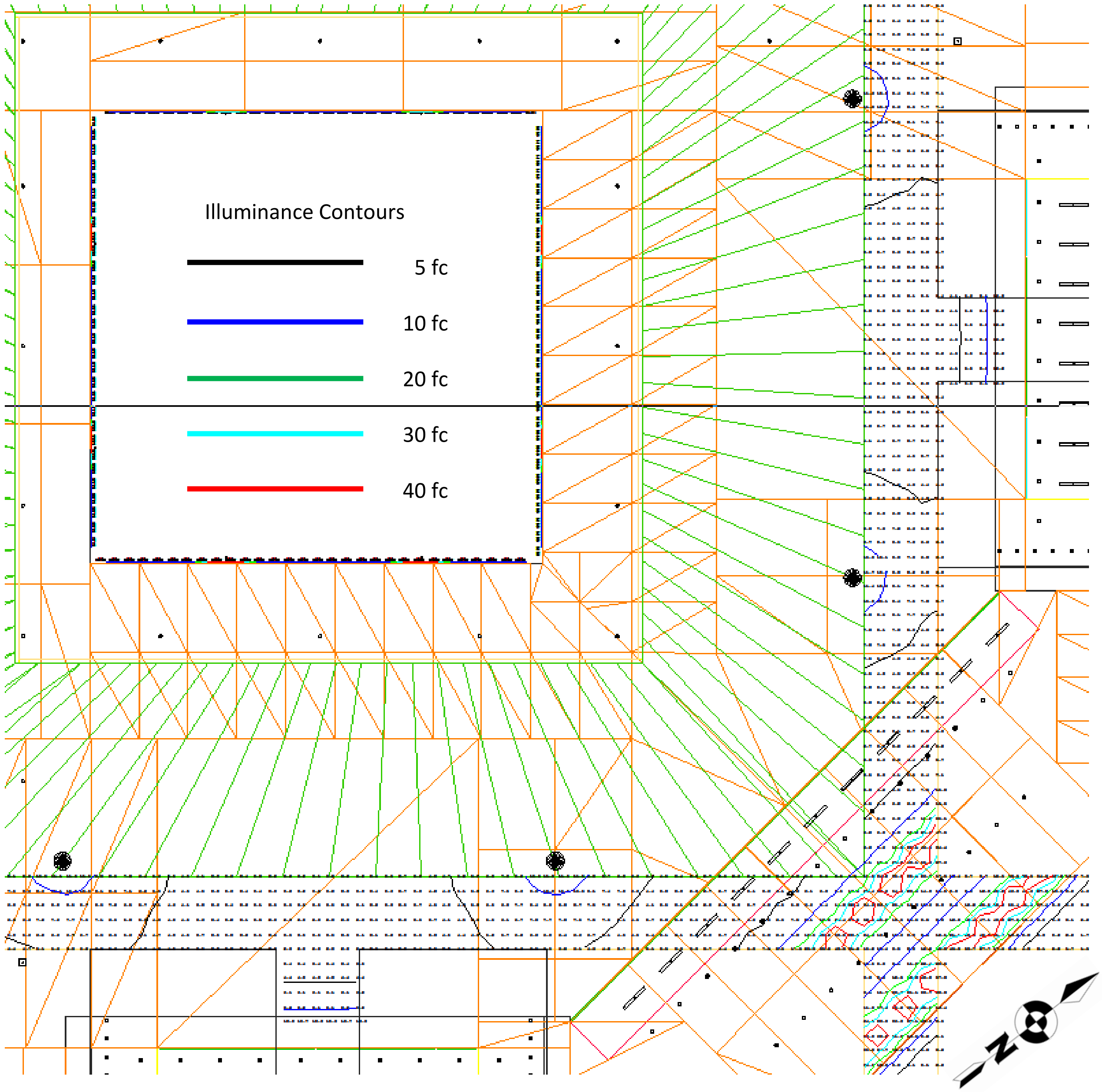


Figure 3.23: Courtyard AGI32 Illuminance Contours

ASHRAE Standard 90.1 Compliance

Lighting Type	Area (ft^2)	Allowable LPD (W/ft^2) or (W/Lf)	Allowable Power (W)**	Total Power Used (W)	Actual LPD (W/ft^2)
Building Grounds*	See Area Summary Table Below	1.0 W/Lf	339.5	7191.00 (total redesign – all luminaires)	0.25 (All surfaces redesign is intended to illuminate)
Plaza Areas and Walkways (>10' Wide)*	See Area Summary Table Below	0.2 W/sq.ft.	N/A		
Canopies and Overhangs*	See Area Summary Table Below	1.25 W/sq.ft	32599.35 to 38044.35		
Building Façades	See Area Summary Table Below	1.25 W/sq.ft.	11910.13 to 24219.83	2176.00 to 3791.00	0.16 to 0.23
*Areas are tradable by ASHRAE Standard 90.1, Table 9.4.5 **Allowable power varies depending upon the classification of the areas in the table below					

Area Location	Area (ft^2)
Walkway	4703.50
Courtyard Grass	7962.42
Courtyard Planting	8877.38
Cantilever Soffit*	14691.73
Light Well Walls	9528.10
Entry Outer Planting	5526.18
*Area of slope that will be floodlighted	

Illuminance Summary Table

Courtyard Illuminance Summary									
Calculation Grid	AGI Illuminance (fc)			3ds Illuminance (fc)			AGI Specific Values		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Max./Min.	Coeff. Of Variation	Uniformity Gradient
Paths	1.10	7.72	63.20	0.102	23.15	59.00	57.45	1.16	3.10
LS Interior Well	1.90	10.32	72.40	Not Measured			38.11	0.59	13.30
LS Exterior Well	1.80	9.33	39.10				21.72	0.41	7.48
MS Interior Well	1.90	9.91	47.60				25.05	0.49	15.03
MS Exterior Well	2.00	9.68	54.10				27.05	0.51	18.03

Ambient light for pathways are designed to be delivered from diffuse sources such as the light well and bouncing off of the underside of the cantilever. To accommodate for such low levels from these sources, campus standard lighting has been carried through the orthogonal paths leading to the entrances of the Millennium Science Complex. As stated previously, the major design goal of this space is to light the sculpture that is the cantilever redesign structure. The following discussions outline how the lighting design achieved the design goals stated at the beginning of this redesign section:

Building Exteriors

Active Entrances — 5 fc horizontal, 3 fc vertical

There is some irony when discussing this aspect of the courtyard space. The original design included a pathway that meandered through a relaxing landscape. The irony of this space is that due to the sensitive nature of the nanotechnology labs beneath ground level, foot traffic needs to be limited, so this space needs to draw occupants into the building, yet not over the main surfaces. The lighting redesign achieves this by not changing existing design in the entryways and using floodlighting for ambient light. Examining Figure 3.22, it is evident that there is ample light present at the building entrances while the Louis Poulsen post luminaires lead pedestrians along the pathway to these well-lit entrances. This design can be considered successful, however it shall be suggested that the entryway lamping be cut in half to save energy.

Prominent Structures 5 fc horizontal, 3 fc vertical

The prominent structure within this space is apparent to the onlooker from afar. The redesign is the definition of prominent structure. Figure 3.22 illustrates that the area of the courtyard around the structure is illuminated to 10 fc in the center of the structure and 5 fc within its landscape walls. Since the structure was not included in the AGI32 renderings, it is unclear whether the vertical illuminance reaches 3 fc. However, grazing portions of the uplighting will undoubtedly illuminate the structure to 3 fc at the height of the viewer.

Buildings and Monuments, Floodlighted

Light and Dark Surroundings 3-10 fc vertical

The floodlighting portion of the presented design criteria can be embodied in the soffit face of the cantilever and the light well above the center structure. Also visible in Figure 3.22, the light well surface is uniformly illuminated to 10 fc, with the exclusion of surfaces very close to the light sources. The cantilever soffit is also floodlighted to a uniform 10 fc seen in Figure 3.22. The application of wide floodlights next to the entrance area balances illuminance and luminance at the outer ends of the entryways. There are small hot-spots on this section of the soffit, but they can be dismissed due to the average eye sensitivity. These hot-spots are at approximately 15 fc while the surrounding surfaces are in the 10-12 fc range. This design criterion can be considered to be achieved.

Parks, Plazas, and Pedestrian Malls 5 fc horizontal, 3 fc vertical

The pathways under the cantilever may fall within this blanket of design spaces. Figures 3.21, 22, and 23 can be consulted for design effectiveness for the pedestrian areas. Examining Figure 3.21 first, the light meters within 3D Studio Max calculate an average of 23.5 fc of illuminance on the pathways. This is also including the more powerful luminaires under the second floor walkway. Excluding the higher power luminaires, the campus standard lighting slightly under illuminates the pathways around the building (in Revit and 3D Studio models). This underachievement is due to modeling translation between programs. For this design will achieve its goals due to its ambient nature, flooding the area with reflectance off of the cantilever structure.

The cantilever space concludes the lighting portion of this unit. For a more in-depth discussion on the modeling processes used to achieve the presented lighting goals, as mentioned throughout this document, see Unit 1 of KGB Maser's final report. The following section is an in-depth design of the power delivery to each of the aforementioned redesign spaces. Secondly, it will include coordination with KGB Maser's mechanical engineer on the Penn State IPD/BIM thesis team.

ELECTRICAL OVERVIEW

The following section presents the electrical requirements of AE482. There are three spaces that have been redesigned along with two depth topics. The spaces include a student study area connected to a corridor, a perimeter office, and the courtyard space below the large cantilever of the Millennium Science Complex. The first depth topic entails modeling a portion of the existing electrical system in SKM Power Tools for Windows. The second depth topic comprises of a motor control center design in reaction to mechanical changes in the building.

Located on the perimeter of the third floor, the student study area allows occupants to have views to the exterior and to be able to work at computer stations along an open portion of the corridor. The lighting redesign includes overhead luminaires being changed from recessed to pendant mounted and additional task lighting at the desk plane. The overhead lighting will operate at 277V while the task lighting will operate at 120V. The overhead lighting is connected to a dimmable system and all space lighting will be connected to occupancy sensors. A second aspect in the redesign includes two rows of bottom-up shading devices connected to a computer system with an open-loop daylight sensor override.

Offices are also located around the perimeter of the building. The largest difference between these spaces and the study areas is their isolation from the corridor. The lighting redesign includes new 2-lamp T8 luminaires that are controlled by dimming switches, the addition of a chalkboard light to illuminate shelving, and a wall wash application to balance luminance levels between the windows and the opposite wall. Neither the shading nor the dimming lighting will be automatically controlled as this space has no real known hours of operation.

A major architectural redesign for KGB Maser is the courtyard beneath the cantilever. A steel structure and sculpture was added for two reasons – to limit pedestrian traffic over the nanotechnology labs and to add a second artistic feature to the corner of the complex. All lighting redesign in this space is high intensity discharge metal halide that is controlled by Eaton Pow-R-Command lighting optimization. Luminaires within the footprint of the courtyard have three basic functions. The first is to flood the underside of the cantilever and light well walls, the second is to graze the structure, and the third is to provide area lighting on site pathways. The Pow-R-Command 1000 system allows for daylight on/off switching allowing for building façade lighting at any hour of the evening in which night falls.

Depth topic 1 involves creating a power system model in SKM Power Tools for Windows®. The three IPD/BIM lighting students collaborated to create a large portion of the base model, and then each completed his own portion of the remaining system. KGB Maser's remaining portion of the system includes motors affected by changing from air handling units to chilled beams.

Depth topic 2 is reactionary to equipment addition and sizing from applying chilled beams to the mechanical system. After chilled beam usage has been finalized and sized, the motors for the remaining mechanical system will be consolidated into several motor control centers.

Panelboards						
Panelboard Tag	Voltage	System	Study Area	Office	Courtyard	Chilled Beam Application
HL-3D	480Y/277V, 3P, 4W	N	X	X		
HLE-3D	480Y/277V, 3P, 4W	N/E	X			
LR-3D1	208Y/120V, 3P, 4W	N	X			
LCP-1	480Y/277V, 3P, 4W	N			X	
EDPS-M41	480Y/277V, 3P, 4W	N/E				X
EDPS-M42	480Y/277V, 3P, 4W	N/E				X
MDP-M41	480Y/277V, 3P, 4W	N				X
MDP-M42	480Y/277V, 3P, 4W	N				X

EXISTING CONDITIONS REVIEW

The electrical system for the Millennium Science Complex is a 12.47kV service feeding a set of dual 5000A, 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.

CONTROL DESCRIPTIONS

STUDENT STUDY AREA AND CORRIDOR

The student study area and corridor within the scope of the space occupy three zones in the new control system. The first zone consists of overhead pendant luminaires within the study area. This zone is controlled through a digitally addressable dimming system with an occupancy sensor override. The second zone is also within the study area and includes under shelf task lighting. These task lights are controlled by integrated switches at each luminaire. Since the study area has hours of operation that are essentially open, the task luminaires will be switched off by vacancy sensors located on the back of the cabinets at the end of selected rows. Shading within the study area is operated using the MechoShade SolarTrac system. This system includes a computer-based settings program and override sensors to allow for the shades to be "off" during times of overcast conditions.

Control wiring diagrams for both the lighting system and shading system can be found in the "Dimming and Wiring Diagrams" section of this unit.

OFFICE LOCATIONS

Office throughout the Millennium Science Complex will be controlled similarly to the perimeter study areas, but without the automatic features such as dimming and shading. The office occupancy schedule does not coincide with general building usage hours, so automatic shading and dimming will be overridden by vacancy sensors for most operation. The overhead lights and shelf lights will be controlled by a three-way, two-load wall switch at the main entry to the room and an additional set of local switches. The local three-way switch for the overhead lighting will include dimming capability and the local switch for the shelves will be a simple three-way on/off switch. The wall washing application will be controlled by its own switch at the main entry door, as its primary goal is to balance its wall luminance with the window wall. The shading system will be controlled by the user at the window by a single line-voltage up/off/down switch.

Control wiring diagrams for both the lighting system and shading system can be found in the "Dimming and Wiring Diagrams" section of this unit.

COURTYARD

The area within the scope of work for the courtyard beneath the cantilever includes areas enclosed by the building footprint, but outside of entryway canopies. All ballasts for the HID luminaires within the redesigned space will be controlled at the head-end by the Eaton Pow-R-Command Lighting Optimization System. This system includes the building automation system SOAP/XML client, at least one SOAP/XML server, a workstation to run the optimization software, the network access control device, and the Pow-R-Command 1000 lighting control panels. The system will be connected to a daylight sensor for override – when predetermined daylight levels have been reached, the system will switch off the night-time environment that is illuminating the courtyard. Additionally, the interface is programmable with up to thirty holidays and has custom occupancy scheduling ability within its software. Information on the product, such as exact wiring diagrams, could not be found; however a simplified control system wiring diagram can be found in the "Dimming and Wiring Diagrams" section of this document.

LUMINAIRE CONTROL AND CIRCUITING

The following drawings appear in Appendix 3.B:

LE101 – Study Area Luminaire Layout and Switching
LE102* – Office Luminaire Layout and Switching
*Includes Conduit and Tick-mark Diagram
LE103A – Courtyard Light Well Layout and Switching A
LE103B – Courtyard Light Well Layout and Switching B
LE401A – Courtyard Lighting Layout and Switching A
LE401B – Courtyard Lighting Layout and Switching B
LE401C – Courtyard Lighting Layout and Switching C
LE401D – Courtyard Lighting Layout and Switching D

EXISTING PANELBOARD AND DIMMING SCHEDULES

In the following existing panelboard schedules, colored highlighting corresponds to which circuits will be changed as a result of lighting redesign. Each color is analogous to the redesign summary table in the electrical executive summary. Naming conventions – including typographical errors – have not been changed in the existing schedules.

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		X
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 LTG*	2
3	*ELECTROACTIVE POLY LTG*	20		1.60		3	4		1.90		20	*STUDENT LIGHTING*	4
5	*ORGANIC ELEC & PHO LTG*	20			1.60	5	6			1.90	20	*STUDENT LIGHTING*	6
7	*DRY LAB A&B, STAFF LTG*	20	1.41			7	8	2.20			20	*STAFF LIGHTING*	8
9	*STAFF ADMIN, KITCHEN LTG*	20		1.23		9	10		1.32		20	*CONFERENCE ROOM LTG*	10
11	*DRY LAB, MISC. COMP. LTG*	20			1.28	11	12			1.52	20	*CONFERENCE ROOM LTG*	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			90.00 %				Demand Factor	
			Phase B:		7.59 kVA			20.98 kVA				Demand Load	
			Phase C:		7.98 kVA			26.22 kVA				Load x 1.25	
	Total Connected Load:				23.31 kVA			31.58 A				AMP	

Figure 3.24: Existing panelboard schedule for HL-3D

BRANCH CIRCUIT PANELBOARD SCHEDULE													
Panel Name: HLE-3D		Mounting:		Surface:	X			Main Lugs Only:		.	Amp Main CB		100
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: 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	*EXIT SIGN*	20	0.10			1	2	1.02				*STAIR N-1 LIGHTING*	2
3	*TOILET & CORRIDOR LTG*	20		2.16		3	4		1.45			*STAIR N-1 LIGHTING*	4
5	*OFFICE LIGHTING*	20			2.30	5	6					*SPARE*	6
7	*SPARE*	20				7	8					*SPARE*	8
9	*SPARE*	20				9	10					*SPARE*	10
11	*SPARE*	20				11	12					*SPARE*	12
13	*SPARE*	20				13	14					*SPARE*	14
15	*SPARE*	20				15	16					*SPARE*	16
17	*SPARE*	20				17	18					*SPARE*	18
19	*SPARE*	20				19	20					*SPARE*	20
21	*SPARE*	20				21	22					*SPARE*	22
23	*SPARE*	20				23	24					*SPARE*	24
25	*SPARE*	20				25	26					*SPARE*	26
27	*SPARE*	20				27	28					*SPARE*	28
29	*SPARE*	20				29	30					*SPARE*	30
31	*SPARE*	20				31	32					*SPARE*	32
33	*SPARE*	20				33	34					*SPARE*	34
35	*SPARE*	20				35	36					*SPARE*	36
37	*PENEL LE-3D VIA*	50	4.94			37	38					*SPARE*	38
39	*XFMR 'TRE-LE-3D'*			3.80		39	40					*SPARE*	40
41	*(50G)*	3P			3.80	41	42					*SPARE*	42
	Subtotals (kVA):		5.04	5.96	6.10			1.02	1.45	0.00		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:				19.6 kVA			17.68 A				AMP	

Figure 3.25: Existing panelboard schedule for HLE-3D

BRANCH CIRCUIT PANELBOARD SCHEDULE

Panel Name: LR-3D1	Mounting: Surface:	X	Main Lugs Only:	.	Amp Main CB	225
120/208, 3 Phase, 4 Wire	Flush:	.	Shunt Trip Main:	.	Amp Bus	225
10,000MIN A.I.C. SYM	In MCC	.	Feed Through:	X	Ground Bus	X
Neutral: 200%	Number of Poles:	42	TVSS:	.	Isolated Ground Bus	X

CKT No.	Load	TRIP (Amp)	KVA/Phase A	KVA/Phase B	KVA/Phase C	Poles	Poles	KVA/Phase A	KVA/Phase B	KVA/Phase C	TRIP (Amp)	Load	CKT No.
1	*P.C. RECEPTACLE*	20	0.80			1	2	0.80			20	*P.C. RECEPTACLE*	2
3	*RECEPTACLE*	20		1.08		3	4		0.80		20	*P.C. RECEPTACLE*	4
5	*P.C. RECEPTACLE*	20			0.80	5	6			0.80	20	*P.C. RECEPTACLE*	6
7	*RECEPTACLE*	20	1.08			7	8	0.80			20	*P.C. RECEPTACLE*	8
9	*P.C. RECEPTACLE*	20		0.80		9	10		0.80		20	*P.C. RECEPTACLE*	10
11	*RECEPTACLE*	20			0.54	11	12			0.80	20	*P.C. RECEPTACLE*	12
13	*P.C. RECEPTACLE*	20	0.80			13	14	0.80			20	*P.C. RECEPTACLE*	14
15	*SPARE*	20				15	16		0.80		20	*P.C. RECEPTACLE*	16
17	*P.C. RECEPTACLE*	20			1.16	17	18			0.80	20	*P.C. RECEPTACLE*	18
19	*RECEPTACLE*	20	1.08			19	20	0.80			20	*P.C. RECEPTACLE*	20
21	*P.C. RECEPTACLE*	20		0.72		21	22		0.80		20	*CLEANING RECEPTACLE*	22
23	*P.C. RECEPTACLE*	20			0.90	23	24			0.80	20	*CLEANING RECEPTACLE*	24
25	*P.C. RECEPTACLE*	20	0.72			25	26	0.80			20	*CLEANING RECEPTACLE*	26
27	*RECEPTACLE*	20		0.72		27	28		0.80		20	*CLEANING RECEPTACLE*	28
29	*P.C. RECEPTACLE*	20			0.40	29	30				20	*SPARE*	30
31	*RECEPTACLE*	20	0.36			31	32				20	*SPARE*	32
33	*RECEPTACLE*	20		0.72		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):		4.84	4.04	3.80			4.00	4.00	3.20		Subtotals (kVA)	
	Total Loads:	Phase A:	8.84 kVA					60.00 %				Demand Factor	
		Phase B:	8.04 kVA					14.33 kVA				Demand Load	
		Phase C:	7.00 kVA					17.91 kVA				Load x 1.25	
	Total Connected Load:	23.88 kVA						49.77 A				AMP	

Figure 3.26: Existing panelboard schedule LR-3D1

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 No.	Load	TRIP (Amp)	KVA/Phase A	KVA/Phase B	KVA/Phase C	Poles	Poles	KVA/Phase A	KVA/Phase B	KVA/Phase C	TRIP (Amp)	Load	CKT No.
1	**ZONE 1 LS LOBBY LTG*	20	0.42					0.72			20	*ZONE 18 SITE LIGHTING**	2
3	*SPARE*	20							0.24		20	*ZONE 19 SITE LIGHTING**	4
5	**ZONE 3 EXTERIOR LTG*	20			1.40					0.24	20	*ZONE 20 SITE LIGHTING**	6
7	**ZONE 4 LS LOBBY LTG*	20	0.31					0.36			20	*ZONE 21 SITE LIGHTING**	8
9	**ZONE 5 LS LOBBY LTG*	20		0.56					0.70		20	*ZONE 22 SITE LIGHTING*	10
11	**ZONE 6 EXTERIOR LTG*	20			1.25						20	*SPARE*	12
13	**ZONE 7 ML LOBBY LTG*	20	0.84					0.38			20	*ZONE 24 SITE LIGHTING**	14
15	**ZONE 8 ML LOBBY LTG*	20		0.56							20	*SPARE*	16
17	**ZONE 9 EXTERIOR LTG*	20			1.40					0.40	20	*ZONE 26 SITE LIGHTING**	18
19	*SPARE*	20						0.05			20	*ZONE 27 SITE LIGHTING**	20
21	**ZONE 11 EXTERIOR LTG*	20		1.25					0.40		20	*ZONE 28 SITE LIGHTING**	22
23	**ZONE 12 ML LOBBY LTG*	20			0.31					0.27	20	*ZONE 29 EXTERIOR LTG**	24
25	**ZONE 13 EXTERIOR LTG*	20	0.63					0.27			20	*ZONE 30 EXTERIOR LTG**	26
27	**ZONE 14 EXTERIOR LTG*	20		0.84					0.23		20	*ZONE 31 EXTERIOR LTG**	28
29	**ZONE 15 SITE LIGHTING*	20			1.70					0.20	20	*ZONE 32 EXTERIOR LTG**	30
31	**ZONE 16 SITE LIGHTING*	20	1.40					0.23			20	*ZONE 33 EXTERIOR LTG**	32
33	**ZONE 17 SITE LILGHTING*	20		1.60					0.27		20	*ZONE 34 EXTERIOR LTG**	34
35	**ZONE 35 ML LOBBY LTG*	20			0.46					0.42	20	*ZONE 36 LS LOBBY LTG*	36
37	*SPARE*	20									20	*SPARE*	38
39	*SPARE*	20									20	*SPARE*	40
41	*SPARE*	20									20	*SPARE*	42
	Subtotals (kVA):		3.60	4.81	6.52			2.01	1.84	1.53		Subtotals (kVA)	
	Total Loads:	Phase A:	5.61 kVA					80.00 %				Demand Factor	
		Phase B:	6.65 kVA					16.25 kVA				Demand Load	
		Phase C:	8.05 kVA					20.31 kVA				Load x 1.25	
	Total Connected Load:	20.31 kVA						24.46 A				AMP	

REMARKS: * - DENOTES REMOTE CONTROL BREAKER

Figure 3.27: Existing panelboard schedule LCP-1

DISTRIBUTION PANEL SCHEDULE

Panel Name: EDPS-M41		Mounting:	Surface: X			Main Lugs Only: .	Amp Main CB	800
277/480, 3 Phase, 4 Wire			Flush: .			Shunt Trip Main: .	Amp Bus	800
65,000MIN A.I.C. SYM			In MCC .			Feed Through: .	100% NEUTRAL	

CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*ACF-1*	253.90	211.00	100	600A	450A	3	*460G*
2	*ACF-3*	253.90	211.00	100	600A	450A	3	*460G*
3	*ACF-5*	253.90	211.00	100	600A	450A	3	*460G (STAND-BY)*
4	*HMS-0B - HMS-3B*	23.80	20.00		225A	225A	3	*300G*
5	*RO-2*	11.00	9.00	7.5	100A	40A	3	*40G*
6	*PRE-TREATMENT*	7.60	6.32	5	100A	30A	3	*30G*
7	*CONTROL PANEL*	20.00	16.00		100A	30A	3	*30NG*
8	*SPACE*							
9	*EFN-24*	65.00		50	100A	70A	3	*115G (STAND-BY)*
10	*EFN-26*	72.20	60.00	75	225A	150A	3	*150G (STAND-BY)*
11	*SPARE*				100A	100A	3	
12	*SPARE*				225A	225A	3	
13								
14								
15								
16								
17								
18								

PROVIDE INTEGRAL TVSS UNIT

Figure 3.28: Existing panelboard schedule EDPS-M41

DISTRIBUTION PANEL SCHEDULE

Panel Name: EDPS-M42		Mounting:	Surface: X			Main Lugs Only: .	Amp Main CB	800
277/480, 3 Phase, 4 Wire			Flush: .			Shunt Trip Main: .	Amp Bus	800
65,000MIN A.I.C. SYM			In MCC .			Feed Through: .	100% NEUTRAL	

CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*ACF-2*	253.90	211.00	100	400A	380A	3	*400G*
2	*ACF-4*	253.90	211.00	100	400A	380A	3	*400G*
3	*ACF-9*	52.00	30.00	40	100A	100A	3	*115G (STAND-BY)*
4	*ACF-10*	52.00	30.00	40	100A	100A	3	*115G*
5	*ACF-11*	34.00	28.00	25	100A	70A	3	*85G*
6	*HMS-0D - HMS-3D*	16.00	13.30		225A	225A	3	*300NG*
7	*ACF-12*	156.00	94.00	125	225A	225A	3	*230G*
8	*VACUUM PUMP (VCP-1)*	104.00		3(40)	200A	200A	3	*200G - (2 ACTIVE, 1 STAND-BY)*
9	*SPARE*				100A	30A	3	
10	*SPARE*				100A	30A	3	
11								
12								
13								
14								
15								
16								
17								
18								

PROVIDE INTEGRAL TVSS UNIT

Figure 3.29: Existing panelboard schedule EDPS-M42

DISTRIBUTION PANEL SCHEDULE								
Panel Name: MDP-M41	Mounting: Surface: X				Main Lugs Only: .	Amp Main CB 1000		
277/480, 3 Phase, 4 Wire	Flush: .				Shunt Trip Main: .	Amp Bus 1000		
65,000MIN A.I.C. SYM	In MCC .				Feed Through: .	100% NEUTRAL		
CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*ACF-7*	77.00	63.00	60	225A	110A	3	*115G*
2	*RTF-1*	40.00	33.00	30	100A	80A	3	*85G*
3	*GWP-12*	34.00	28.00	25	100A	70A	3	*85G (STAND-BY)*
4	*RTF-3*	27.00	21.49	20	100A	60A	3	*60G*
5	*HM-3B - HM-0B*	57.44	47.70		225A	225A	3	*255G*
6	*HL-3B - HL-0B*	166.74	138.00		400A	400A	3	*400NG*
7	*HM-4A*	26.19	21.75		400A	400A	3	*380G*
8	*HL-M4*	9.15	7.60		100A	100A	3	*115NG*
9	*LR-4C VIA 30 KVA XFMR 'TRE-LR-4C'*	18.70	15.50		100A	50A	3	*50G*
10	*SPARE*				225A	225A	3	
11	*SPARE*				225A	225A	3	
12								
13								
14								
15								
16								
17								
18								
PROVIDE INTEGRAL TVSS UNIT								

Figure 3.30: Existing panelboard schedule MDP-M41

DISTRIBUTION PANEL SCHEDULE								
Panel Name: MDP-M42	Mounting: Surface: X				Main Lugs Only: .	Amp Main CB 1000		
277/480, 3 Phase, 4 Wire	Flush: .				Shunt Trip Main: .	Amp Bus 1000		
65,000MIN A.I.C. SYM	In MCC .				Feed Through: .	100% NEUTRAL		
CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*ACF-6*	77.00	64.00	60	225A	110A	3	*115G*
2	*ACF-8*	77.00	64.00	60	225A	110A	3	*115G*
3	*ACF-12*	96.00	80.00	75	225A	125A	3	*130G*
4	*HM-3D - HM-0D*	159.84	132.73	7.5	400A	400A	3	*400G*
5	*HL-3D - HL-0D*	113.63	94.36	7.5	225.00	225A	3	*255NG*
6	*HM-4B*	37.93	31.50	7.5	400A	400A	3	*380G*
7								
8	*SPARE*				225A	225A	3	
9	*SPARE*				225A	225A	3	
10	*GWP-11*	34.00	28.00	25	100A	70A	3	*85G*
11	*RTF-2*	27.00	21.49	20	100A	60A	3	*60G*
12								
13								
14								
15								
16								
17								
18								
PROVIDE INTEGRAL TVSS UNIT								

Figure 3.31: Existing panelboard schedule MDP-M42

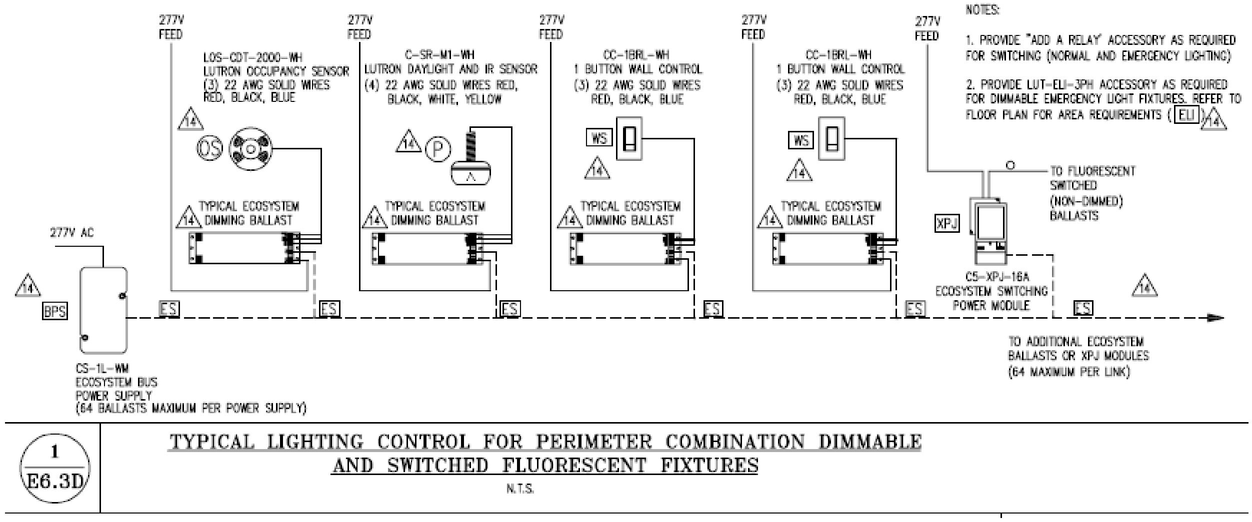


Figure 3.32: Existing control system for dimmable zones

PANELBOARD WORKSHEETS

The following figures are to serve as calculations for sizing panelboards that have been affected by changes in lighting design. There are two factors that have been addressed with respect to the unique nature of these panelboards. First, as most of the affected panelboards have more than 60% spare capacity already built in, the calculation has been changed to address each spare individually, rather than one multiplier to the connected load. Secondly, all receptacle circuits have been addressed with respect to NFPA 70: The National Electric Code Table 220.44 (seen below in Figure 3.23). This calculation was built-in to the panelboard sizing worksheet.

Table 220.44 Demand Factors for Non-Dwelling Receptacle Loads

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

Figure 3.33: NEC Table 220.44

The spare capacity sizing was performed under a "worst case scenario" including the application of continuous loading and maximum branch circuit current per breaker. The two scenarios were computed as follows:

20A Branch Circuit Protection for "Spare" circuits

20A x 80% Loaded x 80% for continuous = 12.8A

This current is then applied to both 120V and 277V

12.8A x 120V panelboard voltage = 1536 VA
→ Round to 1500 VA for a 208Y/120V Branch Circuit

12.8A x 277V panelboard voltage = 3545.6 VA
→ Round to 3500 VA for a 480Y/277V Branch Circuit

Please not that each circuit redesign load was calculated as if it were feeding only the space being changed. This means that if corridor lights appear on both the office redesign and the study redesign circuits, only the color-coded space will be applied. The summary of all redesigned circuits are as follows:

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Panelboard HL-3D Circuit Calculations					
Circuit 2					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
DC-1A	8	46.0	368.00	0.98	375.51
NF-1	23	65.0	1495.00	0.99	1510.10
O-1	4	65.7	262.80	0.99	265.45
OS-1	1	70.0	70.00	0.98	71.43
WW-1	1	62.0	62.00	0.98	63.27
		Totals:	**2257.80**	**0.99**	**2285.76**
Circuit 4					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
S-1	12	65.7	788.40	0.99	796.36
NF-1	9	65.0	585.00	0.99	590.91
		Totals:	**1373.40**	**0.99**	**1387.27**
Circuit 13					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
C-1	14	32.0	448.00	0.98	457.14
DF-8	5	65.0	325.00	0.99	328.28
		Totals:	**773.00**	**0.98**	**785.43**

Panelboard LR-3D1 Circuit Calculations					
Circuit 5 - Zone 3 Exterior					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
UL-1	19	85.0	1615.00	0.90	1794.44
UL-2	2	85	170.00	0.9	188.89
		Totals:	**1615.00**	**0.90**	**1794.44**
Circuit 11 - Zone 6 Exterior					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
XWM-1	20	48.0	960.00	0.90	1066.67
		Totals:	**960.00**	**0.90**	**1066.67**
Circuit 17 - Zone 9 Exterior					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
FL-1	8	272.0	2176.00	0.90	2417.78
		Totals:	**2176.00**	**0.90**	**2417.78**
Circuit 18 - Zone 26 Site					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
XPO-1	4	118.0	472.00	0.90	524.44
		Totals:	**472.00**	**0.90**	**524.44**
Circuit 21 - Zone 11 Exterior					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
XWM-1	20	48.0	960.00	0.90	1066.67
		Totals:	**960.00**	**0.90**	**1066.67**
Circuit 25 - Zone 13 Exterior					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
XAM-1	12	48.0	576.00	0.90	640.00
		Totals:	**576.00**	**0.90**	**640.00**
Circuit 27 - Zone 14 Exterior					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
XAM-1	9	48.0	432.00	0.90	480.00
		Totals:	**432.00**	**0.90**	**480.00**

Panelboard HLE-3D Circuit Calculations					
Circuit 3					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
C-1	20	32.0	640.00	0.99	646.46
NF-4	2	65.0	130.00	0.98	132.65
SC-2	4	20.0	80.00	0.98	81.63
NF-5	3	65.0	195.00	0.99	196.97
		Totals:	**1045.00**	**0.99**	**1057.72**

Panelboard LR-3D1 Circuit Calculations					
Circuit 30					
Mark	Quantity	W/Luminaire	Total W	PF	Total VA
T-1	96	6.0	576.00	0.99	581.82
		Totals:	**576.00**	**0.99**	**581.82**

Since the spare circuits were addressed individually, no spare capacity multiplier appears in the panelboard sizing worksheets. The following figures contain calculations for panelboard sizing:

PANELBOARD SIZING WORKSHEET

Pos	Ph.	Load Type	Cat.	Location	Load	Units	I. PF	Watts	VA	Remarks	
Panel Tag------------------------->					HL-3D	Panel Location:			N-P347		
Nominal Phase to Neutral Voltage------->					277	Phase:			3		
Nominal Phase to Phase Voltage-------->					480	Wires:			4		
Pos	Ph.	Load Type	Cat.	Location	Load	Units	I. PF	Watts	VA	Remarks	
1	A	LIGHTING	3	STUDY/OFFICE	0.83	kva	0.80	664.00	830.00		
2	A	LIGHTING	10	OFFICE/STAFF	2285.76	va	0.99	2257.80	2285.76		
3	B	LIGHTING	3	CORRIDOR/LAB	1.60	kva	0.80	1280.00	1600.00		
4	B	LIGHTING	9	STUDY/OFFICE	1387.27	kva	0.99	1373.40	1387.27		
5	C	LIGHTING	3	LAB SPACES	1.60	kva	0.80	1280.00	1600.00		
6	C	LIGHTING	3	STUDY/OFFICE	1.90	kva	0.80	1520.00	1900.00		
7	A	LIGHTING	3	LAB SPACES	1.41	kva	0.80	1128.00	1410.00		
8	A	LIGHTING	3	OFFICE/STAFF	2.20	kva	0.80	1760.00	2200.00		
9	B	LIGHTING	3	ADMIN/STOR	1.23	kva	0.80	984.00	1230.00		
10	B	LIGHTING	3	SEMINAR	1.32	kva	0.80	1056.00	1320.00		
11	C	LIGHTING	3	CONF./ OFFICE	1.28	kva	0.80	1024.00	1280.00		
12	C	LIGHTING	3	CONFERENCE	1.52	kva	0.80	1216.00	1520.00		
13	A	LIGHTING	9	CORRIDOR	773.00	w	0.98	773.00	785.43		
14	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
15	B	LIGHTING	3	CORRIDOR	1.54	kva	0.80	1232.00	1540.00		
16	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
17	C	LIGHTING	3	CORRIDOR	1.68	kva	0.80	1344.00	1680.00		
18	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
19	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
20	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
21	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
22	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
23	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
24	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
25	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
26	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
27	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
28	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
29	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
30	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
31	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
32	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
33	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
34	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
35	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
36	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
37	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
38	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
39	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
40	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
41	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
42	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00		
PANEL TOTAL								94.49	117.07	Amps=	140.88
PHASE LOADING								kW	kVA	%	Amps
		PHASE TOTAL	A					31.78	39.01	34%	140.83
		PHASE TOTAL	B					31.13	38.58	33%	139.27
		PHASE TOTAL	C					31.58	38.08	33%	137.47
LOAD CATAGORIES				Connected			Demand				Ver. 104
				kW	kVA	DF	kW	kVA	PF		
1		receptacles		0.00	0.00	NEC	0.00	0.00	0.80		
2		computers		0.00	0.00	0.70	0.00	0.00			
3		fluorescent lighting		14.49	18.11	0.90	13.04	16.30	0.80		
4		HID lighting		0.00	0.00	0.90	0.00	0.00			
5		incandescent lighting		0.00	0.00	1.00	0.00	0.00			
6		HVAC fans		0.00	0.00	0.80	0.00	0.00			
7		heating		0.00	0.00	0.70	0.00	0.00			
8		kitchen equipment		0.00	0.00	0.60	0.00	0.00			
9		Student Area Redesign		2.15	2.17	0.90	1.93	1.96	0.99		
10		Office Redesign		2.26	2.29	0.90	2.03	2.06	0.99		
11		Courtyard Redesign		0.00	0.00	0.90	0.00	0.00			
12		unassigned		75.60	94.50	0.60	45.36	56.70	0.80		
		Total Demand Loads					62.36	77.01			
		Spare Capacity		0%			0.00	0.00			
		Total Design Loads					62.36	77.01	0.81	Amps=	92.67

Figure 3.34: Panelboard worksheet for HL-3D

PANELBOARD SIZING WORKSHEET

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

Pos	Ph.	Load Type	Cat.	Location	Load	Units	I. PF	Watts	VA	Remarks
1	A	EXIT SIGN	12	CORRIDOR	0.10	kva	0.80	80.00	100.00	
2	A	LIGHTING	3	STAIR N-1	1.02	kva	0.80	816.00	1020.00	
3	B	LIGHTING	9	RR/CORRIDOR	1.05	w	0.99	1045.00	1057.72	
4	B	LIGHTING	3	STAIR N-1	1.45	kva	0.80	1160.00	1450.00	
5	C	LIGHTING	3	OFFICE	2.30	kva	0.80	1840.00	2300.00	
6	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
7	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
8	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
9	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
10	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
11	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
12	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
13	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
14	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
15	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
16	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
17	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
18	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
19	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
20	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
21	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
22	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
23	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
24	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
25	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
26	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
27	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
28	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
29	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
30	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
31	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
32	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
33	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
34	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
35	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
36	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
37	A	FEEDER	12	TO LE-3D	4.94	kva	0.80	3952.00	4940.00	
38	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
39	B	FEEDER	12	TO LE-3D	3.80	kva	0.80	3040.00	3800.00	
40	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
41	C	FEEDER	12	TO LE-3D	3.80	kva	0.80	3040.00	3800.00	
42	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
PANEL TOTAL								110.17	137.47	Amps= 165.42

PHASE LOADING		kW	kVA	%	Amps
PHASE TOTAL	A	35.65	44.56	33%	160.87
PHASE TOTAL	B	36.05	44.81	33%	161.76
PHASE TOTAL	C	38.48	46.64	34%	168.38

LOAD CATAGORIES		Connected			Demand			Ver. 104
		kW	kVA	DF	kW	kVA	PF	
1	receptacles	0.00	0.00	NEC	0.00	0.00	0.80	
2	computers	0.00	0.00	0.70	0.00	0.00		
3	fluorescent lighting	3.82	4.77	0.90	3.43	4.29	0.80	
4	HID lighting	0.00	0.00	0.90	0.00	0.00		
5	incandescent lighting	0.00	0.00	1.00	0.00	0.00		
6	HVAC fans	0.00	0.00	0.80	0.00	0.00		
7	heating	0.00	0.00	0.70	0.00	0.00		
8	kitchen equipment	0.00	0.00	0.60	0.00	0.00		
9	Student Area Redesign	1.05	1.06	0.90	0.94	0.95	0.99	
10	Corridor Redesign	0.00	0.00	0.90	0.00	0.00		
11	Office Redesign	0.00	0.00	0.90	0.00	0.00		
12	unassigned	105.31	131.64	0.60	63.19	78.98	0.80	
Total Demand Loads					67.56	84.23		
Spare Capacity		0%			0.00	0.00		
Total Design Loads					67.56	84.23	0.80	Amps= 101.36

Figure 3.35: Panelboard worksheet for HLE-3D

PANELBOARD SIZING WORKSHEET

Panel Tag------------------------->	LR-3D1	Panel Location:	N-P346
Nominal Phase to Neutral Voltage------->	120	Phase:	3
Nominal Phase to Phase Voltage-------->	208	Wires:	4

Pos	Ph.	Load Type	Cat.	Location	Load	Units	I. PF	Watts	VA	Remarks	
1	A	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
2	A	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
3	B	RECEPTACLE	1	3F MAT SCI	1.08	kva	0.80	864.00	1080.00		
4	B	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
5	C	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
6	C	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
7	A	RECEPTACLE	1	3F MAT SCI	1.08	kva	0.80	864.00	1080.00		
8	A	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
9	B	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
10	B	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
11	C	RECEPTACLE	1	3F MAT SCI	0.54	kva	0.80	432.00	540.00		
12	C	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
13	A	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
14	A	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
15	B	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
16	B	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
17	C	PC RECEP	2	3F MAT SCI	1.16	kva	0.88	1020.80	1160.00		
18	C	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
19	A	RECEPTACLE	1	3F MAT SCI	1.08	kva	0.80	864.00	1080.00		
20	A	PC RECEP	2	3F MAT SCI	0.80	kva	0.88	704.00	800.00		
21	B	PC RECEP	2	3F MAT SCI	0.72	kva	0.88	633.60	720.00		
22	B	CLN RECEP	1	3F MAT SCI	0.80	kva	0.80	640.00	800.00		
23	C	PC RECEP	2	3F MAT SCI	0.90	kva	0.88	792.00	900.00		
24	C	CLN RECEP	1	3F MAT SCI	0.80	kva	0.80	640.00	800.00		
25	A	PC RECEP	2	3F MAT SCI	0.72	kva	0.88	633.60	720.00		
26	A	CLN RECEP	1	3F MAT SCI	0.80	kva	0.80	640.00	800.00		
27	B	RECEPTACLE	1	3F MAT SCI	0.72	kva	0.80	576.00	720.00		
28	B	CLN RECEP	1	3F MAT SCI	0.80	kva	0.80	640.00	800.00		
29	C	PC RECEP	2	3F MAT SCI	0.40	kva	0.88	352.00	400.00		
30	C	LIGHTING	9	N-324 THRU 328	576.00	w	0.80	576.00	720.00		
31	A	RECEPTACLE	1	N/A	0.36	kva	0.80	288.00	360.00		
32	A	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
33	B	RECEPTACLE	1	N/A	0.72	kva	0.80	576.00	720.00		
34	B	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
35	C	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
36	C	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
37	A	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
38	A	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
39	B	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
40	B	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
41	C	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
42	C	SPARE	12	N/A	1500.00	va	0.80	1200.00	1500.00		
PANEL TOTAL								34.09	41.10	Amps=	114.17

PHASE LOADING		kW	kVA	%	Amps
PHASE TOTAL	A	11.11	13.34	33%	111.17
PHASE TOTAL	B	11.55	14.04	35%	117.00
PHASE TOTAL	C	11.43	13.12	32%	109.33

LOAD CATAGORIES			Connected			Demand				Ver. 104
			kW	kVA	DF	kW	kVA	PF		
1	receptacles		7.02	8.78	NEC	7.02	8.78	0.80		
2	computers		13.29	15.10	0.70	9.30	10.57	0.88		
3	fluorescent lighting		0.00	0.00	0.90	0.00	0.00			
4	HID lighting		0.00	0.00	0.90	0.00	0.00			
5	incandescent lighting		0.00	0.00	1.00	0.00	0.00			
6	HVAC fans		0.00	0.00	0.80	0.00	0.00			
7	heating		0.00	0.00	0.70	0.00	0.00			
8	kitchen equipment		0.00	0.00	0.60	0.00	0.00			
9	Student Area Redesign		0.58	0.72	0.90	0.52	0.65	0.80		
10	Corridor Redesign		0.00	0.00	0.90	0.00	0.00			
11	Office Redesign		0.00	0.00	0.90	0.00	0.00			
12	unassigned		13.20	16.50	0.60	7.92	9.90	0.80		
Total Demand Loads						24.76	29.90			
Spare Capacity			0%			0.00	0.00			
Total Design Loads						24.76	29.90	0.83	Amps=	83.05

Figure 3.36: Panelboard worksheet for LR-3D1

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	LIGHTING	3	ZONE 1 LS LBY	0.42	kva	0.80	336.00	420.00	
2	A	LIGHTING	12	ZONE 18 SITE	0.72	kva	0.80	576.00	720.00	
3	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
4	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
5	C	LIGHTING	11	ZONE 3 EXT	1615.00	w	0.90	1615.00	1794.44	
6	C	LIGHTING	12	ZONE 20 SITE	0.24	kva	0.80	192.00	240.00	
7	A	LIGHTING	3	ZONE 4 LS LBY	0.31	kva	0.80	248.00	310.00	
8	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
9	B	LIGHTING	3	ZONE 5 LS LBY	0.56	kva	0.80	448.00	560.00	
10	B	LIGHTING	12	ZONE 22 SITE	0.70	kva	0.80	560.00	700.00	
11	C	LIGHTING	11	ZONE 6 EXT	960.00	w	0.90	960.00	1066.67	
12	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
13	A	LIGHTING	3	ZONE 7 ML LBY	0.84	kva	0.80	672.00	840.00	
14	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
15	B	LIGHTING	3	ZONE 8 ML LBY	0.56	kva	0.80	448.00	560.00	
16	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
17	C	LIGHTING	11	ZONE 9 EXT	2176.00	w	0.90	2176.00	2417.78	
18	C	LIGHTING	11	ZONE 26 SITE	472.00	w	0.90	472.00	524.44	
19	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
20	A	LIGHTING	12	ZONE 27 SITE	0.05	kva	0.80	40.00	50.00	
21	B	LIGHTING	11	ZONE 11 EXT	960.00	w	0.90	960.00	1066.67	
22	B	LIGHTING	12	ZONE 28 SITE	0.40	kva	0.80	320.00	400.00	
23	C	LIGHTING	3	ZONE 12 ML LBY	0.31	kva	0.80	248.00	310.00	
24	C	LIGHTING	4	ZONE 29 EXT	0.27	kva	0.90	243.00	270.00	
25	A	LIGHTING	11	ZONE 13 EXT	576.00	w	0.90	576.00	640.00	
26	A	LIGHTING	4	ZONE 30 EXT	0.27	kva	0.90	243.00	270.00	
27	B	LIGHTING	11	ZONE 14 EXT	432.00	w	0.90	432.00	480.00	
28	B	LIGHTING	4	ZONE 31 EXT	0.23	kva	0.90	207.00	230.00	
29	C	LIGHTING	12	ZONE 15 SITE	1.70	kva	0.80	1360.00	1700.00	
30	C	LIGHTING	4	ZONE 32 EXT	0.20	kva	0.90	180.00	200.00	
31	A	LIGHTING	12	ZONE 16 SITE	1.40	kva	0.80	1120.00	1400.00	
32	A	LIGHTING	4	ZONE 33 EXT	0.23	kva	0.90	207.00	230.00	
33	B	LIGHTING	12	ZONE 17 SITE	1.60	kva	0.80	1280.00	1600.00	
34	B	LIGHTING	4	ZONE 34 EXT	0.27	kva	0.90	243.00	270.00	
35	C	LIGHTING	3	ZONE 35 ML LBY	0.46	kva	0.80	368.00	460.00	
36	C	LIGHTING	3	ZONE 36 LS LBY	0.42	kva	0.80	336.00	420.00	
37	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
38	A	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
39	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
40	B	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
41	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
42	C	SPARE	12	N/A	3500.00	va	0.80	2800.00	3500.00	
PANEL TOTAL								53.47	65.65	Amps= 79.00

PHASE LOADING		kW	kVA	%	Amps
PHASE TOTAL	A	18.02	22.38	34%	80.79
PHASE TOTAL	B	18.90	23.37	36%	84.36
PHASE TOTAL	C	16.55	19.90	30%	71.85

	LOAD CATAGORIES	Connected			Demand			Ver. 104
		kW	kVA	DF	kW	kVA	PF	
1	receptacles	0.00	0.00	NEC	0.00	0.00	0.80	
2	computers	0.00	0.00	0.70	0.00	0.00		
3	fluorescent lighting	3.10	3.88	0.90	2.79	3.49	0.80	
4	HID lighting	1.32	1.47	0.90	1.19	1.32	0.90	
5	incandescent lighting	0.00	0.00	1.00	0.00	0.00		
6	HVAC fans	0.00	0.00	0.80	0.00	0.00		
7	heating	0.00	0.00	0.70	0.00	0.00		
8	kitchen equipment	0.00	0.00	0.60	0.00	0.00		
9	Student Area Redesign	0.00	0.00	0.90	0.00	0.00		
10	Office Redesign	0.00	0.00	0.90	0.00	0.00		
11	Courtyard (HID)	7.19	7.99	0.90	6.47	7.19	0.90	
12	unassigned	41.85	52.31	0.60	25.11	31.39	0.80	
	Total Demand Loads				35.57	43.39		
	Spare Capacity	0%			0.00	0.00		
	Total Design Loads				35.57	43.39	0.82	Amps= 52.22

Figure 3.37: Panelboard worksheet for LCP-1

Air Handling Unit Branch Circuit Sizing

According to the National Electrical Code Article 430.24 and Article 430.53(C), several motors on one circuit, as in the case of the mechanical system redesign, the total ampacity of the circuit conductor cannot be less than 125% of the largest motor full load current plus 100% of the full load current of each additional motor and the overcurrent device can be sized to 250% of the largest motor full load amps in the circuit's motor group. These sections of the NEC results in the following calculation for air handling units:

$$43\ Series, 75hp\ Circuits$$

$$Conductor\ Ampacity = (1.25)(96A) + 96A = 216A$$

4/0 AWG feeding into the air handling unit

$$Overcurrent\ Device = (96A)(2.5) = 240A$$

250A inverse-time current circuit breaker

#4 ground based on breaker size

$$35\ Series, 50hp\ Circuits$$

$$Conductor\ Ampacity = (1.25)(65A) + 65A = 146.25A$$

1/0 AWG feeding into the air handling unit

$$Overcurrent\ Device = (65A)(2.5) = 162.5A$$

175A inverse-time current circuit breaker

#6 ground based on breaker size

REVISED PANELBOARD SCHEDULES

As discussed in the "Panelboard Worksheets" section of this unit, the spare circuits were addressed individually. These appear in the revised panelboard schedules as having "3.5kVA" or "1.5kVA" loads, whereas the original panelboard schedules have been left blank. These sizing adjustments allow for a worst-case-scenario of feeder sizing for each panel. The demand factors seen in the revised panelboard schedules were computed using the panelboard worksheets seen in the previous section. A summary of the demand factor calculation is as follows:

Panelboard Demand Factor Summary			
Panelboard	Connected VA	Demand VA	Calculated DF
HL-3D	117.07	77.01	65.78%
HLE-3D	137.47	84.23	64.27%
LR-3D1	41.10	29.90	72.74%
LCP-1	65.50	43.39	66.24%

As with the existing panelboard schedules, some naming conventions and some original typographical errors have not changed. The revised feeder schedule and panelboard schedules are as follows:

BRANCH CIRCUIT PANELBOARD SCHEDULE

Panel Name: HL-3D	Mounting: Surface:	X	Main Lugs Only:	.	Amp Main CB	125
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: 100%	Number of Poles:	42	TVSS:	.	Isolated Ground Bus	.

CKT No.	Load	TRIP (Amp)	KVA/Phase A	B	C	Poles	Poles	KVA/Phase A	B	C	TRIP (Amp)	Load	CKT No.
1	*STUDENT LIGHTING*	20	0.83			1	2	2.29			20	*STAFF & FACULTY LTG*	2
3	*ELECTROACTIVE POLY LTG*	20		1.60		3	4		1.39		20	*STUDENT LIGHTING*	4
5	*ORGANIC ELEC & PHO LTG*	20			1.60	5	6			1.90	20	*STUDENT LIGHTING*	6
7	*DRY LAB A&B, STAFF LTG*	20	1.41			7	8	2.20			20	*STAFF LIGHTING*	8
9	*STAFF ADMIN, KITCHEN LTG*	20		1.23		9	10		1.32		20	*CONFERENCE ROOM LTG*	10
11	*DRY LAB, MISC. COMP. LTG*	20			1.28	11	12			1.52	20	*CONFERENCE ROOM LTG*	12
13	*CORRIDOR LIGHTING*	20	0.79			13	14	3.50			20	*SPARE*	14
15	*CORRIDOR LIGHTING*	20		1.54		15	16		3.50		20	*SPARE*	16
17	*CORRIDOR LIGHTING*	20			1.68	17	18			3.50	20	*SPARE*	18
19	*SPARE*	20	3.50			19	20	3.50			20	*SPARE*	20
21	*SPARE*	20		3.50		21	22		3.50		20	*SPARE*	22
23	*SPARE*	20			3.50	23	24			3.50	20	*SPARE*	24
25	*SPARE*	20	3.50			25	26	3.50			20	*SPARE*	26
27	*SPARE*	20		3.50		27	28		3.50		20	*SPARE*	28
29	*SPARE*	20			3.50	29	30			3.50	20	*SPARE*	30
31	*SPARE*	20	3.50			31	32	3.50			20	*SPARE*	32
33	*SPARE*	20		3.50		33	34		3.50		20	*SPARE*	34
35	*SPARE*	20			3.50	35	36			3.50	20	*SPARE*	36
37	*SPARE*	20	3.50			37	38	3.50			20	*SPARE*	38
39	*SPARE*	20		3.50		39	40		3.50		20	*SPARE*	40
41	*SPARE*	20			3.50	41	42			3.50	20	*SPARE*	42
	Subtotals (kVA):		17.03	18.37	18.56			21.99	20.21	20.92		Subtotals (kVA)	
	Total Loads:		Phase A:	39.02 kVA				65.78 %				Demand Factor (worksheet)	
			Phase B:	38.58 kVA				77.02 kVA				Demand Load	
			Phase C:	39.48 kVA				96.27 kVA				Load x 1.25	
	Total Connected Load:		117.08 kVA					115.93 A				AMP	

Figure 3.38: Revised panelboard schedule for HL-3D

BRANCH CIRCUIT PANELBOARD SCHEDULE

Panel Name: HLE-3D	Mounting: Surface:	X	Main Lugs Only:	.	Amp Main CB	150
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: 100%	Number of Poles:	42	TVSS:	.	Isolated Ground Bus	.

CKT No.	Load	TRIP (Amp)	KVA/Phase A	B	C	Poles	Poles	KVA/Phase A	B	C	TRIP (Amp)	Load	CKT No.
1	*EXIT SIGN*	20	0.10			1	2	1.02				*STAIR N-1 LIGHTING*	2
3	*TOILET & CORRIDOR LTG*	20		1.06		3	4		1.45			*STAIR N-1 LIGHTING*	4
5	*OFFICE LIGHTING*	20			2.30	5	6			3.50		*SPARE*	6
7	*SPARE*	20	3.50			7	8	3.50				*SPARE*	8
9	*SPARE*	20		3.50		9	10		3.50			*SPARE*	10
11	*SPARE*	20			3.50	11	12			3.50		*SPARE*	12
13	*SPARE*	20	3.50			13	14	3.50				*SPARE*	14
15	*SPARE*	20		3.50		15	16		3.50			*SPARE*	16
17	*SPARE*	20			3.50	17	18			3.50		*SPARE*	18
19	*SPARE*	20	3.50			19	20	3.50				*SPARE*	20
21	*SPARE*	20		3.50		21	22		3.50			*SPARE*	22
23	*SPARE*	20			3.50	23	24			3.50		*SPARE*	24
25	*SPARE*	20	3.50			25	26	3.50				*SPARE*	26
27	*SPARE*	20		3.50		27	28		3.50			*SPARE*	28
29	*SPARE*	20			3.50	29	30			3.50		*SPARE*	30
31	*SPARE*	20	3.50			31	32	3.50				*SPARE*	32
33	*SPARE*	20		3.50		33	34		3.50			*SPARE*	34
35	*SPARE*	20			3.50	35	36			3.50		*SPARE*	36
37	*PENEL LE-3D VIA*	50	4.94			37	38	3.50				*SPARE*	38
39	*XFMR 'TRE-LE-3D'*			3.80		39	40		3.50			*SPARE*	40
41	*(50G)*	3P			3.80	41	42			3.50		*SPARE*	42
	Subtotals (kVA):		22.54	22.36	23.60			22.02	22.45	24.50		Subtotals (kVA)	
	Total Loads:		Phase A:	44.56 kVA				61.27 %				Demand Factor (worksheet)	
			Phase B:	44.81 kVA				84.23 kVA				Demand Load	
			Phase C:	48.10 kVA				105.28 kVA				Load x 1.25	
	Total Connected Load:		137.5 kVA					126.79 A				AMP	

Figure 3.39: Revised panelboard schedule for HLE-3D

BRANCH CIRCUIT PANELBOARD SCHEDULE													
Panel Name: LR-3D1		Mounting:		Surface:	X			Main Lugs Only:			.	Amp Main CB	110
120/208, 3 Phase, 4 Wire				Flush:	.			Shunt Trip Main:			.	Amp Bus	225
10,000MIN A.I.C. SYM				In MCC	.			Feed Through:			X	Ground Bus	X
Neutral: 200%		Number of Poles:			42			TVSS:			.	Isolated Ground Bus	X
CKT No.	Load	TRIP (Amp)	KVA/Phase A	B	C	Poles	Poles	KVA/Phase A	B	C	TRIP (Amp)	Load	CKT No.
1	*P.C. RECEPTACLE*	20	0.80			1	2	0.80			20	*P.C. RECEPTACLE*	2
3	*RECEPTACLE*	20		1.08		3	4		0.80		20	*P.C. RECEPTACLE*	4
5	*P.C. RECEPTACLE*	20			0.80	5	6			0.80	20	*P.C. RECEPTACLE*	6
7	*RECEPTACLE*	20	1.08			7	8	0.80			20	*P.C. RECEPTACLE*	8
9	*P.C. RECEPTACLE*	20		0.80		9	10		0.80		20	*P.C. RECEPTACLE*	10
11	*RECEPTACLE*	20			0.54	11	12			0.80	20	*P.C. RECEPTACLE*	12
13	*P.C. RECEPTACLE*	20	0.80			13	14	0.80			20	*P.C. RECEPTACLE*	14
15	*SPARE*	20		1.50		15	16		0.80		20	*P.C. RECEPTACLE*	16
17	*P.C. RECEPTACLE*	20			1.16	17	18			0.80	20	*P.C. RECEPTACLE*	18
19	*RECEPTACLE*	20	1.08			19	20	0.80			20	*P.C. RECEPTACLE*	20
21	*P.C. RECEPTACLE*	20		0.72		21	22		0.80		20	*CLEANING RECEPTACLE*	22
23	*P.C. RECEPTACLE*	20			0.90	23	24			0.80	20	*CLEANING RECEPTACLE*	24
25	*P.C. RECEPTACLE*	20	0.72			25	26	0.80			20	*CLEANING RECEPTACLE*	26
27	*RECEPTACLE*	20		0.72		27	28		0.80		20	*CLEANING RECEPTACLE*	28
29	*P.C. RECEPTACLE*	20			0.40	29	30			0.72	20	*STUDY AREA TASK LIGHTING*	30
31	*RECEPTACLE*	20	0.36			31	32	1.50			20	*SPARE*	32
33	*RECEPTACLE*	20		0.72		33	34		1.50		20	*SPARE*	34
35	*SPARE*	20			1.50	35	36			1.50	20	*SPARE*	36
37	*SPARE*	20	1.50			37	38	1.50			20	*SPARE*	38
39	*SPARE*	20		1.50		39	40		1.50		20	*SPARE*	40
41	*SPARE*	20			1.50	41	42			1.50	20	*SPARE*	42
	Subtotals (kVA):		6.34	7.04	6.80			7.00	7.00	6.92		Subtotals (kVA)	
	Total Loads:		Phase A:		13.34 kVA			72.74 %				Demand Factor (worksheet)	
			Phase B:		14.04 kVA			29.90 kVA				Demand Load	
			Phase C:		13.72 kVA			37.37 kVA				Load x 1.25	
	Total Connected Load:				41.10 kVA			103.85 A				AMP	

Figure 3.40: Revised panelboard schedule for LR-3D1

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 No.	Load	TRIP (Amp)	KVA/Phase A	B	C	Poles	Poles	KVA/Phase A	B	C	TRIP (Amp)	Load	CKT No.
1	**ZONE 1 LS LOBBY LTG*	20	0.42			1	2	0.72			20	*ZONE 18 SITE LIGHTING**	2
3	*SPARE*	20		3.50		3	4		3.50		20	*SPARE*	4
5	**ZONE 3 COURTYARD UPLT*	20			1.79	5	6			0.24	20	*ZONE 20 SITE LIGHTING**	6
7	**ZONE 4 LS LOBBY LTG*	20	0.31			7	8	3.50			20	*SPARE*	8
9	**ZONE 5 LS LOBBY LTG*	20		0.56		9	10		0.70		20	*ZONE 22 SITE LIGHTING*	10
11	**ZONE 6 EXTERIOR LTG*	20			1.07	11	12			3.50	20	*SPARE*	12
13	**ZONE 7 ML LOBBY LTG*	20	0.84			13	14	3.50			20	*SPARE*	14
15	**ZONE 8 ML LOBBY LTG*	20		0.56		15	16		3.50		20	*SPARE*	16
17	**ZONE 9 LIGHT WELL FLOOD*	20			2.42	17	18			0.52	20	*ZONE 26 COURTYARD SITE**	18
19	*SPARE*	20	3.50			19	20	0.05			20	*ZONE 27 SITE LIGHTING**	20
21	**ZONE 11 EXTERIOR LTG*	20		1.07		21	22		0.40		20	*ZONE 28 SITE LIGHTING**	22
23	**ZONE 12 ML LOBBY LTG*	20			0.31	23	24			0.27	20	*ZONE 29 EXTERIOR LTG**	24
25	**ZONE 13 EXTERIOR LTG*	20	0.64			25	26	0.27			20	*ZONE 30 EXTERIOR LTG**	26
27	**ZONE 14 EXTERIOR LTG*	20		0.48		27	28		0.23		20	*ZONE 31 EXTERIOR LTG**	28
29	**ZONE 15 SITE LIGHTING*	20			1.70	29	30			0.20	20	*ZONE 32 EXTERIOR LTG**	30
31	**ZONE 16 SITE LIGHTING*	20	1.40			31	32	0.23			20	*ZONE 33 EXTERIOR LTG**	32
33	**ZONE 17 SITE LILGHTING*	20		1.60		33	34		0.27		20	*ZONE 34 EXTERIOR LTG**	34
35	**ZONE 35 ML LOBBY LTG*	20			0.46	35	36			0.42	20	*ZONE 36 LS LOBBY LTG*	36
37	*SPARE*	20	3.50			37	38	3.50			20	*SPARE*	38
39	*SPARE*	20		3.50		39	40		3.50		20	*SPARE*	40
41	*SPARE*	20			3.50	41	42			3.50	20	*SPARE*	42
	Subtotals (kVA):		10.61	11.27	11.25			11.77	12.10	8.65		Subtotals (kVA)	
	Total Loads:		Phase A:		22.38 kVA			66.24% %				Demand Factor	
			Phase B:		23.37 kVA			43.49 kVA				Demand Load	
			Phase C:		19.90 kVA			54.36 kVA				Load x 1.25	
	Total Connected Load:				65.65 kVA			65.46 A				AMP	

Figure 3.41: Revised panelboard schedule for LCP-1

DISTRIBUTION PANEL SCHEDULE

Panel Name: EDPS-M41		Mounting:	Surface:	X	Main Lugs Only:	.	Amp Main CB	1200
277/480, 3 Phase, 4 Wire			Flush:	.	Shunt Trip Main:	.	Amp Bus	1200
65,000MIN A.I.C. SYM			In MCC	.	Feed Through:	.	100% NEUTRAL	

CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*AHU-INT-LS1*	192.00	159.55	75	400A	250A	3	*(3) 4/0 phase conductors, (1) #4 ground in 2"C*
2	*AHU-INT-LS2*	192.00	159.55	75	400A	250A	3	*(3) 4/0 phase conductors, (1) #4 ground in 2"C*
3	*SPACE*							
4	*HMS-0B - HMS-3B*	23.80	20.00		225A	225A	3	*300G*
5	*RO-2*	11.00	9.00	7.5	100A	40A	3	*40G*
6	*PRE-TREATMENT*	7.60	6.32	5	100A	30A	3	*30G*
7	*CONTROL PANEL*	20.00	16.00		100A	30A	3	*30NG*
8	*SPACE*							
9	*EFN-24*	65.00	54.02	50	100A	70A	3	*115G (STAND-BY)*
10	*EFN-26*	72.20	60.00	75	225A	150A	3	*150G (STAND-BY)*
11	*SPARE*	80.00	66.48		100A	100A	3	
12	*SPARE*	180.00	149.58		225A	225A	3	
13								
14								
15								
16								
17								
18								

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Figure 3.42: Revised panelboard schedule for EDPS-M41

DISTRIBUTION PANEL SCHEDULE

Panel Name: EDPS-M42		Mounting:	Surface:	X	Main Lugs Only:	.	Amp Main CB	1600
277/480, 3 Phase, 4 Wire			Flush:	.	Shunt Trip Main:	.	Amp Bus	2500
65,000MIN A.I.C. SYM			In MCC	.	Feed Through:	.	100% NEUTRAL	

CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*AHU-INT-MS1*	192.00	159.55	75	400A	250A	3	*(3) 4/0 phase conductors, (1) #4 ground in 2"C*
2	*AHU-INT-MS2*	192.00	159.55	75	400A	250A	3	*(3) 4/0 phase conductors, (1) #4 ground in 2"C*
3	*ACF-9*	52.00	30.00	40	100A	100A	3	*115G (STAND-BY)*
4	*ACF-10*	52.00	30.00	40	100A	100A	3	*115G*
5	*ACF-11*	34.00	28.00	25	100A	70A	3	*85G*
6	*HMS-0D - HMS-3D*	16.00	13.30		225A	225A	3	*300NG*
7	*ACF-12*	156.00	94.00	125	225A	225A	3	*230G*
8	*VACUUM PUMP (VCP-1)*	104.00	86.42	3(40)	200A	200A	3	*200G - (2 ACTIVE, 1 STAND-BY)*
9	*SPARE*	80.00	66.48		100A	30A	3	
10	*SPARE*	80.00	66.48		100A	30A	3	
11								
12								
13								
14								
15								
16								
17								
18								

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Figure 3.43: Revised panelboard schedule for EDPS-M42

DISTRIBUTION PANEL SCHEDULE

Panel Name: MDP-M41	Mounting: Surface: X	Main Lugs Only: .	Amp Main CB 1000
277/480, 3 Phase, 4 Wire	Flush: .	Shunt Trip Main: .	Amp Bus 1200
65,000MIN A.I.C. SYM	In MCC .	Feed Through: .	100% NEUTRAL

CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*SPACE*							
2	*RTF-1*	40.00	33.00	30	100A	80A	3	*85G*
3	*GWP-12*	34.00	28.00	25	100A	70A	3	*85G (STAND-BY)*
4	*RTF-3*	27.00	21.49	20	100A	60A	3	*60G*
5	*HM-3B - HM-0B*	57.44	47.70		225A	225A	3	*255G*
6	*HL-3B - HL-0B*	166.74	138.00		400A	400A	3	*400NG*
7	*HM-4A*	26.19	21.75		400A	400A	3	*380G*
8	*HL-M4*	9.15	7.60		100A	100A	3	*115NG*
9	*LR-4C VIA 30 KVA XFMR 'TRE-LR-4C'*	18.70	15.50		100A	50A	3	*50G*
10	*SPARE*	180.00	149.58		225A	225A	3	
11	*SPARE*	180.00	149.58		225A	225A	3	
12								
13								
14								
15								
16								
17								
18								

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Figure 3.44: Revised panelboard schedule for MDP-M41

DISTRIBUTION PANEL SCHEDULE

Panel Name: MDP-M42	Mounting: Surface: X	Main Lugs Only: .	Amp Main CB 1600
277/480, 3 Phase, 4 Wire	Flush: .	Shunt Trip Main: .	Amp Bus 2500
65,000MIN A.I.C. SYM	In MCC .	Feed Through: .	100% NEUTRAL

CKT NO.	EQUIPMENT	LOAD (CONN) AMPS	KVA	HP	BREAKER FRAME (AMPS)	TRIP (AMPS)	Poles	WIRE SIZE / REMARKS
1	*AHU-EXT-1*	130.00	108.03	50	225A	175A	3	*(3) 1/0 phase conductors, (1) #6 ground in 1.5"C*
2	*AHU-EXT-2*	130.00	108.03	50	225A	175A	3	*(3) 1/0 phase conductors, (1) #6 ground in 1.5"C*
3	*ACF-12*	96.00	80.00	75	225A	125A	3	*130G*
4	*HM-3D - HM-0D*	159.84	132.73	7.5	400A	400A	3	*400G*
5	*HL-3D - HL-0D*	113.63	94.36	7.5	225.00	225A	3	*255NG*
6	*HM-4B*	37.93	31.50	7.5	400A	400A	3	*380G*
7								
8	*SPARE*	180.00	149.58		225A	225A	3	
9	*SPARE*	180.00	149.58		225A	225A	3	
10	*GWP-11*	34.00	28.00	25	100A	70A	3	*85G*
11	*RTF-2*	27.00	21.49	20	100A	60A	3	*60G*
12								
13								
14								
15								
16								
17								
18								

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Figure 3.45: Revised panelboard schedule for MDP-M42

REVISED PANELBOARD FEEDER SIZING

Each panelboard redesign also includes a resizing of its main circuit protection and feeder. The spare circuits are already sized below allowable maximum current by the National Electric Code by 25%. The NEC multiplier for continuous loads has been applied to the lighting circuits of each panelboard. The following NEC tables have been applied to each panelboard feeder calculation (in order of NEC article):

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	800
5000	700	1200
6000	800	1200

Figure 3.46: NEC Table 250.122 – Raceway and Equipment Grounding Conductor Sizes

Table 310.15(B)(2)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Number of Current-Carrying Conductors	Percent of Values in Tables 310.16 through 310.19 as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

FPN No. 1: See Annex B, Table B.310.11, for adjustment factors for more than three current-carrying conductors in a raceway or cable with load diversity.

Figure 3.47: NEC Table 310.15(B)(2)(a) Adjustments for more than three current carrying conductors

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

	Temperature Rating of Conductor [See Table 310.13(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14*	20	20	25	—	—	—	—
12*	25	25	30	20	20	25	12*
10*	30	35	40	25	30	35	10*
8	40	50	55	30	40	45	8
6	55	65	75	40	50	60	6
4	70	85	95	55	65	75	4
3	85	100	110	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	150	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	190	230	255	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	355	420	475	285	340	385	600
700	385	460	520	310	375	420	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	450	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	520	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	560	665	750	470	560	630	2000
	CORRECTION FACTORS						
Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below.						Ambient Temp. (°F)
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

* See 240.4(D).

Figure 3.48: NEC Table 310.16 - Allowable Ampacities of Insulated Conductors Rated 0-2000V

Table C.1 *Continued*

CONDUCTORS											
	Conductor Size (AWG kcmil)	Metric Designator (Trade Size)									
Type		16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
RHH*, RHW*, RHW-2*, TW, THW, THHW, THW-2	6	1	3	4	8	11	18	32	48	63	81
	4	1	1	3	6	8	13	24	36	47	60
	3	1	1	3	5	7	12	20	31	40	52
	2	1	1	2	4	6	10	17	26	34	44
	1	1	1	1	3	4	7	12	18	24	31
	1/0	0	1	1	2	3	6	10	16	20	26
	2/0	0	1	1	1	3	5	9	13	17	22
	3/0	0	1	1	1	2	4	7	11	15	19
	4/0	0	0	1	1	1	3	6	9	12	16
	250	0	0	1	1	1	3	5	7	10	13
	300	0	0	1	1	1	2	4	6	8	11
	350	0	0	0	1	1	1	4	6	7	10
	400	0	0	0	1	1	1	3	5	7	9
	500	0	0	0	1	1	1	3	4	6	7
	600	0	0	0	1	1	1	2	3	4	6
	700	0	0	0	0	1	1	1	3	4	5
	750	0	0	0	0	1	1	1	3	4	5
	800	0	0	0	0	1	1	1	3	3	5
	900	0	0	0	0	0	1	1	2	3	4
	1000	0	0	0	0	0	1	1	2	3	4
	1250	0	0	0	0	0	1	1	1	2	3
	1500	0	0	0	0	0	1	1	1	1	2
	1750	0	0	0	0	0	0	1	1	1	2
	2000	0	0	0	0	0	0	1	1	1	1

Figure 3.49: Portion of NEC Table C.1 - Maximum current carrying conductors in EMT

Table 4 Dimensions and Percent Area of Conduit and Tubing
(Areas of Conduit or Tubing for the Combinations of Wires Permitted in Table 1, Chapter 9)

Article 358 — Electrical Metallic Tubing (EMT)													
		Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
Metric Designator	Trade Size	mm	in.	mm²	in.²	mm²	in.²	mm²	in.²	mm²	in.²	mm²	in.²
16	½	15.8	0.622	196	0.304	118	0.182	104	0.161	61	0.094	78	0.122
21	¾	20.9	0.824	343	0.533	206	0.320	182	0.283	106	0.165	137	0.213
27	1	26.6	1.049	556	0.864	333	0.519	295	0.458	172	0.268	222	0.346
35	1¼	35.1	1.380	968	1.496	581	0.897	513	0.793	300	0.464	387	0.598
41	1½	40.9	1.610	1314	2.036	788	1.221	696	1.079	407	0.631	526	0.814
53	2	52.5	2.067	2165	3.356	1299	2.013	1147	1.778	671	1.040	866	1.342
63	2½	69.4	2.731	3783	5.858	2270	3.515	2005	3.105	1173	1.816	1513	2.343
78	3	85.2	3.356	5701	8.846	3421	5.307	3022	4.688	1767	2.742	2280	3.538
91	3½	97.4	3.834	7451	11.545	4471	6.927	3949	6.119	2310	3.579	2980	4.618
103	4	110.1	4.334	9521	14.753	5712	8.852	5046	7.819	2951	4.573	3808	5.901

Figure 3.50: Portion of NEC Chapter 9, Table 4 - Percent Area of EMT

Table 8 Conductor Properties

Size (AWG or kcmil)	Area		Conductors: Stranding			Conductors: Overall				Direct-Current Resistance at 75°C (167°F): Copper				Aluminum	
				Diameter		Diameter		Area		Uncoated		Coated			
	mm²	Circular mils	Quantity	mm	in.	mm	in.	mm²	in.²	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
18	0.823	1620	1	—	—	1.02	0.040	0.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1
16	1.31	2580	1	—	—	1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087	0.505	0.154	0.524	0.160	0.829	0.253
1/0	53.49	105600	19	1.89	0.074	9.45	0.372	70.41	0.109	0.399	0.122	0.415	0.127	0.660	0.201
2/0	67.43	133100	19	2.13	0.084	10.62	0.418	88.74	0.137	0.3170	0.0967	0.329	0.101	0.523	0.159
3/0	85.01	167800	19	2.39	0.094	11.94	0.470	111.9	0.173	0.2512	0.0766	0.2610	0.0797	0.413	0.126
4/0	107.2	211600	19	2.68	0.106	13.41	0.528	141.1	0.219	0.1996	0.0608	0.2050	0.0626	0.328	0.100
250	127	—	37	2.09	0.082	14.61	0.575	168	0.260	0.1687	0.0515	0.1753	0.0535	0.2778	0.0847
300	152	—	37	2.29	0.090	16.00	0.630	201	0.312	0.1409	0.0429	0.1463	0.0446	0.2318	0.0707
350	177	—	37	2.47	0.097	17.30	0.681	235	0.364	0.1205	0.0367	0.1252	0.0382	0.1984	0.0605
400	203	—	37	2.64	0.104	18.49	0.728	268	0.416	0.1053	0.0321	0.1084	0.0331	0.1737	0.0529
500	253	—	37	2.95	0.116	20.65	0.813	336	0.519	0.0845	0.0258	0.0869	0.0265	0.1391	0.0424
600	304	—	61	2.52	0.099	22.68	0.893	404	0.626	0.0704	0.0214	0.0732	0.0223	0.1159	0.0353
700	355	—	61	2.72	0.107	24.49	0.964	471	0.730	0.0603	0.0184	0.0622	0.0189	0.0994	0.0303
750	380	—	61	2.82	0.111	25.35	0.998	505	0.782	0.0563	0.0171	0.0579	0.0176	0.0927	0.0282
800	405	—	61	2.91	0.114	26.16	1.030	538	0.834	0.0528	0.0161	0.0544	0.0166	0.0868	0.0265
900	456	—	61	3.09	0.122	27.79	1.094	606	0.940	0.0470	0.0143	0.0481	0.0147	0.0770	0.0235
1000	507	—	61	3.25	0.128	29.26	1.152	673	1.042	0.0423	0.0129	0.0434	0.0132	0.0695	0.0212
1250	633	—	91	2.98	0.117	32.74	1.289	842	1.305	0.0338	0.0103	0.0347	0.0106	0.0554	0.0169
1500	760	—	91	3.26	0.128	35.86	1.412	1011	1.566	0.02814	0.00858	0.02814	0.00883	0.0464	0.0141
1750	887	—	127	2.98	0.117	38.76	1.526	1180	1.829	0.02410	0.00735	0.02410	0.00756	0.0397	0.0121
2000	1013	—	127	3.19	0.126	41.45	1.632	1349	2.092	0.02109	0.00643	0.02109	0.00662	0.0348	0.0106

Figure 3.51: NEC Chapter 9, Table 8 – Conductor Properties

Additionally, the existing panelboard feeders are sized to either 100% or 200% neutral conductor. These conventions will be adopted in the redesign of panelboards.

The feeder and conduit sizing calculations were performed with the above figures and an automatic raceway calculation spreadsheet. The calculation for each panelboard feeder ampacity, wire size, and conduit is as follows:

Panelboard HL-3D:

$$\frac{(117.08\ kVA)(1000)}{(3)(277\ V)} = 140.9\ A, \quad and \quad (140.9\ A)(1.25\ Continuous)(1.25\ Growth) = 220.14\ A$$

Panelboard HLE-3D:

$$\frac{(124.93\ kVA)(1000)}{(3)(277\ V)} = 150.3\ A, \quad and \quad (150.3\ A)(1.25\ Continuous) = 187.92\ A\ Lighting$$

$$\frac{(12.54\ kVA)(1000)}{(3)(277\ V)} = 15.09\ A\ Other\ Loads$$

$$Total\ Ampacity = (187.92 + 15.09)(1.25\ Growth) = 253.76\ A$$

Panelboard LR-3D1:

$$\frac{(0.72\ kVA)(1000)}{(3)(120\ V)} = 2.00\ A, \quad and \quad (2.00\ A)(1.25\ Continuous) = 2.50\ A\ Lighting$$

$$\frac{(25.28\ kVA)(1000)}{(3)(120\ V)} = 70.2\ A\ Other\ Loads$$

$$\frac{(15.10\ kVA)(1000)}{(3)(120\ V)} = 41.9\ A, \quad and \quad (41.9\ A)(1.25\ Harmonics) = 52.43\ A\ Computers$$

$$Total\ Ampacity = \frac{(2.50 + 70.2 + 52.43)(1.25\ Growth)}{0.80\ for\ five\ conductors} = 195.52\ A$$

With the large number of computer loads on this panel, the neutral will be doubled. This will cause a de-rating in wire ampacity since there will be five current carrying conductors in the conduit.

Panelboard LCP-1:

$$\frac{(65.65\ kVA)(1000)}{(3)(277\ V)} = 79.0\ A, \quad and \quad (79.0\ A)(1.25\ Continuous)(1.25\ Growth) = 123.44\ A$$

The above calculations are summarized in the following table for all panelboards in the redesign:

Panelboard				
Tag	HL-3D	HLE-3D	LR-3D1	LCP-1
Voltage System	480Y/277 V	480Y/277 V	208Y/120 V	480Y/277 V
Calculated Design Load (kW)	147.64	169.01	46.94	83.55
Calculated Power Factor	0.807	0.801	0.833	0.81
Calculated Design Load (kVA)	182.94	210.88	56.32	102.58
Calculated Design Load (A)	220.14	253.76	156.44*	123.44
Feeder				
Feeder Protection Size	125 A	150 A	110 A	70 A
Number of Sets	1	1	1	1
Wire Size				
Phase	(3) 4/0	(3) 250 kcmil	(3) 3/0	(3) #1
Neutral	(1) 4/0	(1) 250 kcmil	(2) 3/0	(1) #1
Ground	#6	#6	#6	#8
Wire Area (Sq. in.) (Table above)				
Each Phase	0.3718	0.4598	0.3117	0.1901
Total – All Phases	1.1154	1.3788	0.9351	0.5703
Neutral	0.3718	0.4598	0.6234	0.1901
Ground	0.0726	0.0726	0.0726	0.0437
Total – All Wires	1.5598	1.911	1.6311	0.8041
Minimum Conduit Area (Sq. in.) (Above x 2.5)	4.0513	4.9293	4.1395	4.1395
Conduit Size (NEC Chapter 9, Table 4)	2.50" EMT	2.50" EMT	2.50" EMT	2.50" EMT
Conduit Size (NEC Table C.1)	2.50" EMT	2.50" EMT	2.50" EMT	2.50" EMT
Feeder Length	207 ft.	25 ft.	140 ft.	140 ft.
Final Voltage Drop (V)	4.80	0.60	1.70	1.70
Final Voltage Drop (%)	1.00%	0.12%	1.4%	1.4%
Feeder Re-sizing	Not Needed	Not Needed	Not Needed	Not Needed

The final panelboard redesigns include circuits affected by mechanical system design changes. To size the feeder into the units, the National Electrical Code Table 430.250 below was used.

Table 430.250 Full-Load Current, Three-Phase Alternating-Current Motors

The following values of full-load currents are typical for motors running at speeds usual for belted motors and motors with normal torque characteristics.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120, 220 to 240, 440 to 480, and 550 to 600 volts.

	Induction-Type Squirrel Cage and Wound Rotor (Amperes)							Synchronous-Type Unity Power Factor* (Amperes)			
Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts	575 Volts	2300 Volts	230 Volts	460 Volts	575 Volts	2300 Volts
½	4.4	2.5	2.4	2.2	1.1	0.9	—	—	—	—	—
¾	6.4	3.7	3.5	3.2	1.6	1.3	—	—	—	—	—
1	8.4	4.8	4.6	4.2	2.1	1.7	—	—	—	—	—
1½	12.0	6.9	6.6	6.0	3.0	2.4	—	—	—	—	—
2	13.6	7.8	7.5	6.8	3.4	2.7	—	—	—	—	—
3	—	11.0	10.6	9.6	4.8	3.9	—	—	—	—	—
5	—	17.5	16.7	15.2	7.6	6.1	—	—	—	—	—
7½	—	25.3	24.2	22	11	9	—	—	—	—	—
10	—	32.2	30.8	28	14	11	—	—	—	—	—
15	—	48.3	46.2	42	21	17	—	—	—	—	—
20	—	62.1	59.4	54	27	22	—	—	—	—	—
25	—	78.2	74.8	68	34	27	—	53	26	21	—
30	—	92	88	80	40	32	—	63	32	26	—
40	—	120	114	104	52	41	—	83	41	33	—
50	—	150	143	130	65	52	—	104	52	42	—
60	—	177	169	154	77	62	16	123	61	49	12
75	—	221	211	192	96	77	20	155	78	62	15
100	—	285	273	248	124	99	26	202	101	81	20
125	—	359	343	312	156	125	31	253	126	101	25
150	—	414	396	360	180	144	37	302	151	121	30
200		552	528	480	240	192	49	400	201	161	40

Figure 3.52: NEC Table 430.250 FLA for 3-Phase Motors

The panelboard feeder design for EDPS-M41, EDPS-M42, MDP-M41, and MDP-M42 consists of removing ACFs numbers 1-8 and replacing them with the following equipment:

Mechanical System Redesign Air Handling Units					
Tag	Manufacturer	Product	Supply Fan (hp)	Exhaust Fan (hp)	Total NEC Current (A)*
AHU-INT-LS1	SEMCO	EP Series 43	75	75	192.00
AHU-INT-LS2	SEMCO	EP Series 43	75	75	192.00
AHU-EXT-1	SEMCO	EP Series 35	50	50	130.00
AHU-EXT-2	SEMCO	EP Series 35	50	50	130.00
AHU-INT-MS1	SEMCO	EP Series 43	75	75	192.00
AHU-INT-MS2	SEMCO	EP Series 43	75	75	192.00
*NEC current sized from Table 430.250					

Switchboards EDPS-M41, EDPS-M42, MDP-M41, and MDP-M42

The switchboards that have been affected by mechanical system redesign are still under design in the documents accessible to KGB Maser. However, the feeders for each switchboard and the main circuit protection will be sized per the minimum sizing in Article 215.2(A)(1) of the National Electrical Code. The process includes summing the total current (including 80% of spare breaker ratings) and kVA on the panel and multiplying by 125% before multiplying by an assumed power factor of 0.80. The sizing is summarized in the table below:

Switchboard					
Tag		EDPS-M41	EDPS-M42	MDP-M41	MDP-M42
Voltage System		480Y/277V	480Y/277V	480Y/277V	480Y/277V
Calculated Design Load (kW)		700.87	796.10	614.29	904.46
Calculated Power Factor		0.80	0.80	0.80	0.80
Calculated Design Load (kVA)		876.08	955.12	767.86	1130.58
Calculated Design Load (A)		1054.25	1197.50	924.03	1360.50
Feeder					
Feeder Protection Size		1200A	1600A*	1000A	1600A
Number of Sets		3	4	3**	4***
Wire Size					
	Phase	500 kcmil	350 kcmil	350 kcmil	500 kcmil
	Neutral	500 kcmil	350 kcmil	350 kcmil	500 kcmil
	Ground	3/0	4/0	2/0	4/0
Wire Area (Sq. in.) (Table above)					
	Each Phase	0.7901	0.5958	0.5958	0.7901
	Total – All Phases	2.3703	1.7874	1.7874	2.3703
	Neutral	0.7901	0.5958	0.5958	0.7901
	Ground	0.3117	0.3718	0.2624	0.3718
	Total – All Wires	3.4721	2.7550	2.6456	3.5322
Minimum Conduit Area (Sq. in.) (Above x 2.5)		8.6803	6.8875	6.6140	8.8305
Conduit Size (NEC Chapter 9, Table 4)		3.0" EMT	3.0" EMT	3.0" EMT	3.0" EMT
Conduit Size (NEC Table C.1)		3.0" EMT	3.0" EMT	3.0" EMT	3.0" EMT
Feeder Length		300 ft.	150 ft.	750 ft.	750 ft.
Final Voltage Drop (V)		2.7	1.7	8.5	6.6
Final Voltage Drop (%)		0.97%	0.61%	3.07%	2.38%
Feeder Re-sizing		Not Needed	Not Needed	500 kcmil**	See Below
*Main circuit protection is too close to the next breaker size to be considered free from accidental trip **Feeder size change to 4 sets of (3) 500 kcmil + (1) 500 kcmil neutral to yield 4.5V (1.62%) drop ***Voltage drop calculation yields adding an extra set with the same 500 kcmil cables					

DIMMING AND WIRING DIAGRAMS

Please note that some of the information provided in the following diagrams was obtained through brochures. They are mostly schematic-level diagrams and would need manufacturer consulting to install properly. Standard wiring diagrams have been omitted including individual shade motor control and office wall wash application.

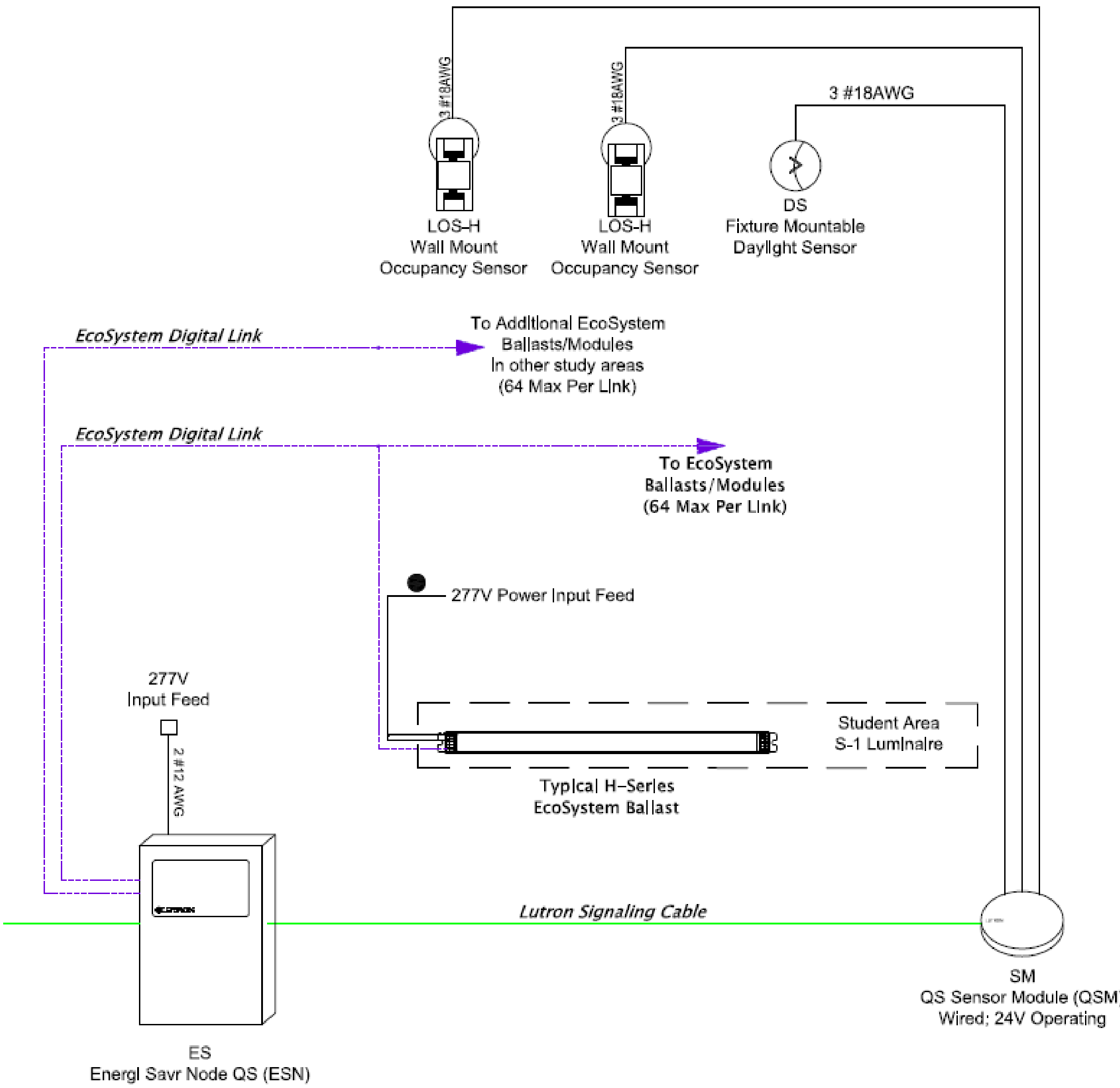

Figure 3.53: Student Study Area overhead control wiring diagram

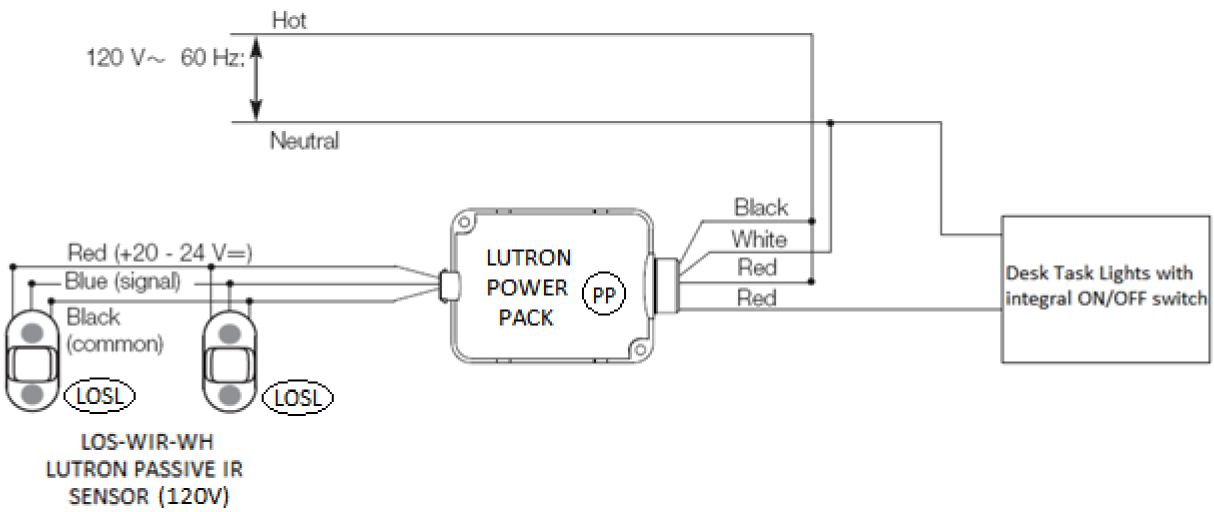

Figure 3.54: Student Study Area task control wiring diagram

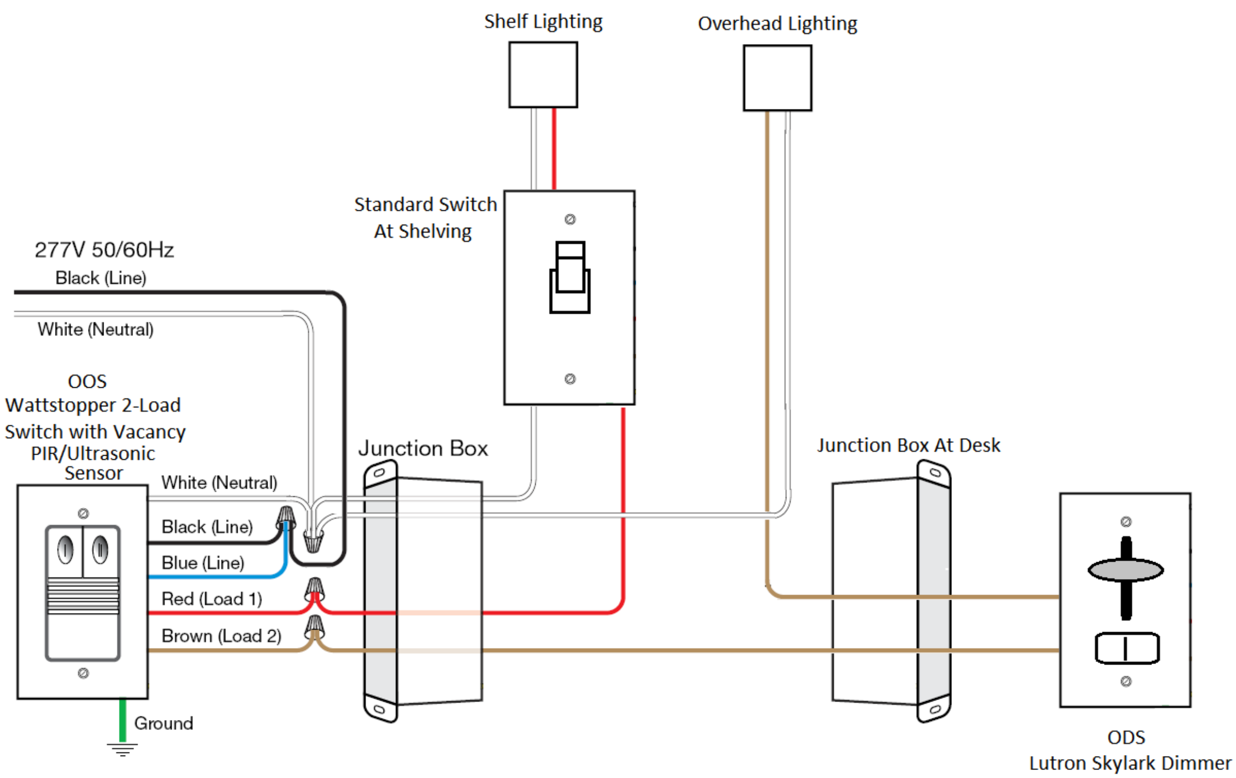

Figure 3.55: Office overhead and task control wiring diagram

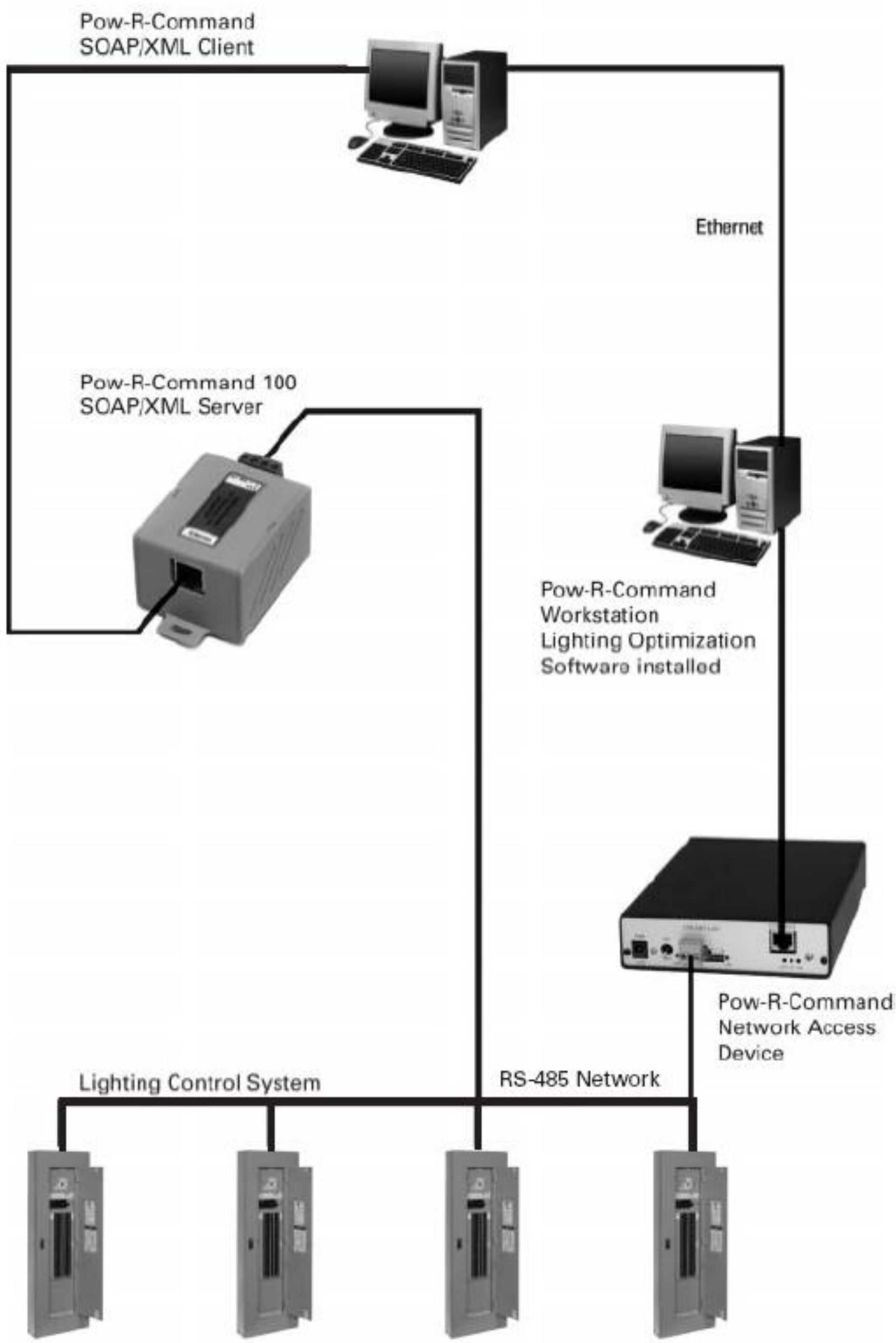

Figure 3.56: Courtyard control wiring diagram *Limited information from manufacturer

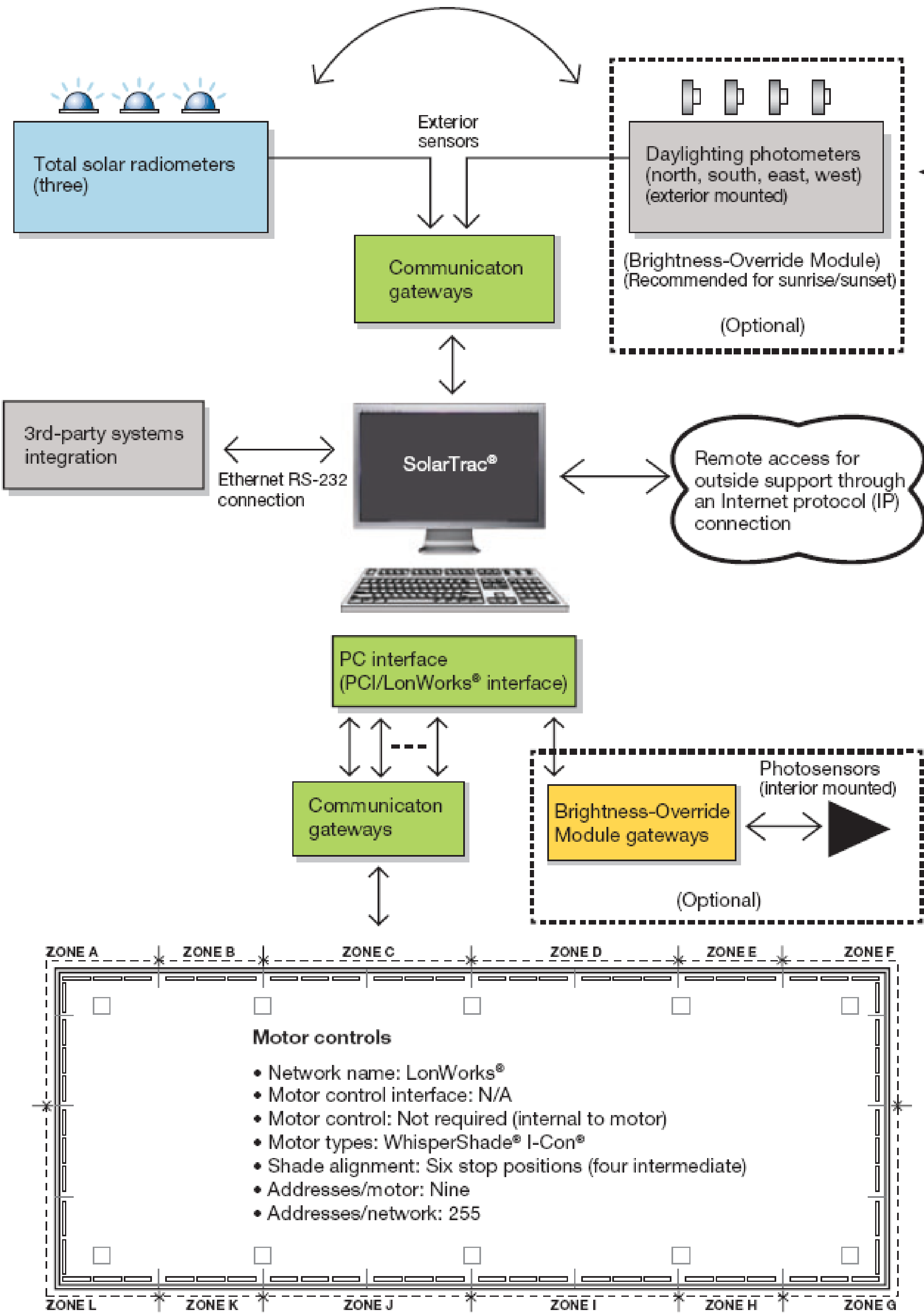

Figure 3.57: Automatic shading control diagram from MechoShade Solar Trac brochure

SHORT CIRCUIT CALCULATION

As part of the requirements for AE482, a hand calculation for short circuit capacity for a section of the power system will be performed. Figure 3.58 illustrates the fault current path that will be used for the short circuit calculation. Utility contribution was calculated from information gained from Penn State OPP. The two utility transformers for the Millennium Science Complex have different short circuit contributions to the calculation. PSU-1, the left transformer, contributes 37,246 A while PSU-2, the right transformer, will contribute 34,732 A. However, since the transformer secondary available fault current was given, that is where the given calculation information will begin. This calculation will be performed using the per-unit method with a base kVA of 10,000. Impedance values for distribution equipment, excluding conductors, have been taken from the SKM model used to perform Depth Topic 1. Using the per-unit method, the available short circuit current at any point can be determined by the following equation:

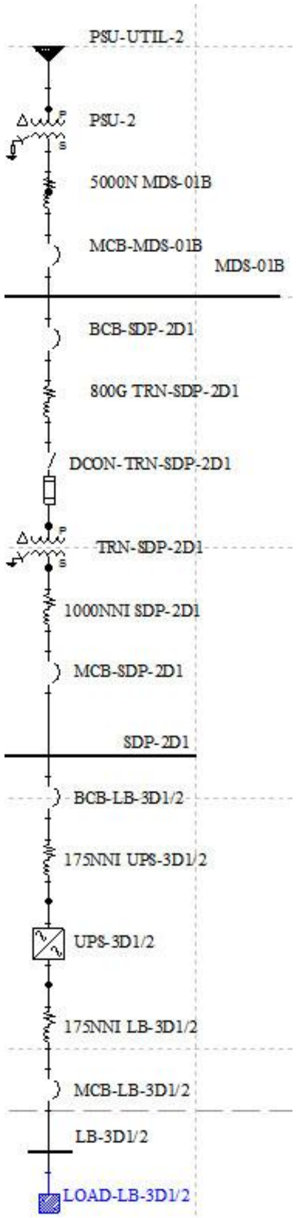

Figure 3.58: Short circuit hand calculation path

$$I_{SC} = \frac{10{,}000kVA}{(\sqrt{3})(kV\ at\ short)\left(\sum_{utility}^{calc\ point} Z_u\right)}$$

Once at PSU-2, the transformer's per-unit impedance and resistance were calculated as follows (typical for other transformers):

$$X_u = \frac{(0.0573)(10{,}000kVA_{base})}{5{,}000kVA_{rating}} = 0.1146$$

$$R_u = \frac{(0.00478)(10{,}000kVA_{base})}{5{,}000kVA_{rating}} = 0.00956$$

$$Z_u = \sqrt{0.1146^2 + 0.00956^2} = 0.114997$$

Since the given information starts at the secondary side of the service transformer, the utility contribution must be calculated in the opposite direction of the short circuit calculation, using the equation for short circuit current above:

$$34{,}372A = \frac{10{,}000kVA}{(\sqrt{3})(0.480)(0.114997 + Z_{utility})}$$

$$28576.34(0.114997 + Z_{utility}) = 10{,}000$$

$$Z_{utility} = 0.23494$$

Now that the utility impedance value has been calculated, the utility contribution in MVA can be obtained. Assuming no resistance from the utility, the following equation can be used to calculate the utility contribution:

$$Utility\ X_u = Utility\ Z_u = \frac{10{,}000kVA_{base}}{(Utility\ MVA)(1000)}$$

$$0.23494 = \frac{10{,}000kVA_{base}}{(Utility\ MVA)(1000)}$$

$$Utility\ MVA = \frac{10{,}000kVA_{base}}{(0.23494)(1000)} = 42.56\ MVA$$

Now the calculation is fluid from the utility contribution through the service transformer. Following the service transformer, the feeder to MDS-01B can be calculated for its contribution to mitigating the available short circuit current as follows (typical for all cable contributions):

Feeder MDS-01B Contribution
600 kcmil, 30ft feeder, 480V

$$X = \frac{(0.038)(30ft)}{(1000ft)(12\ sets)} = 0.000095 \qquad R = \frac{(0.024)(30ft)}{(1000ft)(12\ sets)} = 0.000065$$

$$X_u = \frac{(0.019)(10{,}000kVA_{base})}{(1000)(0.48kV_{system}^2)} = 0.004 \qquad R_u = \frac{(0.012)(10{,}000kVA_{base})}{(1000)(0.48kV_{system}^2)} = 0.003$$

The table below summarizes the calculations for the circuit displayed in Figure 3.58 at the beginning of this section, excluding overcurrent protection:

$$Base\ kVA = 10{,}000 \qquad Utility\ MVA = 42.56 \qquad Utility\ X_u = \frac{10{,}000kVA}{(42.56MVA)(1000)} = 0.235$$

Equipment Characteristics											Per-Unit Value Table				
Mark	%X	%R	%Z	kVA	X/1000ft	R/1000ft	Z/1000ft	Length	# sets	3Ph Voltage (V)	Mark	Xu	Ru	Zu	Isc
Utility	0.235			42563.553						12470	Utility	0.235		0.235	
															1970.656
PSU-2	5.730	0.478	5.750	5000.000							PSU-2	0.115	0.010	0.115	
															34371.978
FEEDER MDS-01B					0.038	0.018	0.042	30.000	12.000	480	FEEDER MDS-01B	0.004	0.002	0.005	
															33931.372
MDS-01B											MDS-01B				
															33931.372
FEEDER TRN-SDP-2D1					0.039	0.022	0.045	1000.000	2.000	480	FEEDER TRN-SDP-2D1	0.846	0.484	0.975	
															9047.603
TRN-SDP-2D1	2.070	4.000	4.504	300.000							TRN-SDP-2D1	0.690	1.333	1.501	
															9805.714
FEEDER SDP-2D1					0.040	0.033	0.052	154.000	3.000	208	FEEDER SDP-2D1	0.475	0.393	0.616	
															8053.162
SDP-2D1											SDP-2D1				
															8053.162
FEEDER UPS-3D1/2					0.043	0.101	0.110	200.000	1.000	208	FEEDER UPS-3D1/2	1.988	4.669	5.075	
															3257.397
UPS-3D1/2	0.992	0.012	0.992	50.000							UPS-3D1/2	1.984	0.025	1.984	
															2642.175
FEEDER LB-3D1/2					0.043	0.101	0.110	10.000	1.000	208	FEEDER LB-3D1/2	0.099	0.233	0.254	
															2579.866
LB-3D1/2											LB-3D1/2				

OVERCURRENT PROTECTION COORDINATION

The previous section calculates available short circuit for a sample path through the Millennium Science Complex. This section provides sample breaker coordination for the said section of the distribution system. The image in this section was composed by overlaying breaker time current curves within image editing software and lining up transparencies at the appropriate scale on each axis. Two of the overcurrent devices in this section are supplied by 480V equipment (MCB MDS-01B and BCB SDP-2D1) and three are at 208V (MCB SDP-2D1, BCB UPS-3D1/2, and MCB LB-3D1/2).

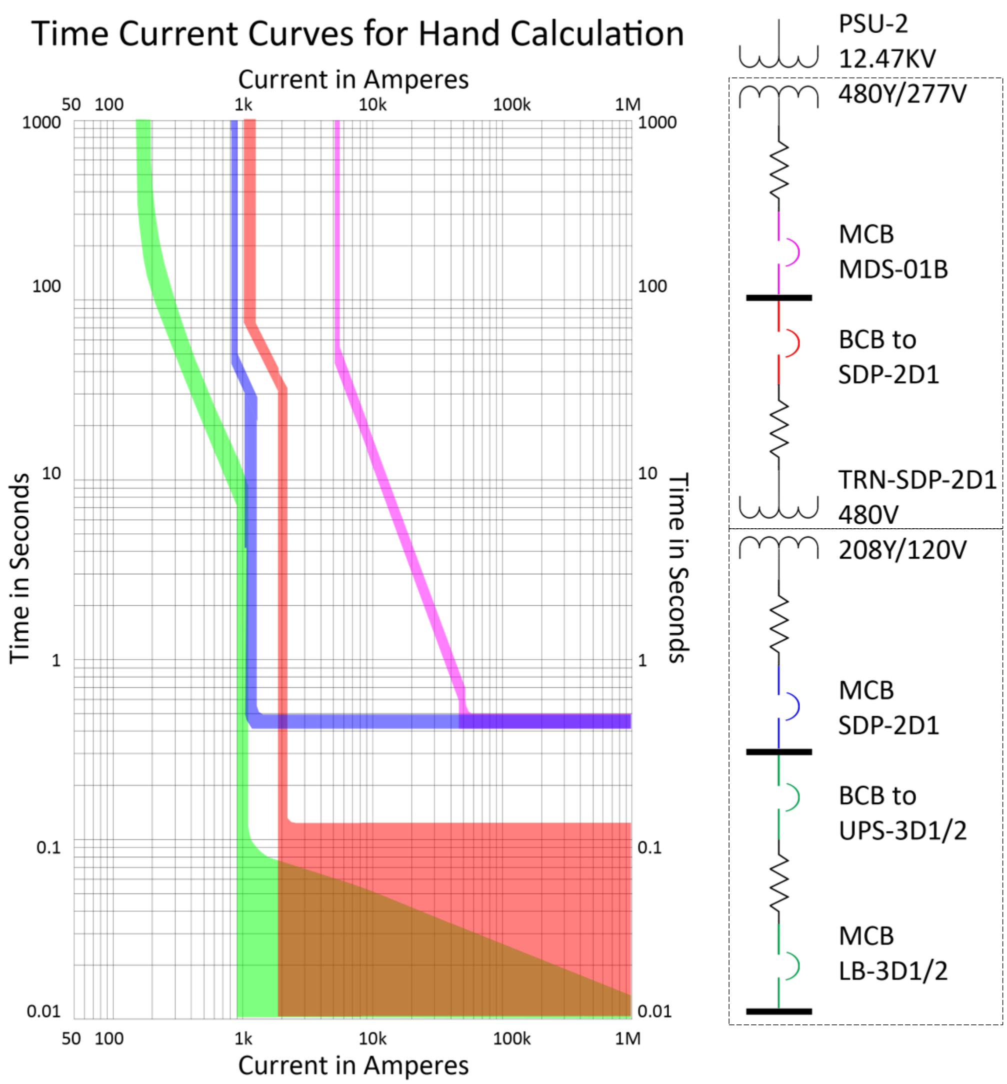

Figure 3.59: Short Circuit Path Device Coordination with One-Line Section

Unique to this path through the distribution system is the extensive use of digital-trip units. All circuit protection ahead of distribution panelboard SDP-2D1 utilizes digital trips. These units are very flexible and allow for custom time-current curves. To complete this analysis, the thermal-magnetic trip units after distribution panelboard SDP-2D1 must be plotted on the time-current graph first. Once the non-negotiable time-current curve is set, the digital trip units can be customized around it. The largest challenge in applying digital trip units is selecting the settings for the unit. This exercise was attempted to the best of the ability of the student. The following Eaton Electrical time-current curves were combined to compose the figure above:

Overcurrent Protection Data				
Device Name	Voltage	Frame Size (A)	Trip Rating (A)	Eaton Time-Current Curve(s)
MCB MDS-01B	480Y/277V	5000	5000	70C1006 70C1007 70C1008
BCB SDP-2D1	480Y/277V	800	800	70C1010 70C1295 70C1296
MCB SDP-2D1	208Y/120V	1200	1000	SC-5376-92A SC-5377-92A
BCB UPS-3D1/2	208Y/120V	225	175	SC-4247-87C
MCB LB-3D1/2	208Y/120V	225	175	SC-4247-87C

If each voltage system is addressed individually, the overcurrent protection is coordinated effectively. Once the figure above is separated, it is easier to visualize the two different voltage systems:

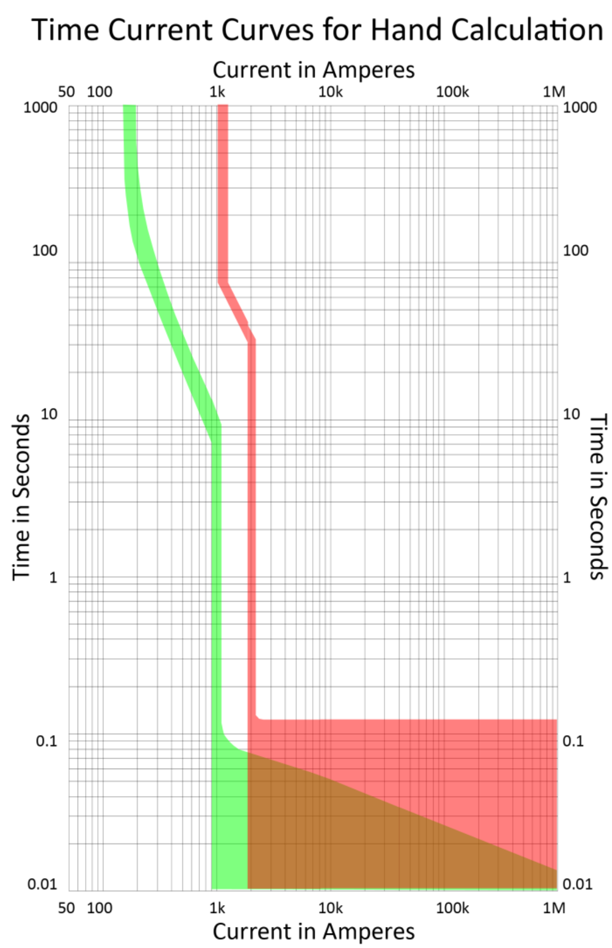

Figure 3.60: 208V Breaker Coordination

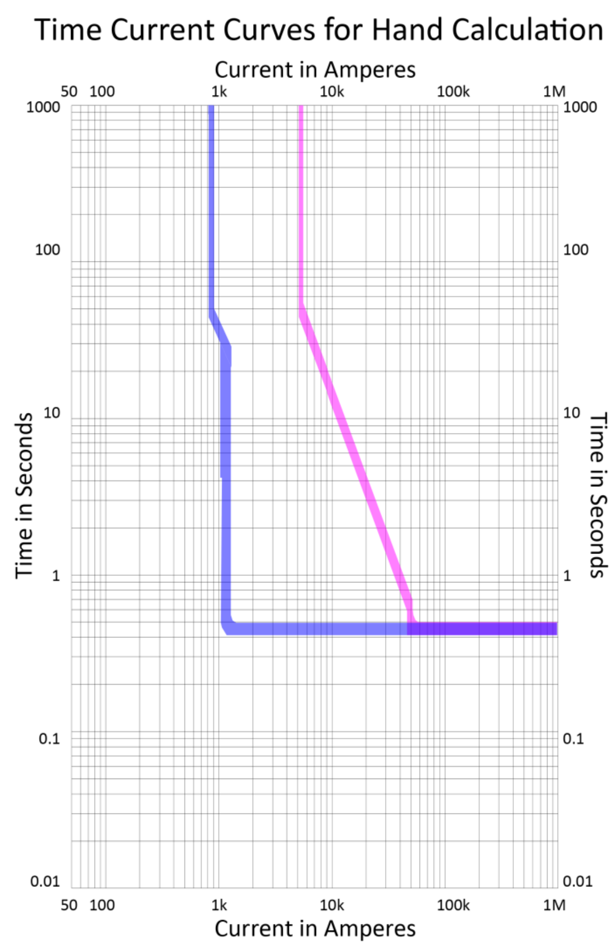

Figure 3.61: 480V Breaker Coordination

From the above images, it can be inferred that the down-stream breaker will trip in overload conditions. The instantaneous trip function overlaps in each scenario for a portion of the curve. Under those conditions, one or both breakers will trip.

ELECTRICAL DEPTH TOPICS

TOPIC 1: SYSTEM MODELING IN SKM

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 the table below:

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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
	Lvl 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
	Pent.	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.
		LS-3B	W-P338	*E2.3B-P*	208/120V	100A	10 kAIC Min.
	3C	LB-3C1/2	W-Q302	*E2.3C-P*	208/120V	150A	10 kAIC Min.
		LR-3C1/2	N-Q307	*E2.3C-P*	208/120V	225A	10 kAIC Min.
	Level 3D	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.
	Lvl	**Name**	**Location**	***Enl. Plan***	**Rating**	**Poles/Ph/Voltage**	**Series Rating**
Distribution Equipment	Mezz.	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		-----

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

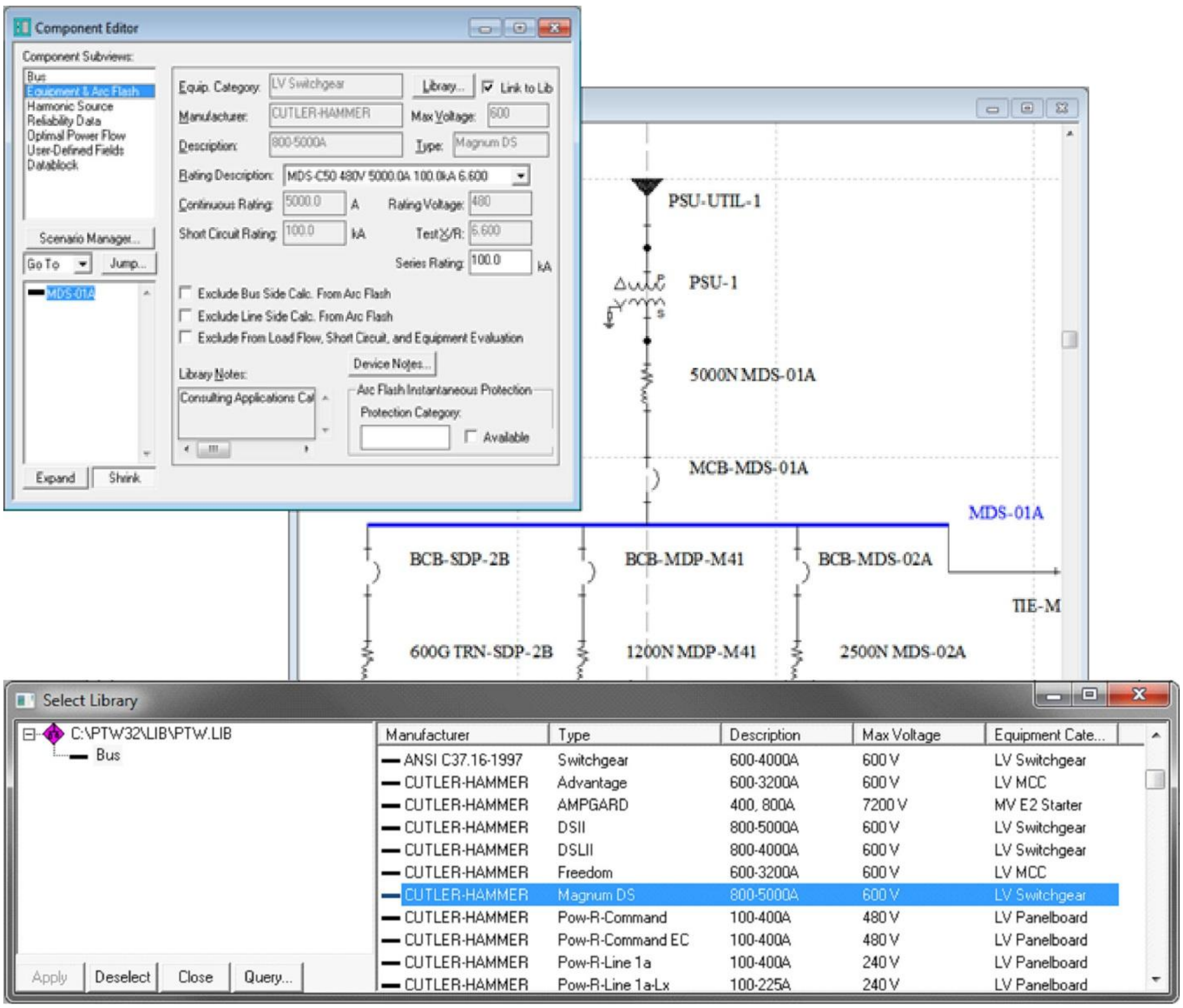

Figure 3.62: MDS-01A Equipment Inputs

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 3.63 below:

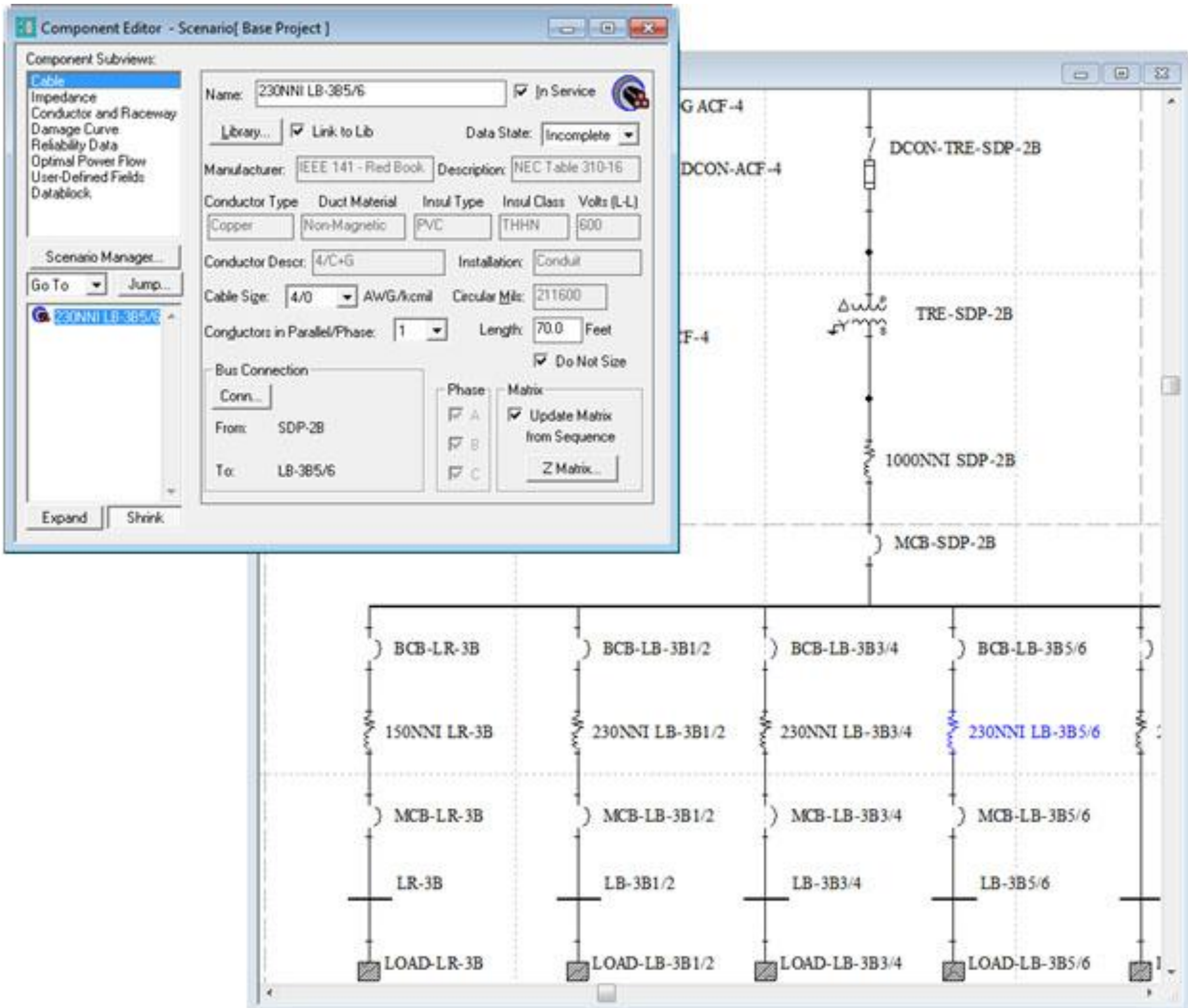

Figure 3.63: Wire Sizing in SKM

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 3.64 below:

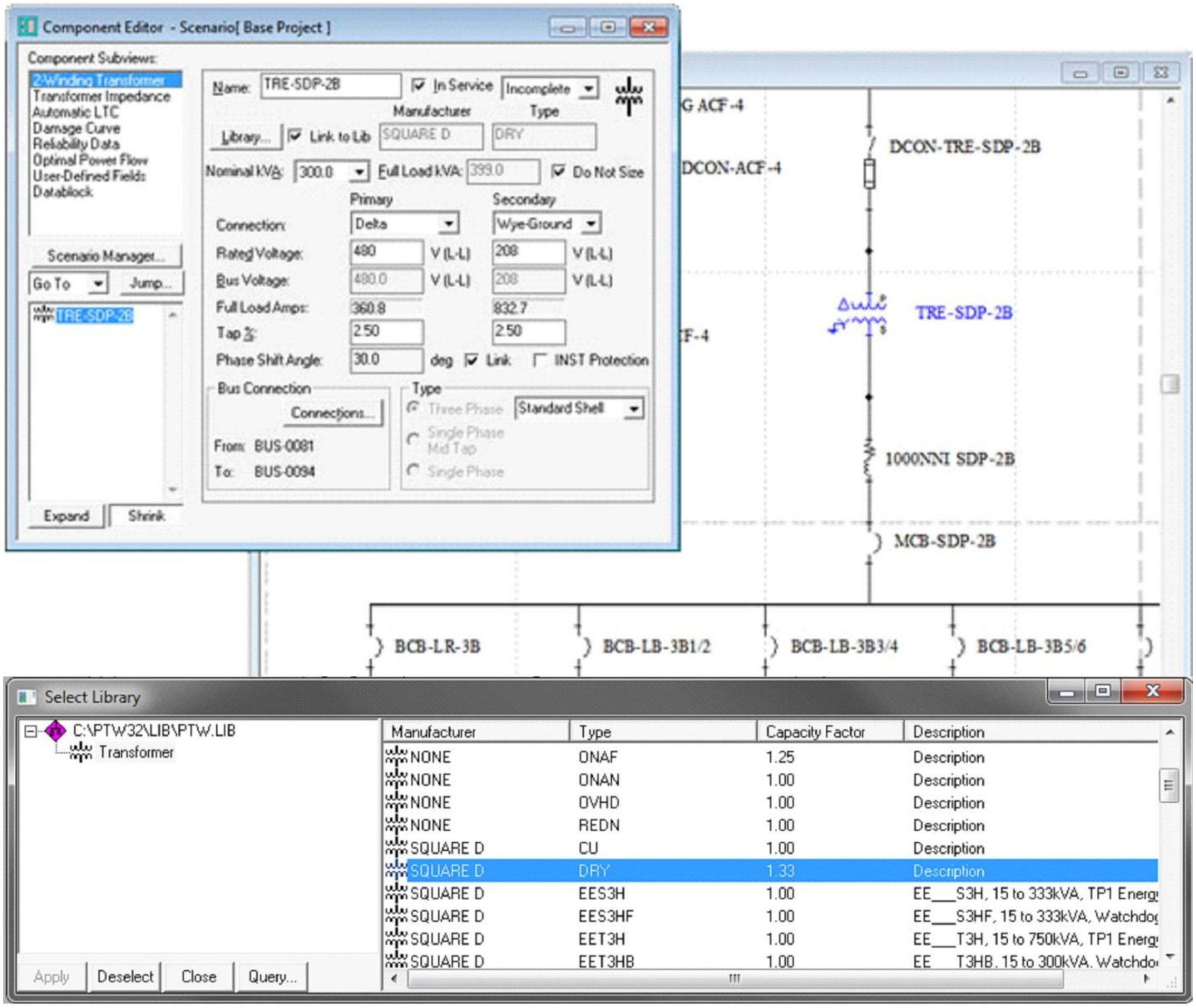

Figure 3.64: Transformer Inputs in SKM

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 3.65 and 3.66 below illustrate the inclusion of an induction motor load and non-motor panelboard load for the third floor of the Millennium Science Complex.

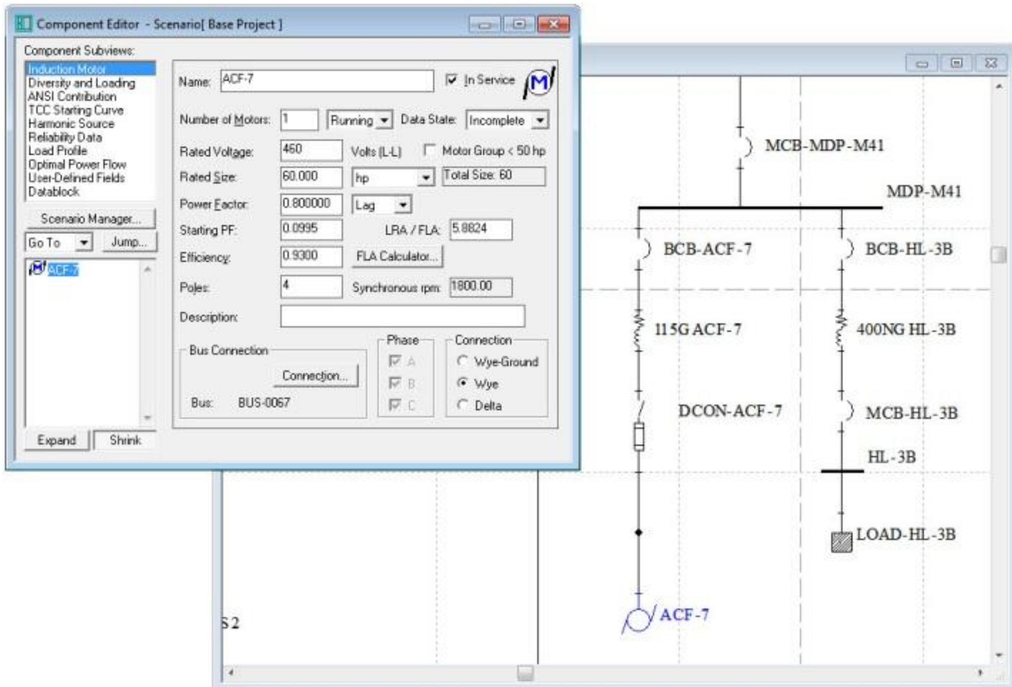

Figure 3.65: Induction Motor Inputs in SKM

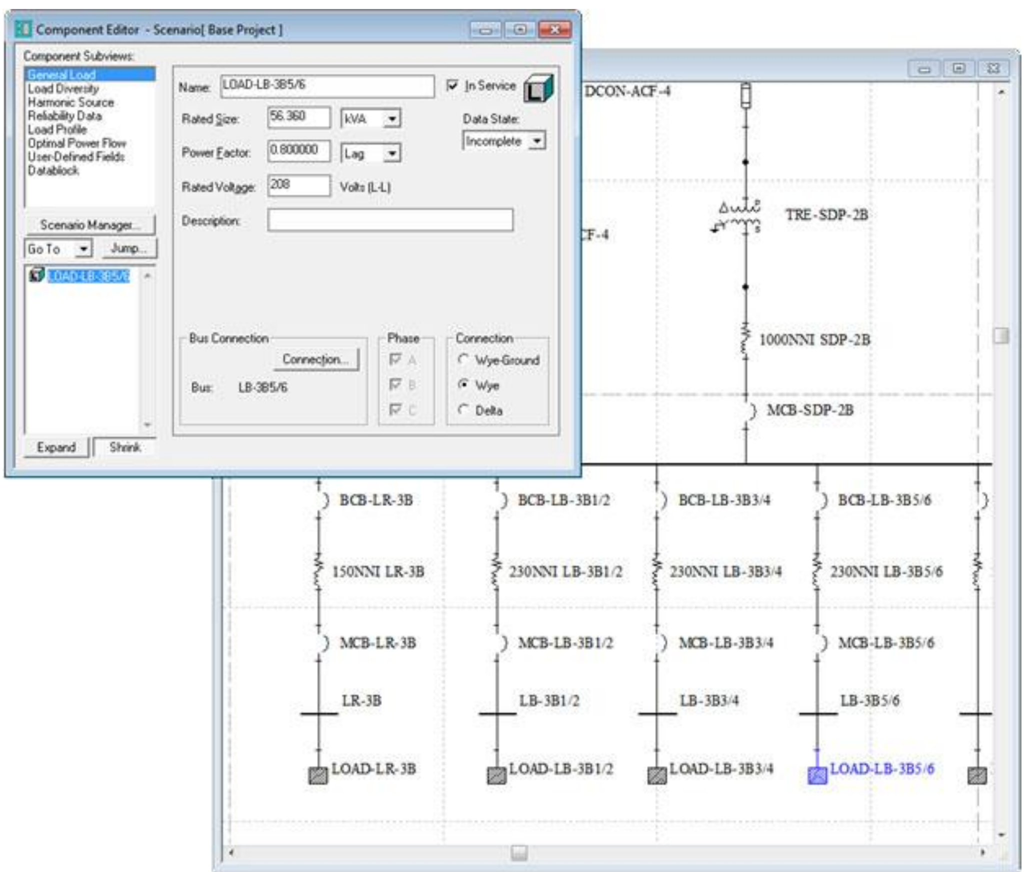

Figure 3.66: Non-Motor Load Inputs in SKM

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

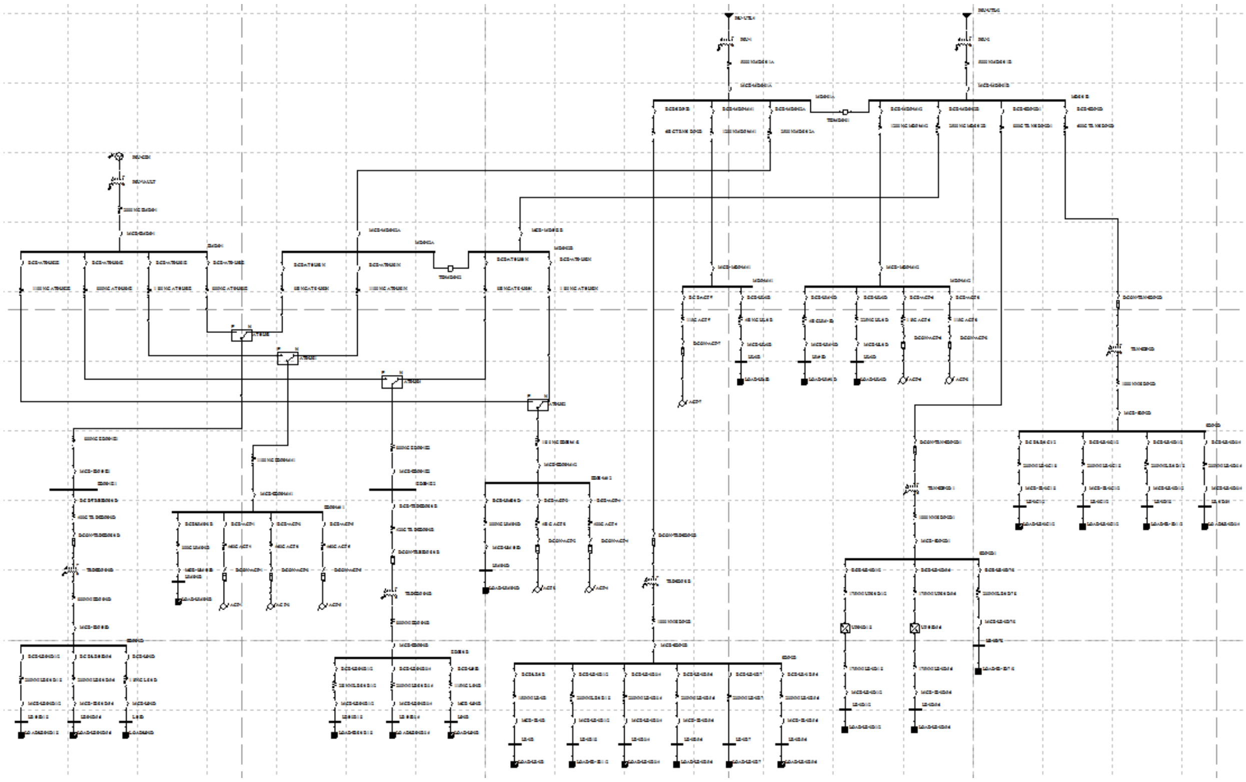

Figure 3.67: Millennium Science Complex third floor service equipment one-line diagram

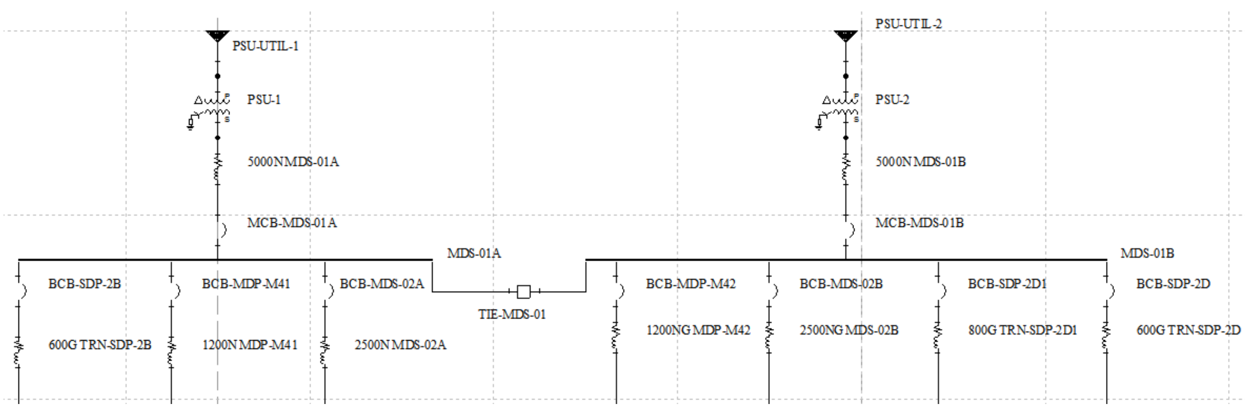

Figure 3.68: MDS-01A and MDS-01B one-line diagram

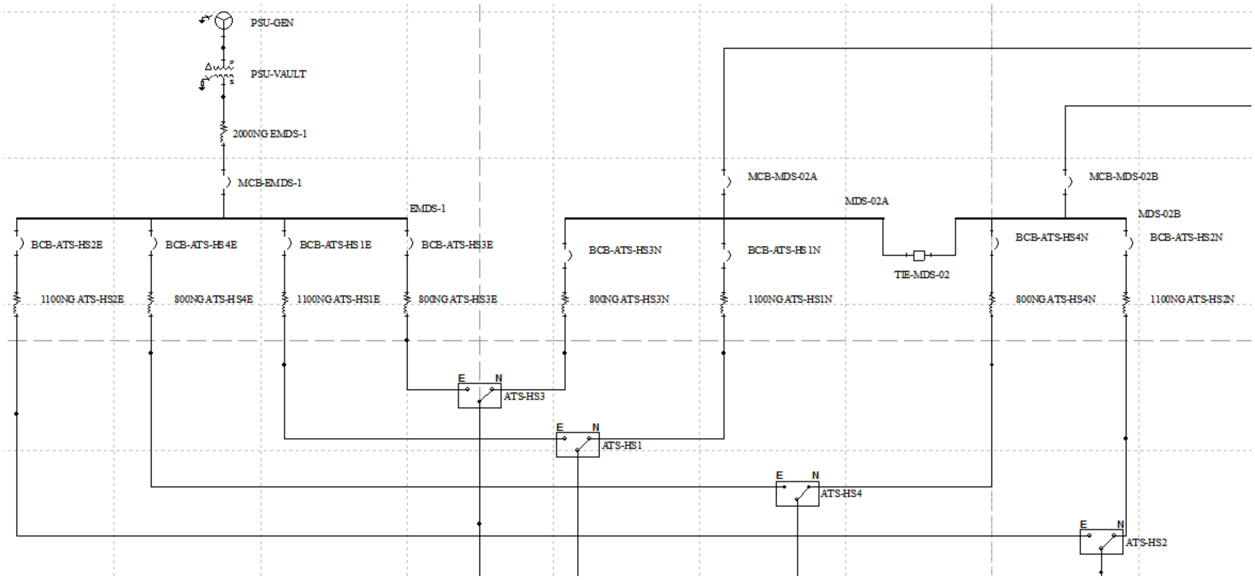

Figure 3.69: EMDS-1, MDS-02A, MDS-02B, and ATSs one-line diagram

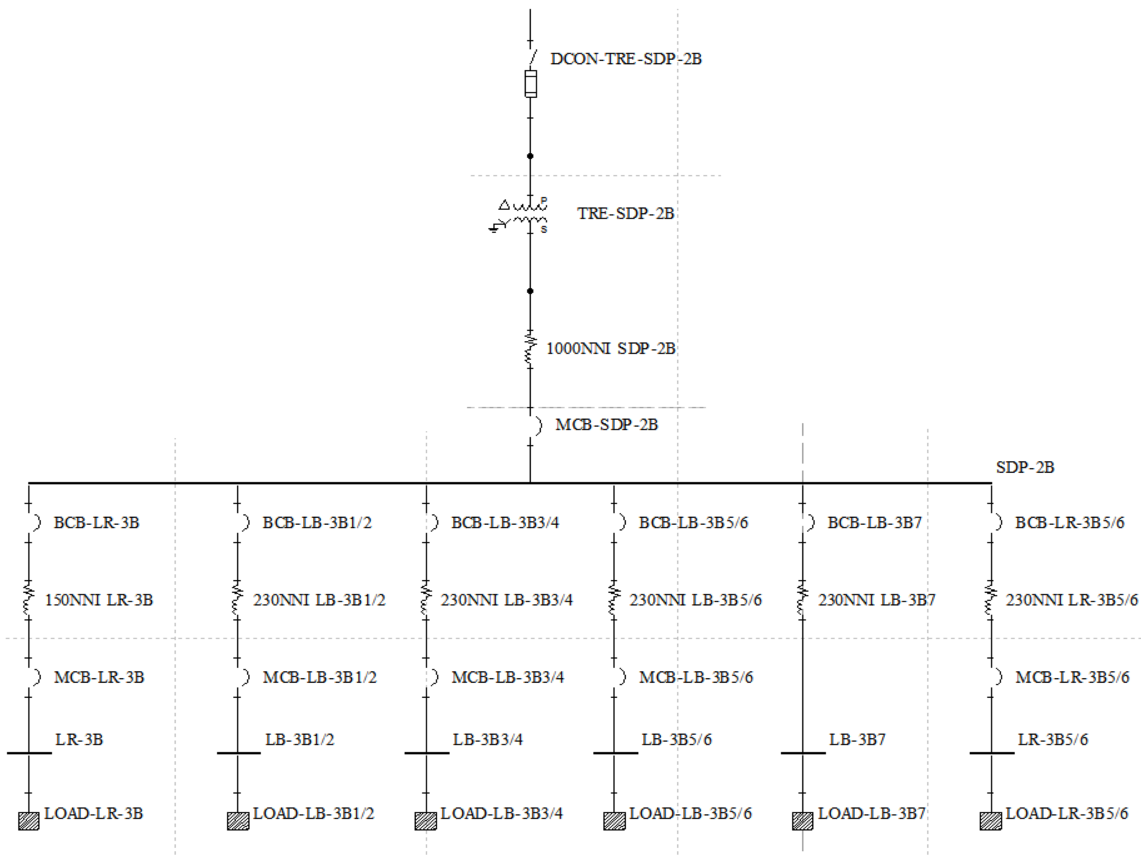

Figure 3.70: SDP-2B and loads one-line diagram

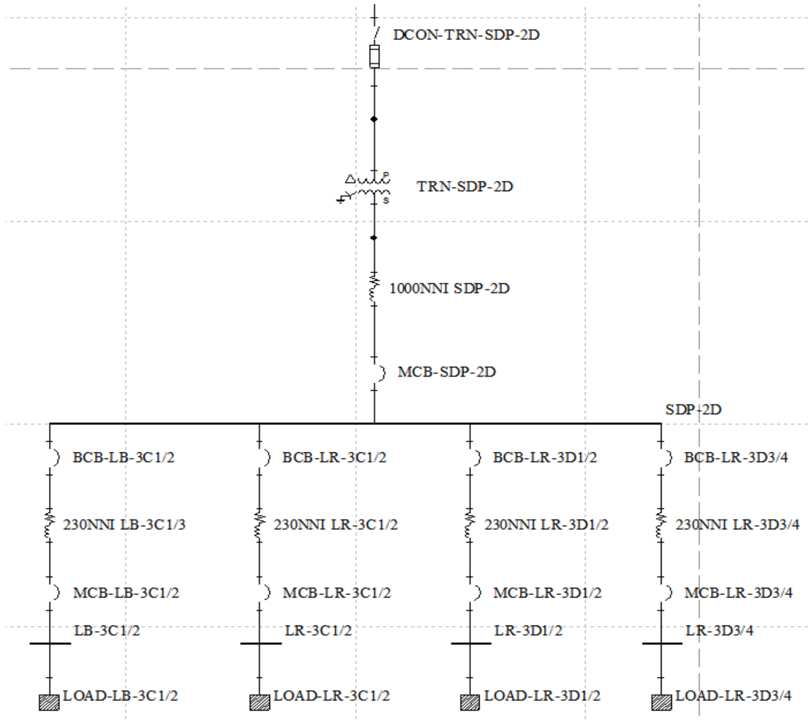

Figure 3.71: SDP-2D and loads one-line diagram

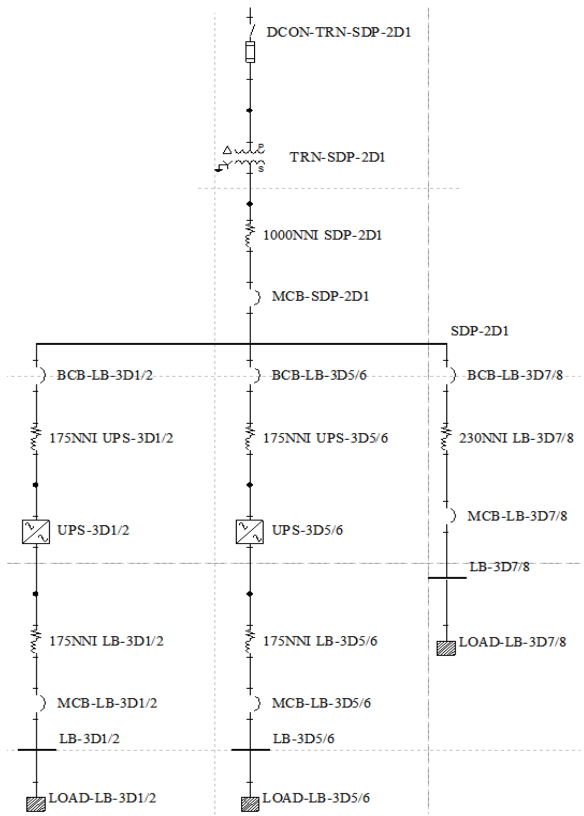

Figure 3.72: SDP-2D1 and loads one-line diagram

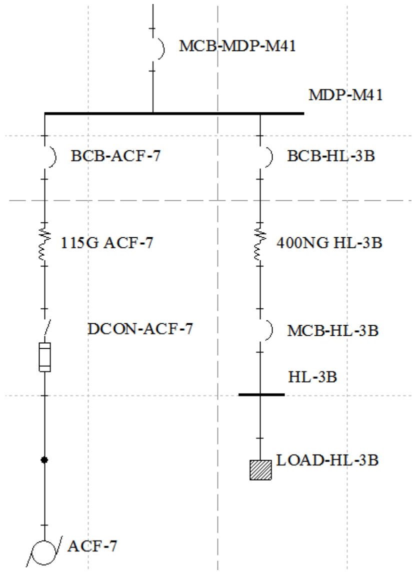

Figure 3.73: MDP-M41 and loads one-line diagram

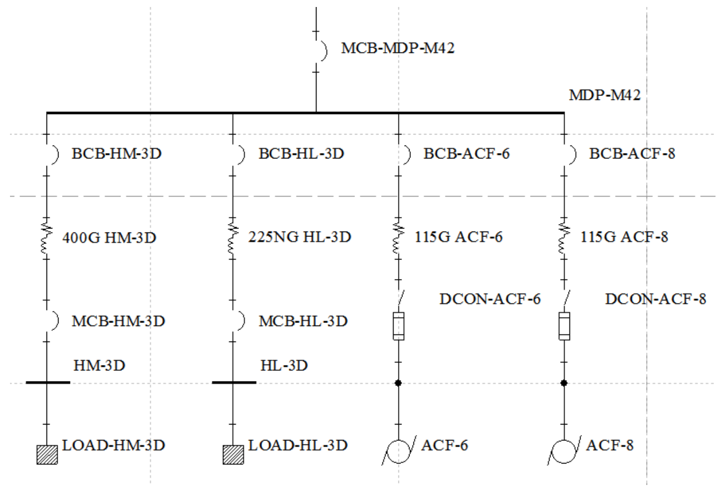

Figure 3.74: MDP-M42 and loads one-line diagram

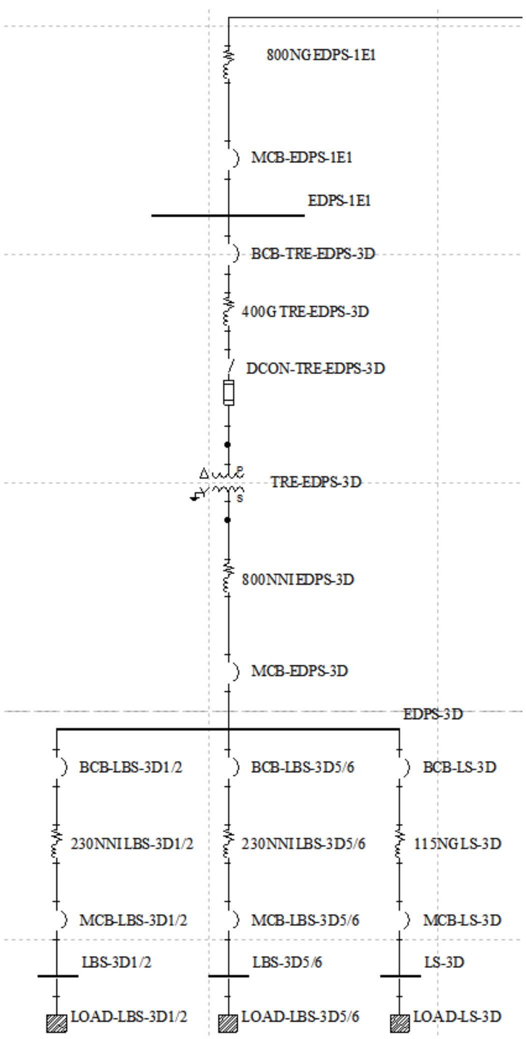

Figure 3.75: EDPS-1E1 and loads one-line diagram

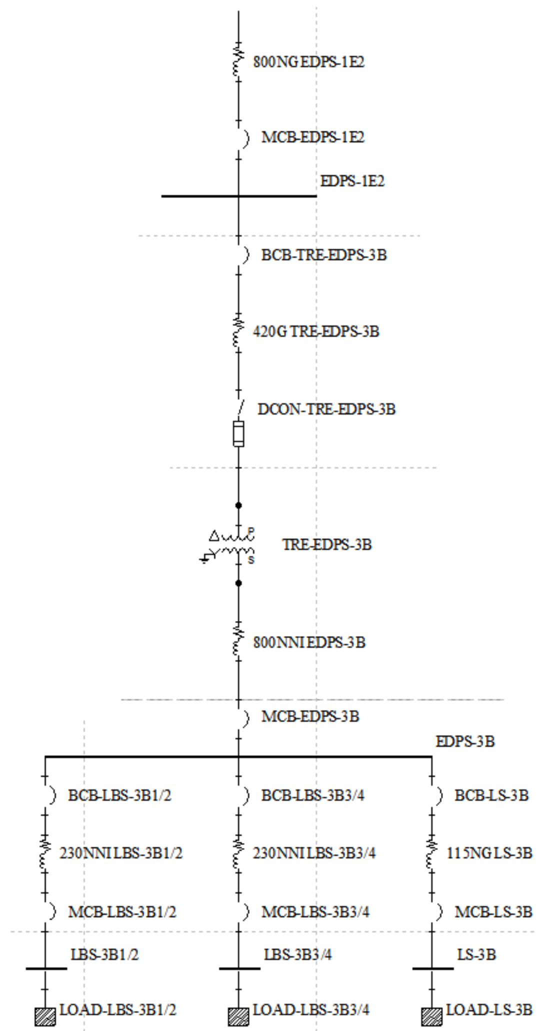

Figure 3.76: EDPS-3B and loads one-line diagram

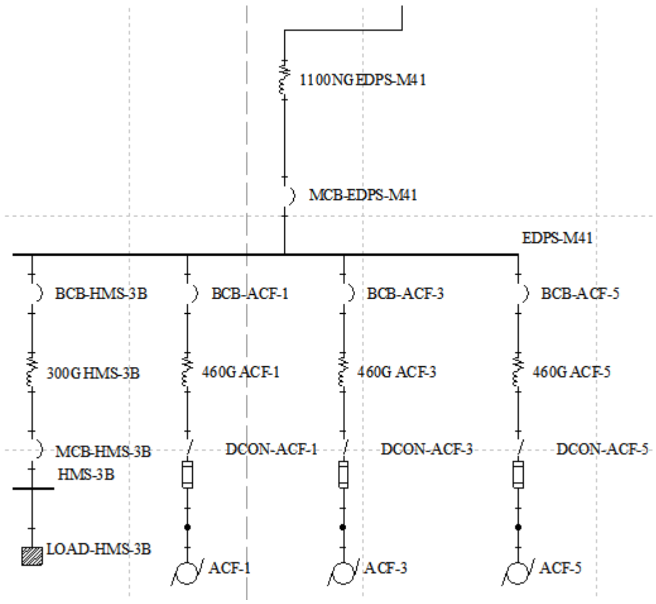

Figure 3.77: EDPS-M41 and loads one-line diagram

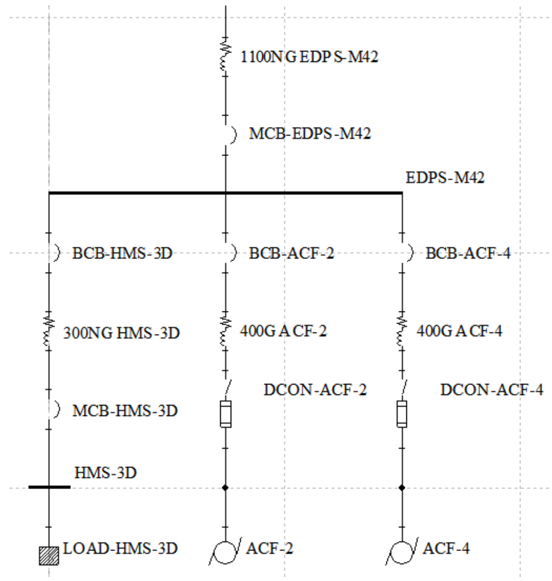

Figure 3.78: EDPS-M41 and loads one-line diagram

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 the table 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

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 the table 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

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 the table 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.

TOPIC 2: MOTOR CONTROL CENTER DESIGN

The inspiration for this electrical depth topic comes from KGB Maser's mechanical goal to reduce energy consumption by applying chilled beams for latent energy control while reducing the size of air handling units supplying the labs and office spaces. The redesign air handling units have a single electrical connection for the entire assembly. Since this is the case, the air handling units will be excluded from the motor control center and simply replace the existing air handling units on their associated distribution panelboards. The air handling unit changes can be reviewed in the "Revised Panelboard Schedules" and "Revised Panelboard Feeder Sizing" section of this document. A summary of the total equipment changes is as follows:

Existing Equipment				
Tag	Service	Location	Supply Motor (hp)	Exhaust Motor (hp)
AHU-1	Lab	Mechanical Penthouse	100	(2) 50
AHU-2	Lab	Mechanical Penthouse	100	(2) 50
AHU-3	Lab	Mechanical Penthouse	100	(2) 50
AHU-4	Lab	Mechanical Penthouse	100	(2) 50
AHU-5	Lab	Mechanical Penthouse	100	(2) 50
AHU-6	Offices	Mechanical Penthouse	60	N/A
AHU-7	Offices	Mechanical Penthouse	60	N/A
AHU-8	Offices	Mechanical Penthouse	60	N/A
CWP-1	Chilled Water	Basement Mezzanine	150	N/A
CWP-2	Chilled Water	Basement Mezzanine	150	N/A
CWP-3	Chilled Water Standby	Basement Mezzanine	150	N/A
CWP-4	Chilled Water Low Flow	Basement Mezzanine	60	N/A
HWP-5	Ventilation Heating	First Floor	40	N/A
HWP-6	Ventilation Heating	First Floor	40	N/A

Redesign Equipment				
Tag	Service	Location	Supply Motor (hp)	Exhaust Motor (hp)
AHU-EXT-1	Lab/Office	Mechanical Penthouse	50	50
AHU-EXT-2	Lab/Office	Mechanical Penthouse	50	50
AHU-INT-LS1	Interior Labs Life Science	Mechanical Penthouse	75	75
AHU-INT-LS-2	Interior Labs Life Science	Mechanical Penthouse	75	75
AHU-INT-MS1	Interior Labs Material Science	Mechanical Penthouse	75	75
AHU-INT-MS2	Interior Labs Material Science	Mechanical Penthouse	75	75
CWP-1	Active Chilled Beams CLG	Basement Mezzanine	150	N/A
CWP-2	Active Chilled Beams CLG Standby	Basement Mezzanine	150	N/A
CWP-3	AHUs + Process Chilled Water	Basement Mezzanine	100	N/A
CWP-4	AHUs + Process Chilled Water Standby	Basement Mezzanine	100	N/A
CWP-5	Chilled Water Low Flow	Basement Mezzanine	60	N/A
HWP-5	Active Chilled Beams HTG	First Floor	50	N/A
HWP-6	Active Chilled Beams HTG Standby	First Floor	50	N/A
Will be consolidated to a motor control center in the basement Mezzanine				

Currently, the location that is possibly available is in N-P052 (electrical room on basement mezzanine level). Since there are only six motors being consolidated to this motor control center, the electrical room layout can be re-organized to accommodate a narrow control center. If the design shows a large center, then the inaccessible space N-129C may be reconfigured to include a satellite electrical closet.

The motor control center will be sized using the Eaton Electrical 2006 Consulting Application Guide with the above highlighted motors. The consulting application guide can be summarized in the table below:

Motor Control Center Summary Data									
Eaton Application Guide Data									Totals
Tag		CWP-1	CWP-2	CWP-3	CWP-4	CWP-5	HWP-5	HWP-6	
Motor hp		150	150	100	100	60	50	50	
Voltage/PH		460/3	460/3	460/3	460/3	460/3	460/3	460/3	
Power Factor		0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Full Load Current (NEC)		180A	180A	124A	124A	77A	65A	65A	815A
Power (kVA)		149.58	149.58	103.04	103.04	63.99	54.02	54.02	677.27
NEMA Starter Size		5	5	4	4	4	3	3	
VFD Option	Variable Frequency Drive Type	VT*	VT	VT	VT	VT	VT	VT	
	HMCP	400	400	150	150	100	100	100	
	MCCB	500	500	300	300	175	150	150	
	Unit Height (spaces)	12	12	12	12	9	9	9	
*VT = Constant Torque drive capable of producing 200% starting torque for 10 seconds and are rated 110% overload for one minute.									

The motor control center design will be contained within an Eaton 2100 Series Freedom and Advantage Motor Control Center. After consulting with KGB Maser's mechanical engineer, it was determined that the pumps for the chilled beam supply water will be variable frequency drive. The main motor control center circuit protection will be an Eaton circuit breaker sized for a 125% of the full load amps of the largest motor plus 100% of the remaining motors connected to the center – in this case 860A. The maximum overcurrent protection by circuit breaker is 250% of the center full load current – 2037.5A, or a 2000A breaker. Considering these two boundaries, the main circuit protection for the motor control center will be an Eaton CNDC circuit breaker frame rated for 1200A with a trip setting of 1200A. This main circuit breaker will occupy 12 units of a single section (one entire section). An isometric view of the unit can be seen in Figure 3.79 below:

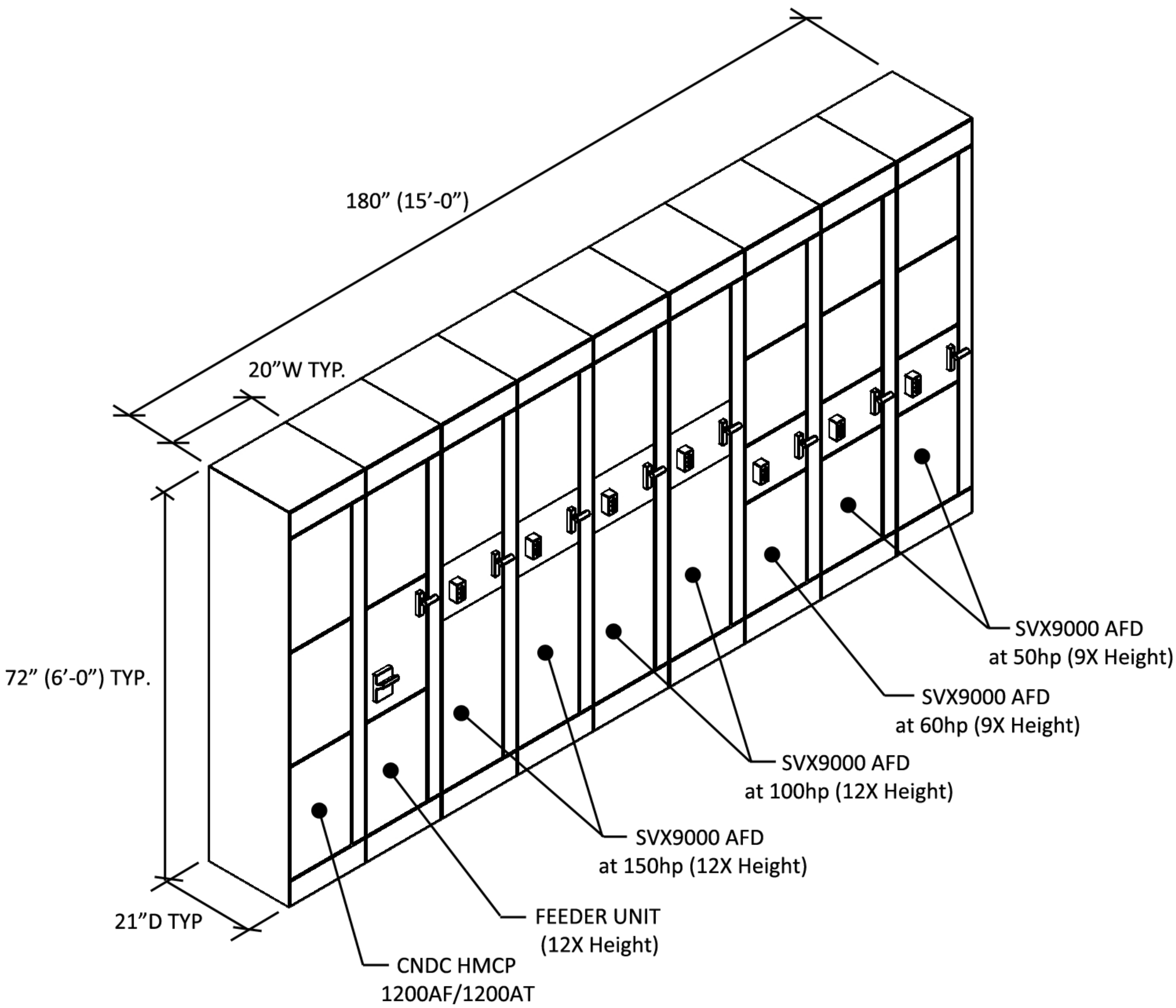

Figure 3.79: Motor Control Center Design Isometric View

Additionally, the sizing and layout sheet from Eaton's application guide can be seen in Figure 3.80:

EATON | Cutler-Hammer

June 2006
Sheet 1313

Motor Control Centers — Low Voltage Intelligent Technologies 30.2-43

Motor Control Center — Layout Form

Table 30.2-83. Arrangement of Structures (Numbered from Left to Right)
Typical Dimensions: Indoor — 20-Inch (508.0 mm) W, 90-Inch (2286.0 mm) H; Outdoor 23.5-Inch (596.9 mm) W, 95.25-Inch (2419.4 mm) H

(STR#)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	( )
A–M	FEEDER SECTION (3) SETS OF 250 KCMIL (2) SETS OF 250 KCMIL NEUTRAL (1) 3/0 GRD	MCB CNDC 1200AF 1200AT	CWP-1 SVX9000 AFD at 150hp	CWP-2 SVX9000 AFD at 150hp	CWP-3 SVX9000 AFD at 100hp	CWP-4 SVX9000 AFD at 100hp	CWP-5 SVX9000 AFD at 60hp	HWP-5 SVX9000 AFD at 50hp	HWP-6 SVX9000 AFD at 50hp	
Shipping Split (When Desired)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

⬦ – Future Space Only
Ø – Unusable Space

Unit No.	Starter Class or Description	Size	HMCP Feeder Breaker or Switch Amperes	hp	Extra Intlks. NO	Extra Intlks. NC	Control Devices – Pushbutton: Start-Stop	Fwd-Rev-Stop	Fast-Slow-Stop	Selector Switches: Hand-Off-Auto	Fwd-Off-Rev-Auto	Fast-Off-Slow-Auto	Indicating Lights: Green (Stopped)	Red (Run, Fwd, Fast)	Red (Rev. Slow)	Push-To-Test	Meters: Elapsed Time			Nameplate Identifications
1A	-------	---	-------	---	---	---	----	---	---	----	----	----	---	---	---	---	-------			FEEDER UNIT
2A	-------	---	1200A	-----	---	---	---	---	----	---	----	----	---	---	----	---	-------			MCB-MCC-1
3A	NEMA	5	400A	150	---	---	Y	---	---	----	---	----	----	---	---	----	-------			CWP-1
4A	NEMA	5	400A	150	---	---	Y	---	---	----	---	----	----	---	---	----	-------			CWP-2
5A	NEMA	4	150A	100	---	---	Y	---	---	----	---	----	----	---	---	----	-------			CWP-3
6D	NEMA	4	150A	100	---	---	Y	---	---	----	---	----	----	---	---	----	-------			CWP-4
7D	NEMA	4	100A	60	---	---	Y	---	---	----	---	----	----	---	---	----	-------			CWP-5
8D	NEMA	3	100A	50	---	---	Y	---	---	----	---	----	----	---	---	----	-------			HWP-5
9D	NEMA	3	100A	50	---	---	Y	---	---	----	---	----	----	---	---	----	-------			HWP-6

30

CA08104001E

For more information visit: www.EatonElectrical.com

Figure 3.80: Eaton Motor Control Center Layout Worksheet

After the motor control center is sized, it can be located within the building. Upon reading available space from the electrical plans, inaccessible space N-129C can be redesigned to include a concrete floor to locate the motor control center for the water pumps. This location was chosen due to the lack of space elsewhere near the pump loads served by the control center. The existing floor plan can be seen in Figure 3.81 below:

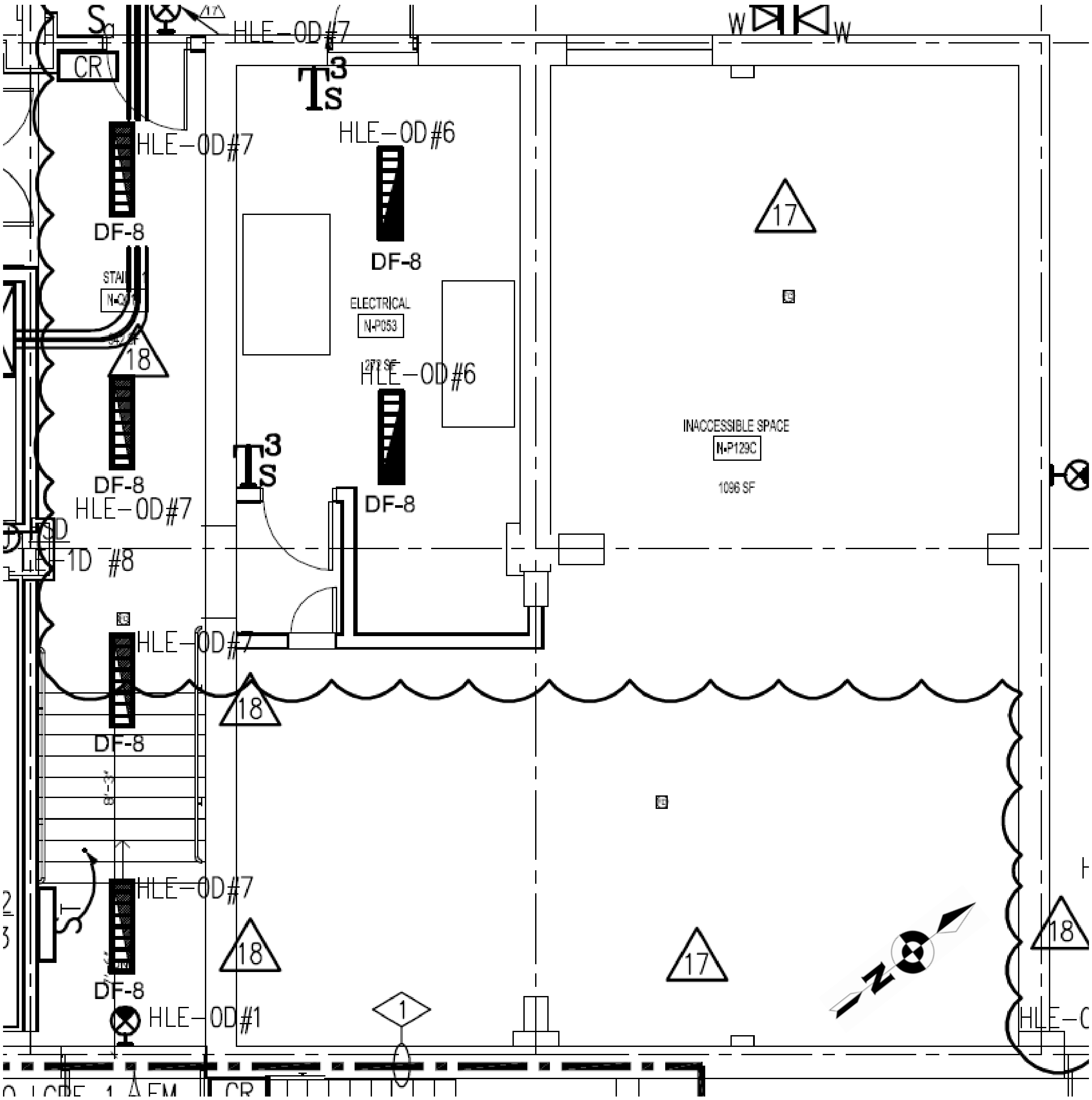

Figure 3.81: Available Space for Motor Control Center, NTS

The dimensions from the aforementioned data result in a motor control center that is 15'-0" in length. With the space now available, the motor control center can be located in the newly formed room using Revit Architecture. The plan for locating the MCC can be seen in Figure 3.82 below:

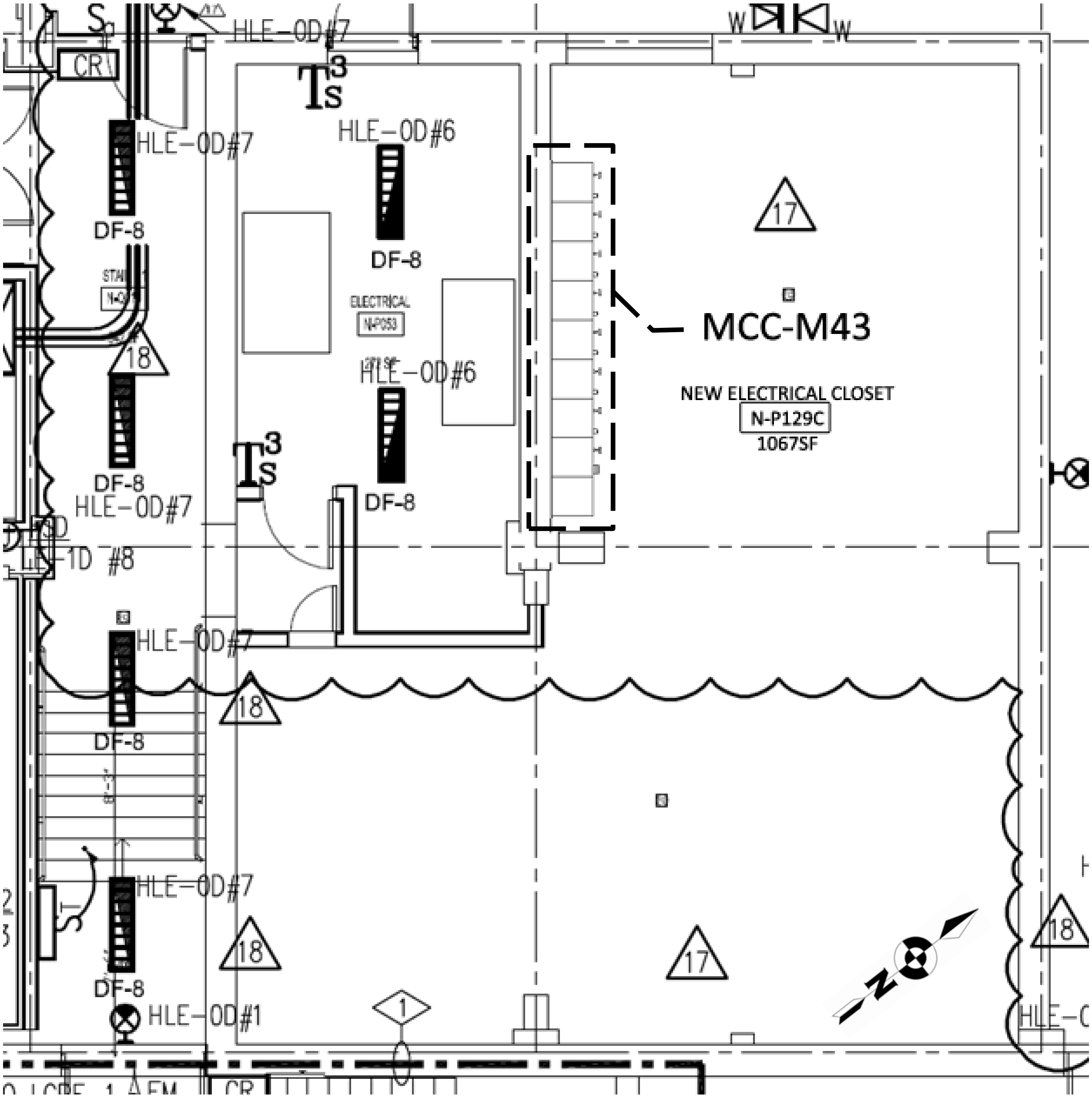

Figure 3.82: Motor Control Center Location Plan, NTS

Finally, a name-plate must be placed on the motor control center. The name-plate for this application should be similar to the following image:

MOTOR CONTROL CENTER: MCC-M43   LOCATION: SUPPLIMENTARY BASEMENT ELECTRICAL CLOSET

AMPS: 1000   VOLTS: 480Y/277   3 PH,   4 W,   60 HZ,   NEMA: 2   AIC: 100,000

UNIT NO.	CIRCUIT	HP/KVA	FLA	STARTER		CIRCUIT PROTECTION		FEEDER	NOTES
				TYPE	SIZE	TYPE	TRIP		
1A	FEEDER UNIT	-----	-----	-----	-----	-----	-----	3 SETS OF (3) 250KCMIL, (2) 250KCMIL N + 3/0 G	INCOMING FEEDER
2A	MCB-MCC-1	-----	------	-----	-----	CNDC	1200A	3 SETS OF (3) 250KCMIL, (2) 250KCMIL N + 3/0 G	MCC MAIN CB
3A	CWP-1	150HP	180A	AFD	5	HMCP	400A	(3) 4/0 PHASE + #3 GRD IN 2"C	
4A	CWP-2	150HP	180A	AFD	5	HMCP	400A	(3) 4/0 PHASE + #3 GRD IN 2"C	
5A	CWP-3	100HP	124A	AFD	4	HMCP	150A	(3) 2/0 PHASE + #6 GRD IN 2"C	
6D	CWP-4	100HP	124A	AFD	4	HMCP	150A	(3) 2/0 PHASE + #6 GRD IN 2"C	
7D	CWP-5	60HP	77A	AFD	4	HMCP	100A	(3) #3 PHASE + #8 GRD IN 1.5"C	
8D	HWP-5	50HP	65A	AFD	3	HMCP	100A	(3) #4 PHASE + #8 GRD IN 1"C	
9D	HWP-6	50HP	65A	AFD	3	HMCP	100A	(3) #4 PHASE + #8 GRD IN 1"C	

Figure 3.83: Sample Motor Control Center Label

The feeders running to the pumps will need to be resized according to voltage drop regulations according to the National Electrical Code. I the figure above, they are sized at 125% of the full load current of each motor.

MANUFACTURER INFORMATION

Manufacturer information for each of the redesign spaces and for panelboard redesigns can be found in Appendix 3.C.

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April 7th, 2011

UNIT 4:
MECHANICAL REPORT

KGB Maser
Management. Engineering. Consulting.

BIM/IPD Team #3

Jason Brognano | Michael Gilroy | David Maser | Stephen Kijak

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MECHANICAL EXECUTIVE SUMMARY

The following unit of KGB-Maser's report details the mechanical study of the Millennium Science Complex which is slated to contain premiere research facilities for the university's Life Science and Material Science departments. The existing VAV reheat mechanical design handles the laboratory and fume hood ventilation demands as well as provides thermal comfort to offices and common areas. To align with the main team goal of energy conservation the following areas were assessed for potential gains in energy efficiency of building systems:

a. Optimization of the façade's glazing and overhangs
b. Replacement the existing VAV system with an active chilled beam system
c. Analysis of lowering fume hood face velocities to 80 fpm from 100 fpm.

Façade changes were analyzed using Trane TRACE and Autodesk Project Vasari models. The Trane TRACE model was created by an exported gbXML file from Revit Architecture containing the third floor. The TRACE space by space model reflected changes in overhang depth and window glazing in each opening. Results were extrapolated by area to provide an estimate of the building wide impact of design alternatives. Project Vasari was used to quickly gauge the results found by Trane TRACE model. From model results, the most effective decision was to replace the existing glazing with triple pane glazing and ensure the façade overhang remains at 3.0 feet. Project Vasari did not contain the detailed information that was present in the Trane TRACE model. Therefore, the Trane TRACE model's 1.5% savings was deemed to be an accurate representation of 3.0' shading devices and triple pane glazing.

After the façade changes were decided, the mechanical distribution system could be sized accurately. Chilled beams and a dedicated outdoor air supply were chosen to handle space loads building wide. In laboratory wings where the demand for ventilation is too immense for chilled beams alone, a dual wheel AHU was used to reheat supply air to 68-72^{o}F. The neutral temperature air will be delivered to chilled beams for sensible loads and additional diffusers as required for ventilation. Chilled beams and the improved façade configuration combined to produce annual savings of 14.1% annually.

In an effort to further improve operating costs, fume hood makeup air conditioning costs were evaluated at the existing 100 feet per minute face velocity and proposed 80 feet per minute face velocity. For a VAV system, the operating cost of the fume hoods decreased 32% when using 80 feet per minute face velocities building wide. The two face velocities were studied for contaminant effectiveness as well. A sample fume hood room from the Life Science wing was modeled in a computational fluid dynamics (CFD) modeling program. While contaminant levels increased 14.2% to 18% at the face of the hood when the face velocity was lowered, the magnitude of the contaminant readings in all models stayed below 0.015% of the contaminant inlet source.

All areas of study required close coordination with other team members to ensure a cohesive conclusion can be reached. Results detailed in the following report were used by team members and affected all areas of analysis. Complete team reports and processes can be found in Unit One of this document package.

TABLE OF CONTENTS

EXISTING SYSTEMS & BACKGROUND

The complex mechanical system of the Millennium Science Complex is designed to handle the multiple uses of the 275,000 square foot building. Laboratory spaces require varying thermal and air quality conditions to ensure the accuracy of experiments. Office spaces need to be serviced to ensure the comfort of building occupants. The AHUs serving the building are located within a 4th floor mechanical penthouse. Pumps used in building chilled water, hot water, process cooling, and radiant cooling loops are located throughout basement and first floor mechanical spaces. A description of each component of the existing mechanical system is detailed in this section.

AIR SIDE

The airside portion of the existing design for the Millennium Science Complex is comprised of a series of VAV systems serving offices, common areas, and laboratories in the building. CO_2 sensors present in the return air and supply air monitor indoor air conditions to ensure the health and productivity of the building's occupants. Five of the AHUs located in the mechanical penthouse service the general laboratory areas within the building. These five laboratory AHUs provide 100% outdoor air to the laboratory areas to ensure proper indoor air quality. Enthalpy wheels are used to save energy by preconditioning incoming outdoor air with exiting general exhaust air. Specialty laboratory spaces in the building, such as vivarium and clean room spaces necessitate their own AHUs to service unique design conditions. Dedicated exhaust fan remove air directly out of the building from fume hoods, biosafety cabinets, and the vivarium to avoid contamination of incoming airstreams. The dedicated exhaust fans are armed with glycol run around coils to precondition incoming outdoor air to the clean room, quiet lab, and animal holding facilities' AHUs. Additionally, three 33,000 CFM AHUs service the remaining office and common areas within the building.

FUME HOODS

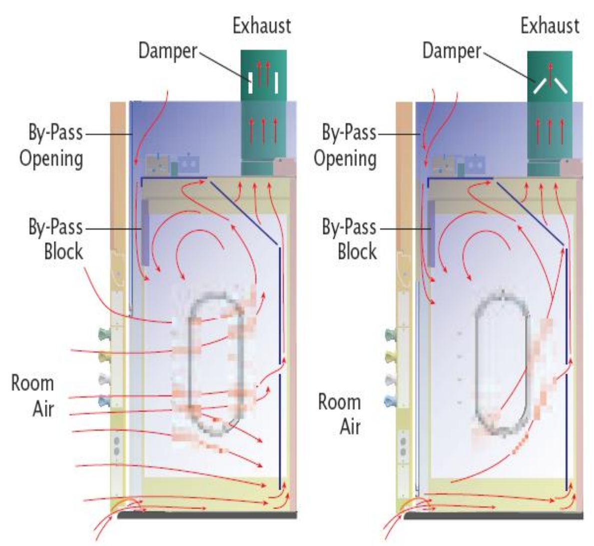


Figure 4.1: Sample VAV Fume Hood Operation. From Labconco

The existing fume hoods in the building are equipped with variable exhaust control that varies flow rates based on sash position. Due to the large number of fume hoods present throughout the building and the diversity of operation, using VAV control on the exhausted air allows for energy savings and proper contaminant control. The current VAV system uses venturi valves that react to changes in duct pressure by moving a spring and cone assembly into or out of a venture opening to regulate airflows exhausted by a fume hood. In Figure 4.1, from Labconco's Fume Hood selection brochure, the operation of a standard VAV hood at different sash positions is shown. The existing fume hoods are intended to operate for consistent face velocities of either 125 or 100 fpm face velocity, regardless of sash position.

CHILLED WATER

The source for the Millennium Science Complex need of chilled water is the central plant at Penn State. Four parallel pumps deliver chilled water to the building's AHUs and to heat exchangers for process cooling loads. Appendix 4.F shows a flow diagram illustrating the chilled water layout. To control varying loads in the building, a control valve modulates to maintain a fixed coil discharge temperature. During low flow conditions, cooling coils have two way valves and a main differential pressure bypass. When demand for chilled water is low, one low flow pump is provided to distribute lower flow rates more efficiently.

Chilled water is pumped to two plate and frame heat exchangers to serve process cooling of equipment and supplemental loads in the building. Within the process cooling system, two variable speed pumps circulate chilled water as necessary. The pumps are heat exchangers of the chilled water system are designed for redundancy. Pumps in the process cooling loop are connected to standby power to provide flow despite loss of power. AHUs for the vivarium and one lab AHU are connected to a standby powered chilled water loop.

HOT WATER/STEAM

One hundred and forty psig high pressure steam is the primary source for all heating in the Millennium Science Complex. Delivered from Penn State's central plant, the high pressure steam enters a series of pressure reducing stations. At the PRV station, the steam pressure is reduced to pressures of 60 psig and 15 psig for safe use in the building. The medium pressure steam is mainly used for sterilization in the laboratories and for heat exchangers for domestic hot water. The laboratory AHU humidifiers receive clean steam from clean steam generators in the penthouse to ensure that humidification does not contaminate incoming air. Low pressure steam is used for most of the mechanical equipment in the building including preheating coils at the AHUs and plate and frame hot water heat exchangers. Compressed air powered condensate pumps collect the medium and low pressure steam condensate return and distribute it to the campus return lines safely. Appendix 4.F also contains a diagram of the flow of steam and hot water in the building.

DESIGN AIR CONDITIONS

For this project, the design indoor and outdoor air conditions for the Millennium Science Complex follow the instructions of Penn State's Office of Physical Plant (OPP). The outdoor air conditions can be compared to the recommended values from ASHRAE. Chilled beam design requires consideration of the worst case dehumidification summer design conditions.

ASHRAE Weather Data Used			
ASHRAE Altoona, PA	Summer Design Condition: Cooling 0.4%	Winter Design Condition: Heating 99.6%	Chilled Beam: Dehumidification 0.4%
Outside Air Dry Bulb (°F)	4.7	88.5	-
Mean Coincident Wet Bulb (°F)	-	72.0	77.7
Humidity Ratio (Grains/lb)	-	85.7	118.0
Dew Point (°F)	-	-	70.4

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

1. Reference "Guide for Care and Use of Laboratory Animals"

SCHEDULES

As a university laboratory facility, the Millennium Science Complex has a unique schedule of operations. The baseline energy rate when the building was not in operation was set at 10% to account for minimum exhaust needs for fume hood operation. On weekdays, from 6am-8am and from 5pm-7pm the schedule is set at 25%. From 8am-11am and 1pm-5pm the schedule is defined at 100% operation. A lunch hour window of 11am-1pm is set at 75%. During the weekend, the hours of 8am-5pm are set at 50% to account for potential weekend users. This unique schedule was created in Trane TRACE to represent a conservative estimate of the operating schedule of the Millennium Science Complex for energy modeling purposes.

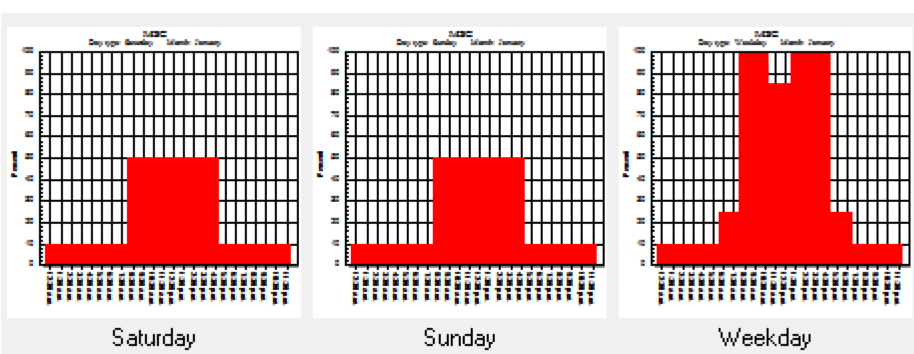


Figure 2: Trane TRACE Schedules

FAÇADE REDESIGN

The envelope of a building is important to overall performance of the building. KGB Maser chose to analyze the façade of the Millennium Science Complex for potential areas of improvement. Each team member's discipline drove their desired façade performance characteristics. Together, the façade was analyzed for the best cohesive solution in terms of costs, thermal performance, constructability, and impact on the overall structural system.

EXISTING FAÇADE

The existing façade of the Millennium Science Complex is innovative in its design and performs well thermally. The precast panels are composed of 2" Face brick adhered to 6" of concrete backing. The concrete backing forms a "C" shape which allows the slab to extend and the precast panels to attach to columns. Beyond the concrete, 4" of rigid insulation is present to slow heat transfer through the facade. On the interior, gypsum wall board panels surround another layer of insulation. The precast panels mostly cover the large plenum space between floors that is required for the complicated distribution systems need by the building. The glazing takes up the majority of the envelope seen by occupants within the space. The existing double pane glazing is divided into two sections of glass to serve two different purposes. The lower pane wraps around the building and provides clear views to the exterior. The upper pane is fritted and meant to improve the daylight environment. The assembly is situated approximately 2.5 feet from the edge of the precast shape. The recession of the windows, in combination with an exterior shade placed between the two panes of glass, provide an effective passive solar design that limits high profile angles of the sun during summer months and invites lower profile angles during the winter. The façade accounts for daylighting and thermal performance effectively.

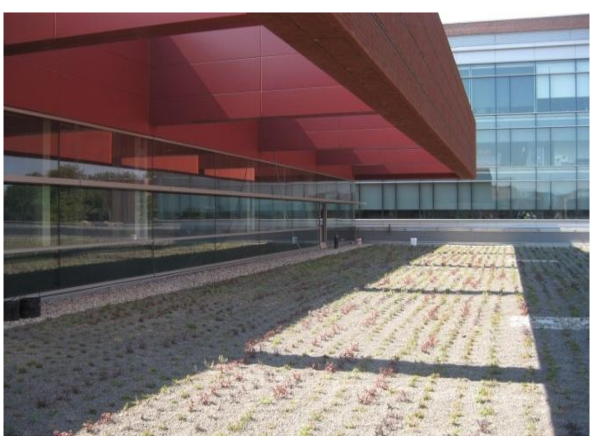


Figure 4.3: Existing Facade Mockup Section and Installed Green Roof

The stepping roofs of the Millennium Science Complex are covered with a green roof. The green roof requires a shallow depth of supporting earthwork and drainage system to minimize the effect on the structural system. The benefits of installing a green roof on the Millennium Science Complex include providing storm water control, and acting as an additional layer of insulation. The roof over the mechanical penthouse, is not a green roof. The penthouse roof structure is composed of concerte slab with rigid insulation covered by a black EPM waterproofing membrane.

KGB Maser looks to challenge the existing façade design and evaluate diffferent options cohesively the façade in a manner that be beneficial for all disciplines. In this unit of the report, the façade's impact on energy performance will be detailed.

METHODOLOGY

The goal of the façade optimization study is to analyze different methods for their potential benefit to HVAC system sizing and ultimately operating cost savings. The success of different scenarios will be based on the energy savings associated with the strategy and aim to have minimal impact on the existing architecture

To analyze the effect of different façade changes, energy models in Trane TRACE and Project Vasari were run and operating costs for Millennium Science Complex will be compared. A Trane TRACE space by space model of the third floor was created and ran with alterations to the construction template and the shading over each opening. In Project Vasari, a technology lab from Autodesk intended to test conceptual designs, a model was created to provide another source of data on a building wide scale. The model in Project Vasari was created more easily than the Trane TRACE model and only used for façade comparisons.

ADDITIONAL INSULATION

Initially, KGB-Maser's goal for a façade redesign was to reduce the thickness of the concrete from 6". The removal of a small amount of concrete from the building's panels was anticipated to produce some material savings. Extra insulation was considered in conjunction with downsizing the panel thickness. As seen in Appendix 4.A the R-Value seen from adding two more inches of rigid insulation is 51.45, up from 36.73 from the existing façade design. The resulting U-Value of 0.0194 Btu/(hr x sq ft x ^{o}F) replaced the 0.0272 Btu/(hr x sq ft x ^{o}F) in a Trane TRACE energy model of existing conditions. The energy model was run to compare façade constructions for effect on building energy demands. However, the majority of envelope load was due to glazing. The additional improvement to the insulation within the façade had a negligible impact on the loads in the spaces. Without further modeling, it was determined that there was no benefit to providing supplemental insulation to the façade's existing design.

OVERHANG AND GLAZING ANALYSIS

Due to the dominant effect of glazing on the envelope load, the focus of the façade redesign shifted to overhang analysis and glazing selection. Triple pane low-e coated glazing was chosen as a potential alternative to the existing double pane glazing. The manufacturer's data for both assemblies listed U values of 0.29 Btu/(hr x sq ft x ^{o}F) for the winter and 0.26 Btu/(hr x sq ft x ^{o}F) for the summer. The ASHRAE Load Calculation Applications Manual was referenced for the U-value required for modeling each assembly. The existing glazing assembly was modeled with a U value of 0.47 Btu/(hr x sq ft x ^{o}F) and a shading coefficient of 0.44. The proposed triple pane glazing was modeled with a U value of 0.36 Btu/(hr x sq ft x ^{o}F) and a shading coefficient of 0.33. The setback of the glazing from the edge of the precast panel was modeled as an external shade. The existing model was modeled as a 2.5' overhang. Half foot increases in the shade depth were analyzed. Only the energy cost ramifications of different alternatives are reported in this section. Reference the Overhang Analysis in Unit 1 of this report for additional team analysis.

After the U-values of the glazing were selected for comparison, each scenario was assigned to a different Trane TRACE energy model. The shading library within Trane TRACE was used to model different shading depths. Shading was modeled as an "Overhang" shading type and the "Overhang projection out" field was changed for each scenario. The model was run with identical zoning, systems, and utility cost data. To reflect the position of the building on site, the building was rotated 52^{o} west of true north within the models.

The addition of another pane of glass decreased the need for heating energy with shading increases, with results tapering off after a 3.0' deep shading device. Cooling energy was kept relatively stable despite the addition of triple pane glazing and increases in shading depths. A study of proposed glazing with no shading device was provided to display the need for a shading device to match or outperform the existing conditions. Results from Trane TRACE are found below.

Trane TRACE: Overhang and Glazing Analysis, 3rd Floor Only							
	Existing Glazing			Proposed Glazing			
Overhang Depth	2.5	3	3.5	0	2.5	3	3.5
Cooling Energy (kbtu/hr)	4,952,785	4,913,117	4,843,475	5,108,286	4,942,328	4,938,260	4,918,512
CHW Cost	$90,636	$89,910	$88,636	$93,482	$90,445	$90,106	$90,009
Heating Energy (kbtu/hr)	7,027,093	6,990,016	7,054,209	6,876,348	6,728,410	6,715,118	6,733,084
Steam Cost	$57,563	$57,260	$57,785	$56,329	$55,118	$55,009	$55,156
Total Energy (kbtu/hr)	16,478,534	16,395,332	16,389,978	16,492,904	16,127,341	16,096,075	16,102,912
Total 3rd floor Costs	**$250,288**	**$249,142**	**$248,400**	**$252,096**	**$246,903**	**$246,440**	**$246,378**
Extrapolated Building Costs	**$1,501,728**	**$1,494,852**	**$1,490,400**	**$1,512,576**	**$1,481,418**	**$1,478,640**	**$1,478,268**

To further analyze the effect of over hangs and glazing on energy consumption, the Millennium Science Building was mass modeled in Autodesk's Project Vasari. Figure 4.4 depicts a rendering of the Millennium Science Complex as a mass model in the program. The energy analysis tool within Vasari was run at different shading depths and the results reported. Only HVAC equipment energy and electric needs reported changes in demand. Results from Project Vasari are found below.

Project Vasari: Overhang and Glazing Analysis, Entire Building							
	Existing Glazing			Proposed Glazing			
Overhang Depth	2.5	3	3.5	0	2.5	3	3.5
HVAC Fuel Energy (therms)	379,161	379,722	317,907	271,550	273,264	336,079	336,458
HVAC Electricity (kWh)	1,587,646	1,568,487	1,555,836	1,574,052	1,507,227	1,495,442	1,484,228
Lighting Electricity (kWh)	1,494,256						
Equipment Electricity (kWh)	1,264,263						
Annual Operating Cost	**$953,470**	**$952,430**	**$951,956**	**$888,241**	**$884,272**	**$883,823**	**$883,286**

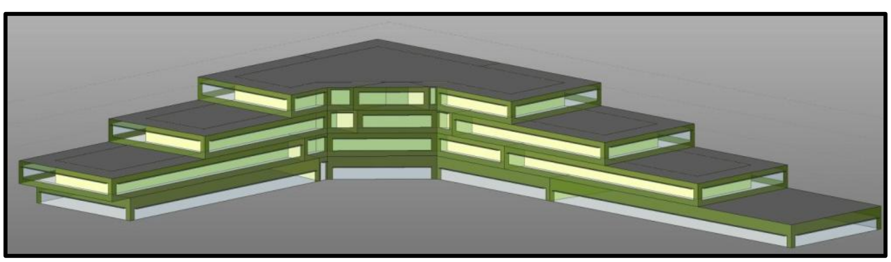


Figure 4.4: Millennium Science Complex modeled in Project Vasari

CONCLUDING RECOMMENDATION

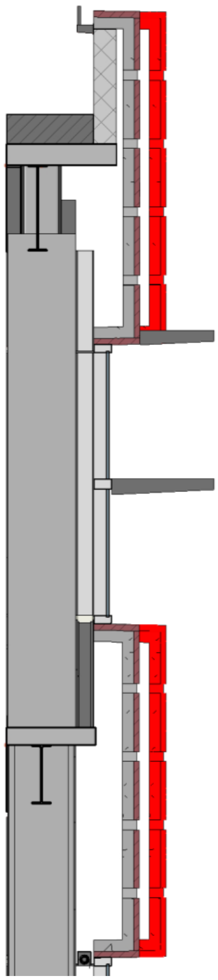


Figure 4.5: Proposed Facade Section

From an energy cost perspective only, the best condition for maximum operating cost savings is to install a 3.5' foot overhang. However, the 3.5' overhang provided only a small margin of savings when compared to the 3.0' overhang. A larger first cost will likely be incurred if a 3.5' overhang was used. In both models, more significant savings are seen with the installation of triple pane glazing. For this reasoning, coupled with daylight and initial cost considerations, 3.0' overhang shading devices placed at the top and middle of the glazing as well as a triple pane glazing assembly will be recommended for the Millennium Science Complex. In the Trane TRACE model, 1.5% savings can be realized building wide. Project Vasari, which analyzed a less accurate representation of the building and its loads, produced an annual savings of 7.3%. Realistically, the Trane TRACE results are believed to be more accurate due to the more intricate data included in the model. Figure 4.5 shows the addition of the 3' overhangs and the reduction of the panel depth versus existing conditions (shown in red). For more information concerning the panel reduction reference Unit 5.

MECHANICAL SYSTEM DISTRIBUTION REDESIGN

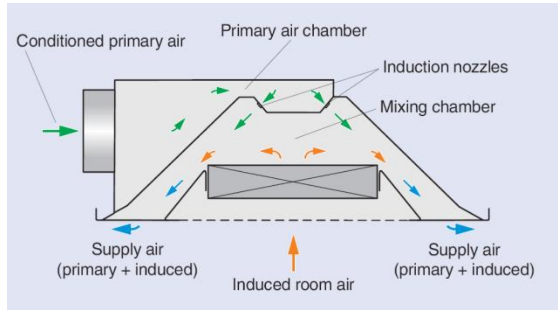


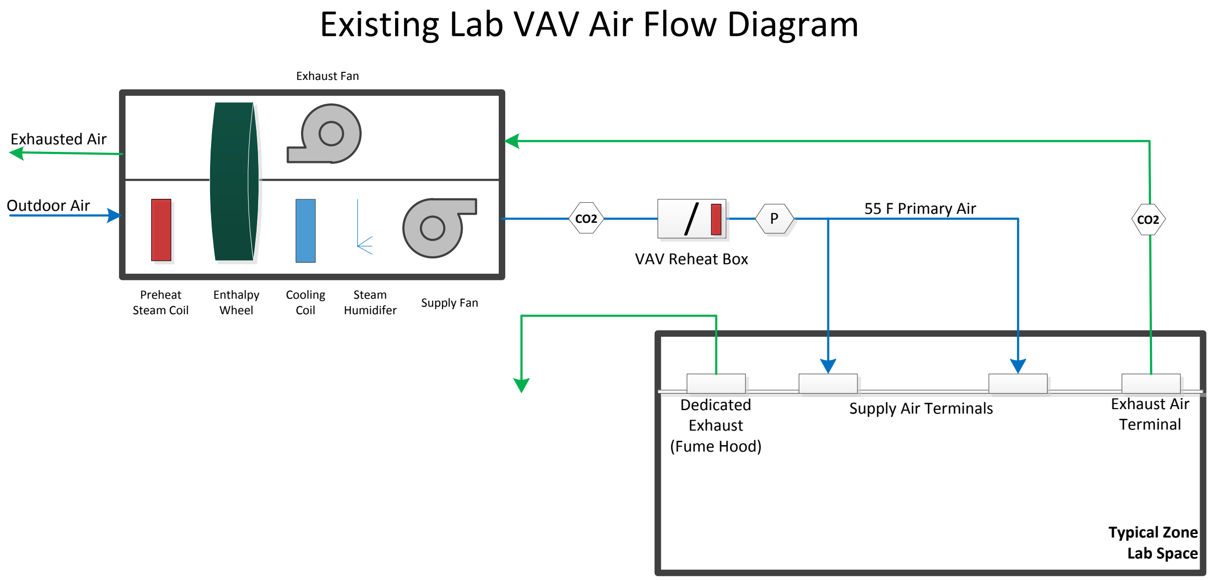
Figure 4.6: Operation of Trox Chilled Beam

A main goal of KGB Maser's redesign of the Millennium Science Complex is the exploration and implementation of energy saving measures. The HVAC system of building typically accounts for a considerable amount of the building's total energy use. Laboratory buildings in particular are more energy intensive due to the extra requirements such as 100% outdoor air systems, fume hood exhaust, and other specialized process loads and equipment. The current VAV reheat design of the Millennium Science Complex provides a reliable and familiar HVAC system capable of handling the needs of the laboratory and offices spaces present in the building. KGB Maser proposes using active chilled beams in combination with a 100% outdoor air system to condition the building. Active chilled beams work by inducing room air over coils that heat or cool induced air as necessary, mixing induced air with ventilation air, and delivering the mixed air to the space. Active chilled beams in the redesign will contain four-pipe heating and cooling chilled beam arrangements along exterior wings and two pipe cooling only beams in the interior zones. The life cycle cost of the two systems will be the predominant measure of success, with considerations to thermal comfort, first cost, and maintenance as well. Due to the size of the building and the variety in size and use from floor to floor, the mechanical distribution redesign was only applied to the third floor. The third floor contains lab areas in both the Life Science and Material Science wings and a common central wing that contains offices, conference rooms, and other support rooms. Included in some calculations are adjusted values for building wide data. To obtain data for AHU and pump resizing, the building interior labs zones, exterior lab zones, interior office spaces, and exterior office spaces' data was tallied for the 3rd floor and multiplied by an area factor for a building wide estimate.

ACTIVE CHILLED BEAM DESIGN OVERVIEW

For the Millennium Science Complex to implement active chilled beams, the building must be zoned efficiently. Laboratory areas, such as those found in the Life Science and Material Science wings, demand levels of ventilation not attainable by chilled beams alone. A dual wheel AHU that supplies neutral air supply temperatures ranging from 68-72^{o}F air will serve chilled beams and additional diffuser in areas with high ventilation demand. This will decrease the cooling capacity of the air to the chilled beam, but will permit use of chilled beams throughout the building. Core areas of the building contain may contain high sensible loads due to equipment loads. A two-pipe, cooling only application of the TROX-632 high capacity chilled beams would handle the cooling needs of the space adequately in combination with supplied neutral air. Surrounding the core laboratory zones of both wings are less intense laboratory areas or office spaces. In these perimeter spaces, four pipe active chilled beam systems will be used to accommodate seasonal changes in space loads. Variable air volume boxes can be incorporated into the chilled beam redesign. The boxes will allow airflow to be turned down in office spaces when occupants are not present. In laboratory spaces, when there is no occupancy, the ventilation rate of 6 air changes per hour can be turned down to 4 air changes per hour to save energy. The following pages further detail how the chilled beam redesign will be achieved in the Millennium Science Complex. Manufacturer information on the chilled beams used in the redesign is located in Appendix 4.B.

AIRSIDE DISTRIBUTION STRATEGY



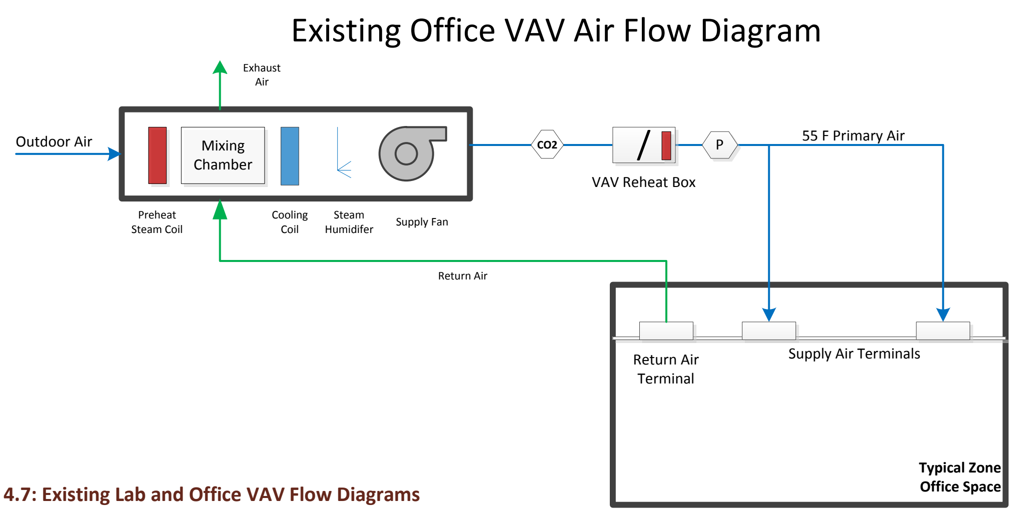


Figure 4.7: Existing Lab and Office VAV Flow Diagrams

In the existing laboratory zoned areas, outdoor air enters the AHU and is preheated to prevent freezing by a steam coil before proceeding to an enthalpy wheel. The enthalpy wheel serves to preheat/precool and dehumidify/humidify the incoming outdoor air before it reaches the coil without additional energy. The cooling coils and steam humidifier work together to produce desired supply air conditions of 55°F with the proper humidity levels. When the air leaves the AHU, VAV boxes at each zone allot the amount of air delivered to a space. The VAV box contains a reheat coil that further conditions the air to the temperature needed in the space. General exhaust terminals from lab spaces return warm air to the enthalpy wheel. Separately, fume hood exhaust risers remove air that could contain harmful contaminants to fans directing the air straight out of the building. The existing office VAV system is similar to the lab VAV system, but instead of an enthalpy wheel to precondition outdoor air, return air mixes with outdoor air. This can be done because there is less concern for cross contamination of molecules between the two airstreams.

Office/Exterior Lab Chilled Beam Air Flow Diagram

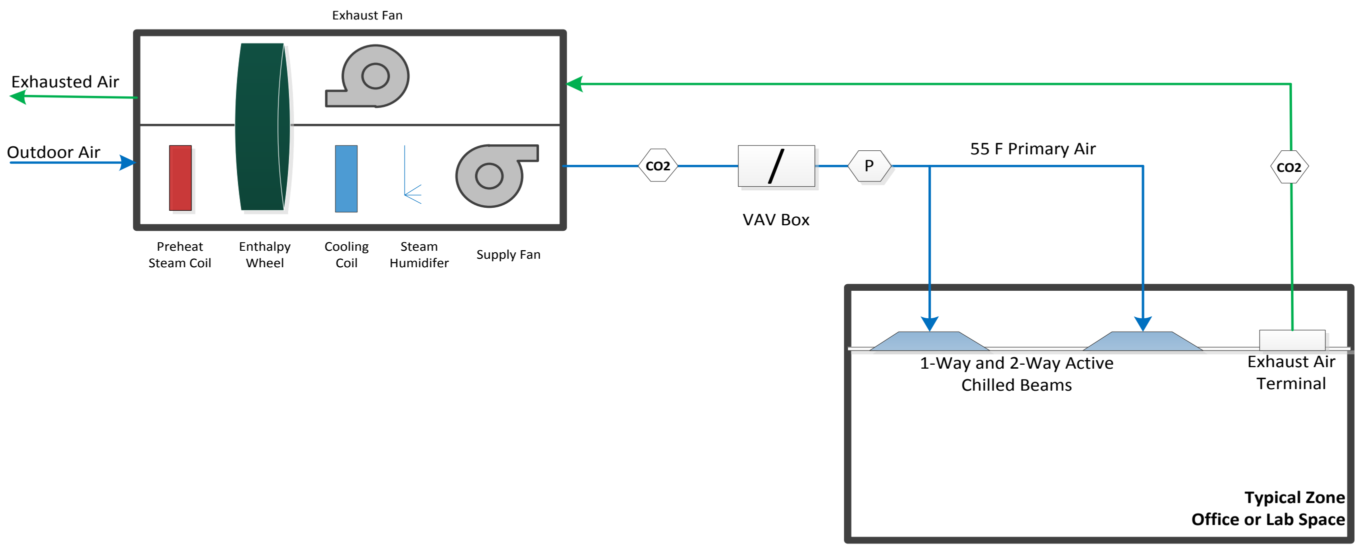


Figure 4.8: Proposed Office and Exterior Air Flow Diagram

Interior Lab Chilled Beam Air Flow Diagram

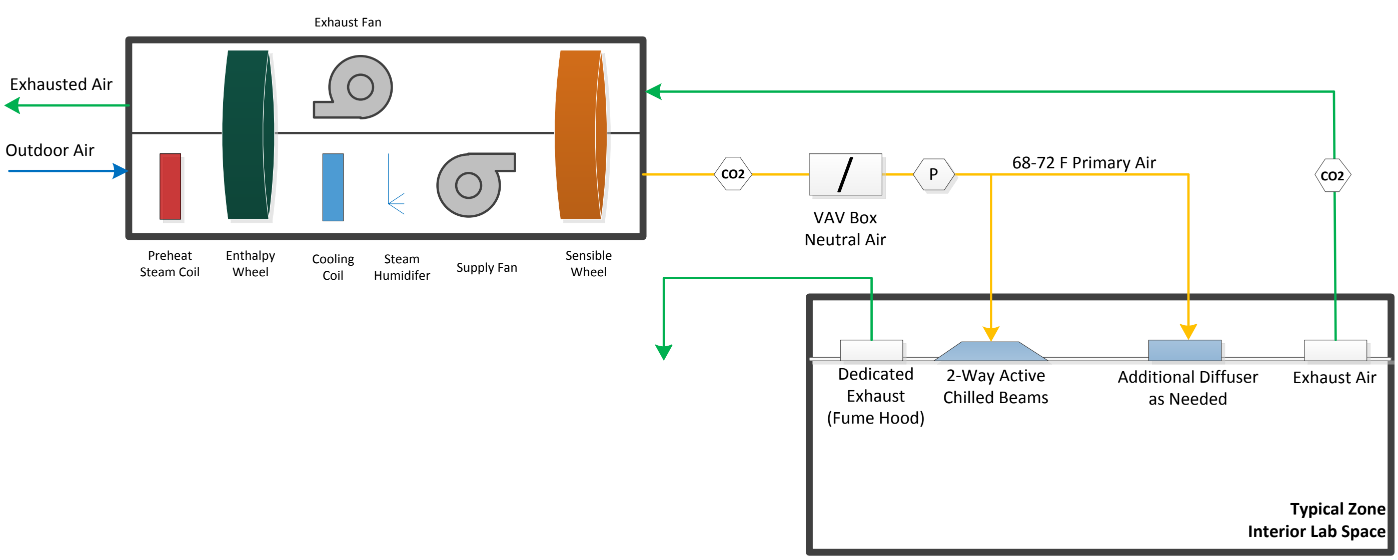


Figure 4.9: Proposed Interior Lab Air Flow Diagram

The office and exterior lab air handling units will condition areas as show in Figure 4.8. The AHU in the proposed redesign will operate similarly to the existing lab VAV system. An enthalpy wheel will be utilized to provide conditioning of outdoor air before it reaches the coil. However, the VAV boxes at zones will not have reheat coils, and only modulate flow into spaces. The chilled beams will handle the majority of heating and cooling needs in the space by inducing room air through coils in the chilled beam, mixing the primary and induced airstreams, and redistributing air into the space. With chilled beams, energy savings occur because less primary air requires reheat than the existing VAV reheat system. To avoid condensation on the beams, which occurs if the dew point of the air is not lower than the temperature of the chilled water supply, the cooling coils condition delivered air to a dew point of 52°F. The 52°F supply dew point temperature will always be lower than the designed chilled water supply of 58°F.

The VAV system specified for laboratory areas was highly effective in handling various airflow requirements needed by the interior laboratory spaces of the Millennium Science Complex. In order to allow the application of chilled beams in areas with high ventilation requirements, an additional sensible wheel was added to the AHUs serving interior lab spaces as seen in Figure 4.9. The sensible wheel preheats the air leaving the coil to a neutral temperature of 68-72°F. The neutral temperature supply air can be directed through chilled beams to handle sensible loads and a small portion of the ventilation air. The remaining ventilation needs of a space can be handled with additional diffusers and will require additional ceiling coordination. The Interior Lab dual wheel AHU will handle ventilation intense areas in the Material Science and Life Science wings. The rest of the building will be served by Exterior Lab/Office AHUs. Figure 4.10 depicts the coverage of the different AHUs on the third floor.

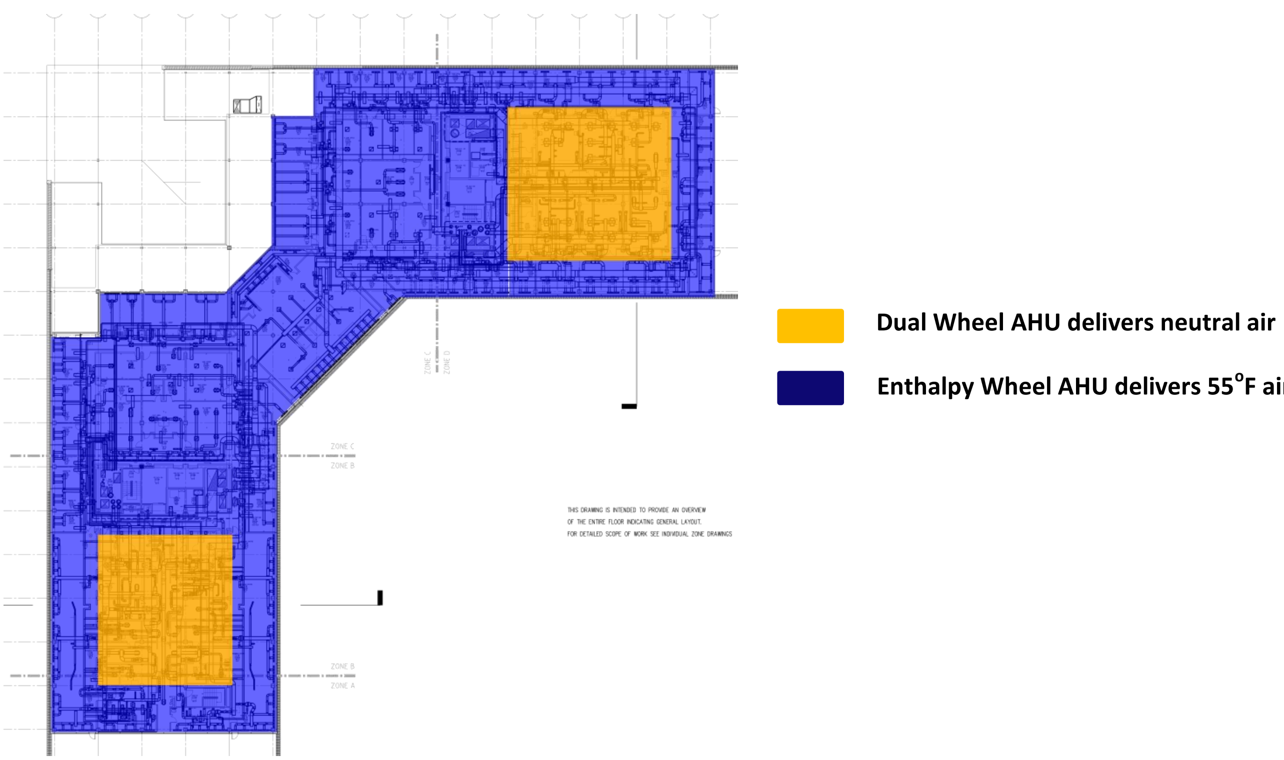


Figure 4.10: Coverage Scheme for AHUs

WATERSIDE DISTRIBUTION STRATEGY

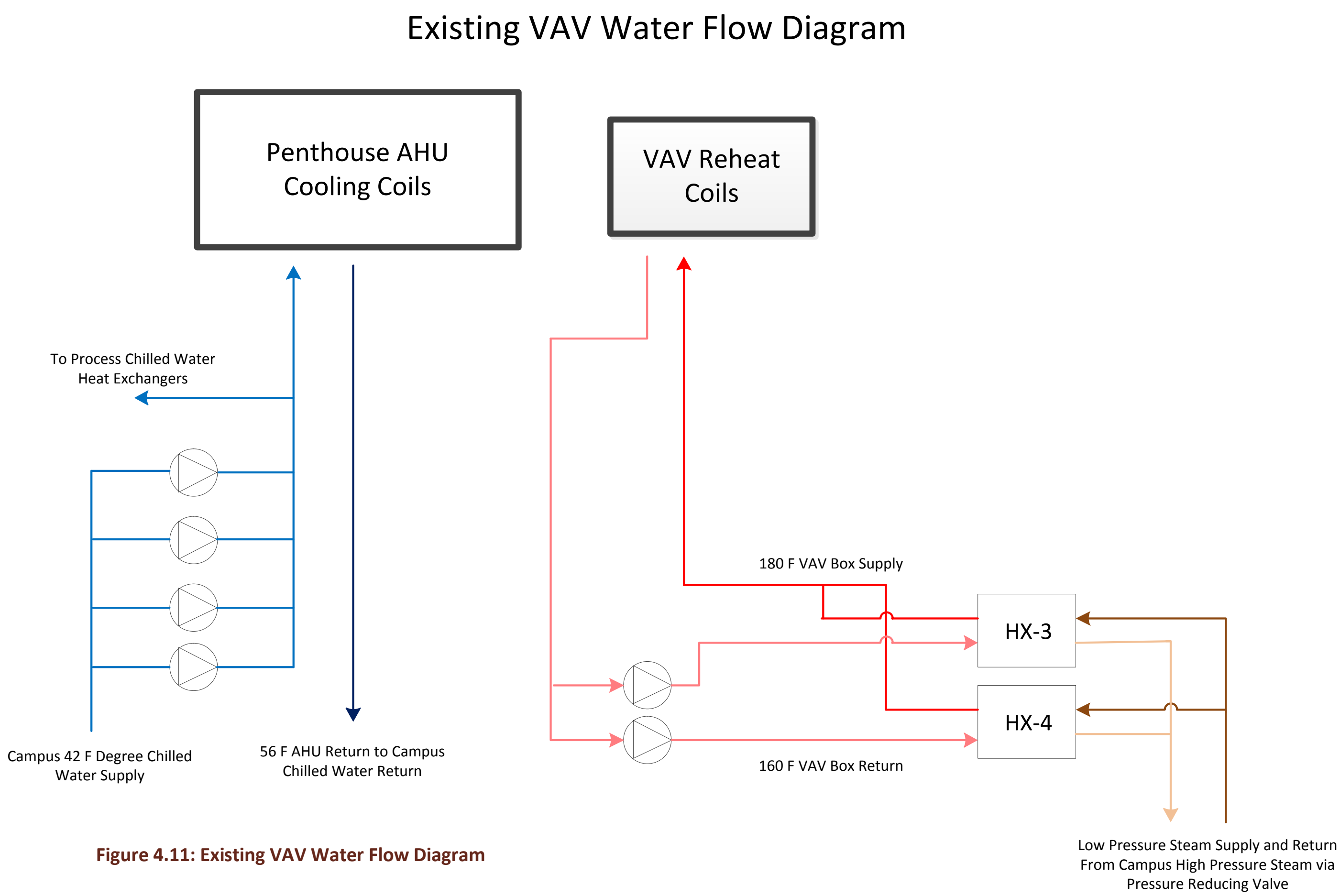


Figure 4.11: Existing VAV Water Flow Diagram

As mentioned in the existing conditions summary, campus chilled water is delivered to the Millennium Science Complex. The chilled water is handled by a series of variable speed pumps. The pumps distributed the chilled water to process chilled water heat exchangers, and penthouse AHU cooling coils. Campus high pressure steam is also utilized by the Millennium Science Complex. In order to allow for the safe use of steam within the building, the high pressure steam is reduced to both medium and low pressure steam with multiple pressure reducing valve stations. Low pressure steam is sent to a heat exchanger to produce the hot water necessary for the reheat coils. Figure 4.11 summarizes this process.

Proposed Chilled Beam Water Flow Diagram

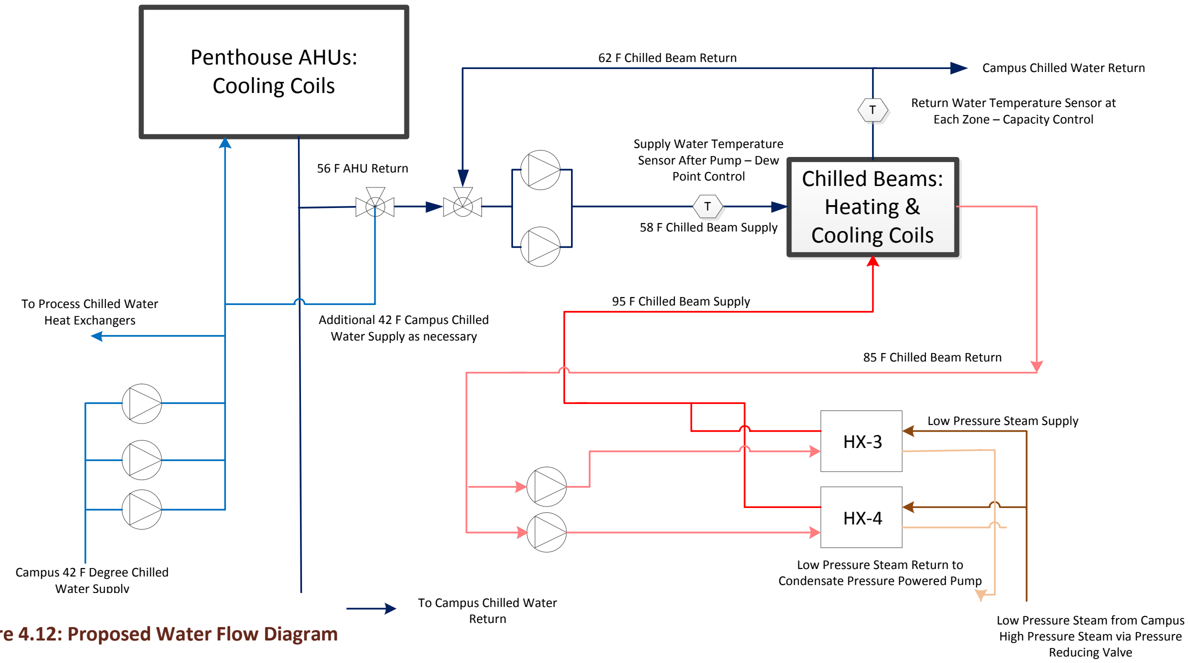


Figure 4.12: Proposed Water Flow Diagram

Figure 4.12 outlines the proposed redesign's strategy for supplying two different supply chilled water temperatures. 42°F water is required by the penthouse air handling unit and 58°F is required by the chilled beams. As in the existing design, campus chilled water is supplied to the penthouse AHUs and process chilled water heat exchangers. The challenge lies in providing a consistent supply temperature of 58°F to the chilled beams without incurring additional energy use. The solution for this problem was to bleed campus chilled water and AHU chilled water return into the chilled beam chilled water loop as necessary to bring the temperature down. An conservative estimate of 3,000 gpm was extrapolated from Trane TRACE results for the building's chilled beam chilled water loop. In comparison, the air handling units only require 1,500 gpm. If a 4 degree delta T is anticipated in the chilled beam loop, at worst case conditions, an additional 187.5 gpm of 42°F campus chilled water will be required.

$$3{,}000\ GPM_{BeamLoop} * (62^oF - 58^oF) * 500 = (1{,}500\ GPM_{AHU} * (58^oF - 56^oF) * 500) + (187.5\ GPM_{Campus} * (58^oF - 42^oF) * 500)$$

A temperature sensor will be positioned after the pumps to ensure the chilled water supply temperature is at 58°F for dew point concerns. Additional sensors will be placed at the return of chilled beam zones to signal the amount of campus chilled water required for cooling capacity needs. Two additional pumps are required to handle the additional chilled water flow to chilled beams and provide redundancy. These pumps will be the same size as current CHW-1 pumps and do not need to be resized. The pumps for the AHUs were downsized because the system has a smaller quantity of airflow. Overall, the system required an additional pump to accommodate chilled water distribution needs.

Hot water is supplied to the four pipe chilled beams in a manner similar to the hot water distribution to VAV reheat coils through heat exchangers HX-3 and HX-4.

CHILLED BEAM SIZING

When determining the amount of chilled beams needed for each space and proposed redesign costs, peak load outputs from the Trane TRACE model were used. Trane TRACE provided an option for exporting reports on chilled beam sizing requirements, however the tool was not used due to differences with manufacturer's data. From the Trane TRACE model, peak loads could be analyzed for chilled beam sensible sizing. To handle the latent loads in the building, ventilation was compared against three criteria, ASHRAE Standard 62.1 criteria, latent load criteria, and air change criteria if necessary. The amount of outdoor air for a space is based upon the space's latent load, desired space conditions, and outdoor air conditions:

$$Q_{Latent_{CFM}} = \frac{q_{latent}}{\left(0.68\ x\ (W_{room} - W_{Primary})\right)}$$

In both systems, ventilation air will enter spaces at 58 grains/pound of dry air. Standard design space conditions are typically 75^{o}F, 50% Relative Humidity. If room conditions are designed to 75^{o}F, 53% Relative Humidity, within the limits specified by ASHRAE Standard 55, the quantity of airflow needed to offset latent loads decreases dramatically. In the areas on the 3rd floor that require large amounts of makeup ventilation air, the quantity of air needed is unaffected by different room design relative humidity conditions. The table below breaks down sample conditions in office and student areas. Airflow requirements for office spaces within the redesign can decrease by as much as 36% and further downsize the amount of airflow and ductwork needed by the building.

Occupant Ventilation Examples: Student/Office Areas				
People	Occupant Latent Load Ventilation Btu/hr	CFM Needed to Offset Latent 50% RH	CFM Needed to Offset Latent 52% RH	CFM Needed to Offset Latent 53% RH
4.8	952	200	140	127
1.1	220	46	32	29
1.8	361	76	53	48

Latent loads drove ventilation needs in the office spaces as expected. Occupant latent ventilation needs were then analyzed against the six air changes requirement for labs. The greater of the two were used for sizing of the chilled beams in lab spaces. In many cases the sensible load was met, but additional ventilation was needed. With sensible and latent loads in consideration, chilled beams were selected and laid out within the existing ceiling. The high capacity TROX DID 632 two-way air distribution chilled beams were sized to handle each space's requirements. Additional Price HVAC ACBL one way diffusers were strategically placed along the perimeter to handle envelope loads and promote mixing in the space. The loads handled by one-way Price HVAC ABCL and two-way TROX DID 632 beams were tracked to ensure that the beams will provide adequate sensible load coverage. Excess ventilation not met by the chilled beams was tracked.

Space	CFM Needed	Peak Load in Space	Perimeter PRICE 1' wide beams Selection			TROX 632 2'x4' Beams				
							Selection			
	(cfm)	(Btuh)	Quantity	Total CFM	Total Load	Load Left	Quantity	Total CFM	Total Load	Leftover CFM
sp-N-302A-Copy	14	617		0	0	617	1	80	4,939	-66
sp-N-302B-Reception	28	1,255		0	0	1,255	1	80	4,939	-52
sp-N-302-Staff_Admin	106	4,785		0	0	4,785	1	110	5,333	-4
sp-N-305-IT_Staff_Office	52	2,340		0	0	2,340	1	80	4,939	-28
sp-N-306A-Conference	284	3,926	3	300	12951	-9,025	0	300	0	-16
sp-N-306B-Conference	284	6,834	3	300	12951	-6,117	0	300	0	-16

Figure 4.13: Calculations of Loads met by Chilled Beam Selections

In the Material Science and Life Science wings where more ventilation is needed, neutral temperature air will be supplied through additional diffusers that complement ventilation delivered by chilled beams. With some columns hidden due to space limitations, the spreadsheet used for calculating the amount of chilled beams needed for ventilation and sensible loads is shown in Figure 4.13. Typical orientation of chilled beams in office spaces are shown in Figure 4.14 and in perimeter lab spaces in Figure 4.15

The reflected ceiling plan needed to be constantly referenced because of its impact on chilled beam locations and airflow movement in the spaces. In office spaces, two one-way, 1' x 4' beams were place parallel to the exterior wall and to the wall containing the doorway entrance. Although a single 1' x4' beam could handle the sensible and latent loads in the space, two beams were specified in order to ensure proper mixing for a thermally comfortable environment. In cases where the beams were oversized for sensible load, the amount of chilled water needed by each beam was lowered and tracked. Similarly, laboratory spaces on the exterior contained one way 1' x 4' beams parallel to the envelope. Perpendicular rows of two-way, 2' x 4' chilled beams were placed in intervals of twelve feet to meet mixing criteria found by using the TROX DID 632 Selection Program.

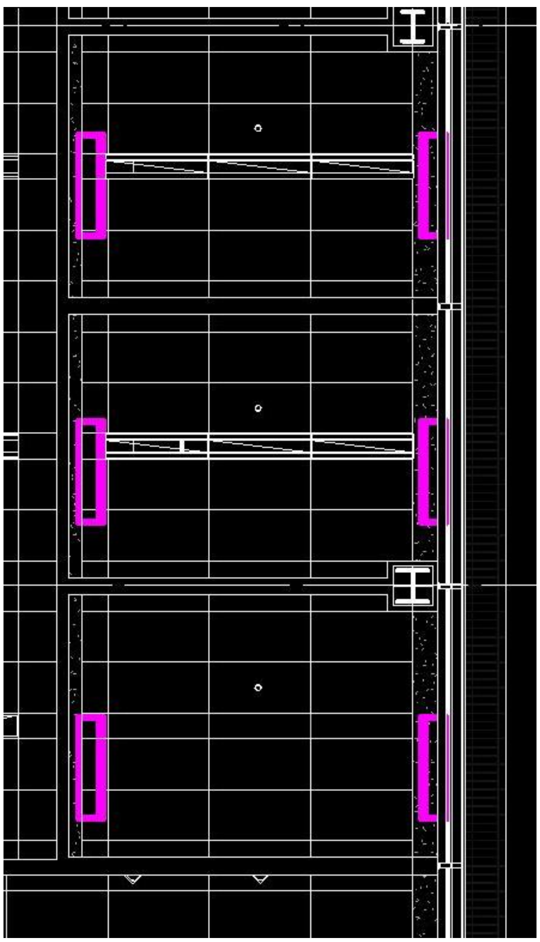


Figure 4.14: Office Chilled beam Layout

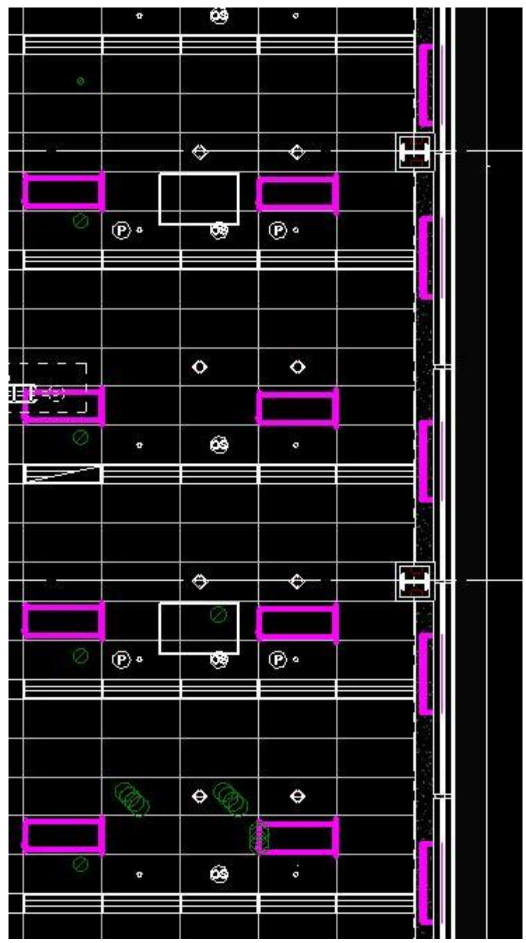


Figure 4.15: Life Science Perimeter Chilled Beams Layout

REDESIGN MODELING

The next step for analyzing the feasibility of implementing chilled beams into the Millennium Science Complex is to model the energy requirements of both VAV and active chilled beam systems. The same Trane TRACE energy model of the 3rd floor that was created off a gbXML file export was used to model annual energy and operating costs. The import of the gbXML was not complete with load information, occupancy, lighting density, or power densities. The spaces needed to be grouped into templates that could reflect the similar conditions across equivalent space types. A summary of key assumptions in the models is provided.

I. Labs
   a. 5 Watts/SF misc. load
   b. 33.3 SF/Person
   c. 1.4 W/SF lighting density
II. Interior Labs – Same as Labs except for noted changes
   a. 10 Watts/SF misc. load
III. Office Spaces
   a. 1.5 Watts/SF misc. load
   b. 143 SF/Person
   c. 1.1 W/SF lighting density
IV. Existing Systems
   a. Variable Volume Reheat
   b. 6 air changes per hour for lab spaces
   c. 30% minimum flow default for office spaces
   d. Total-energy wheel
V. Proposed Systems
   a. Active Chilled Beams
   b. Total-energy wheel for labs and offices
   c. Total-energy wheel and sensible wheel for parallel supply air conditioning
VI. Existing and Proposed Plants
   a. Purchased chilled water
   b. Purchased district steam
VII. Utility cost data was input per OPP

Utility Information from OPP	
Utility	Cost ($)/Unit
Purchased Steam	$9.85/1000 lbm ($0.82/therm)
Purchased Chilled Water	$0.22/ton-hr ($1.83/therm)
Electric Consumption	$0.07517/kWh
Electric On Peak	$1.09/kW
Water (N/A in current model)	$3.32/1000 gallons

ENERGY MODEL RESULTS

Only the third floor was modeled for the Millennium Science Complex due to time constraints. Data reported in this section is based on the 3rd floor and was extrapolated to reflect the size of the entire building. Results have changed from previous models due to incorporation of more data into the model. Earlier models reported in previous reports were run at lowered equipment power densities and resulted in lower energy costs.

The energy model results predicted a savings of 14.1% on yearly energy consumption and operating costs for the chilled beam redesign versus the existing VAV design. Over the course of the year, utility costs for electricity, steam, and purchased chilled water are consistently lower with the proposed redesign. Building wide costs were extrapolated using an area factor to bring the modeled 43,000 square foot 3rd floor totals to a rough building total. The following tables and figures depict operating costs and emission comparisons. Equipment changes were reported to the electrical engineer and are summarized in Appendix 4.E.

3rd Floor and Estimated Building Operating Costs			
		3rd Floor	Building
Existing VAV	Building Energy kBtu/yr	16,478,534	98,871,204
	Source Energy kBtu/yr	26,688,590	160,131,540
	Operating Costs	$250,288	$1,501,728
	Cost/SF	$5.84/ft^2	
Proposed ACB + Triple Pane Glazing	Building Energy kBtu/yr	13,912,786	83,476,716
	Source Energy kBtu/yr	24,018,516	144,111,096
	Operating Costs	$214,983	$1,289,898
	Cost/SF	$5.02/ft^2	
	Percent Savings	14.1%	

3rd Floor and Estimated Building Emissions			
		3rd Floor	Building
Existing Design	CO_2	5,872,120	35,232,720
	SO_2	45,400	272,400
	NO_x	9,125	54,750
Proposed Design	CO_2	4,957,817	29,746,902
	SO_2	38,331	229,986
	NO_x	7,704	46,224

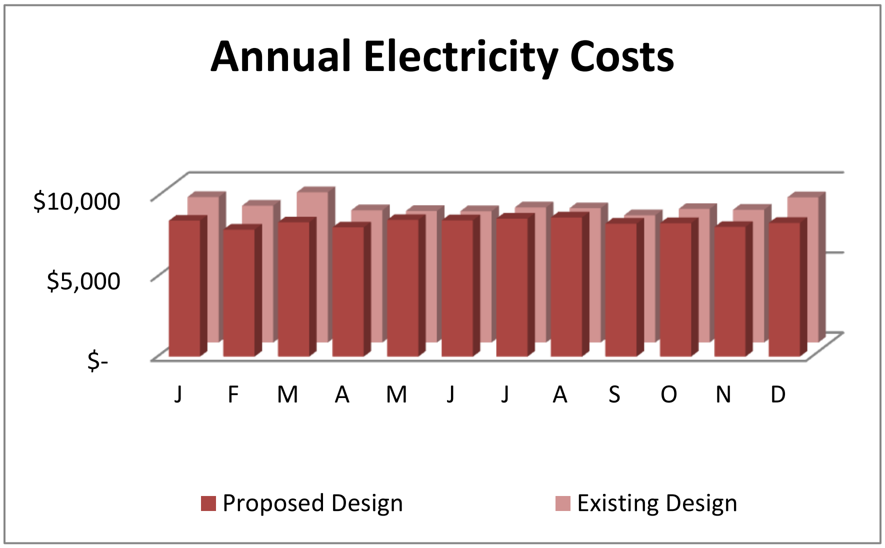


Figure 4.16: Annual Electricity Costs

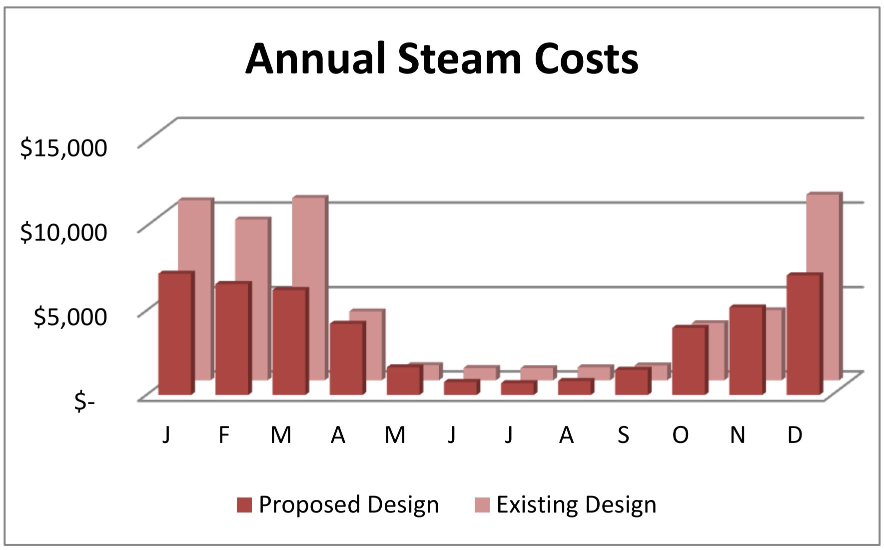


Figure 4.17: Annual Steam Costs

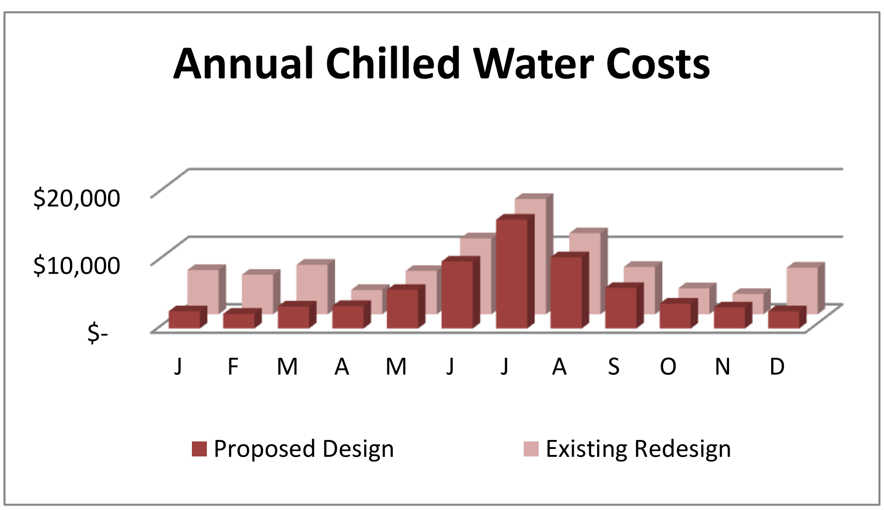


Figure 4.18: Annual Chilled Water Costs

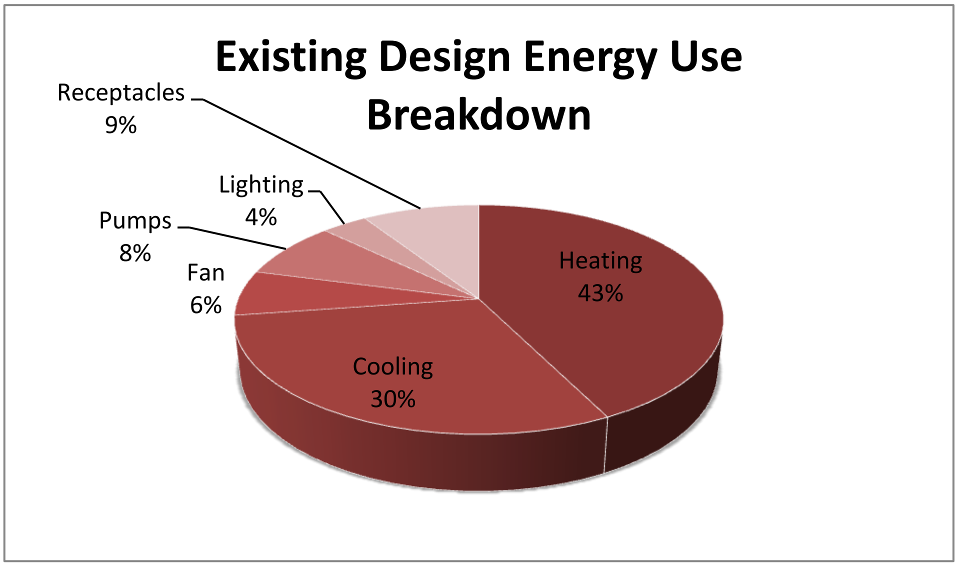


Figure 4.19: Existing Design Energy Use Breakdown

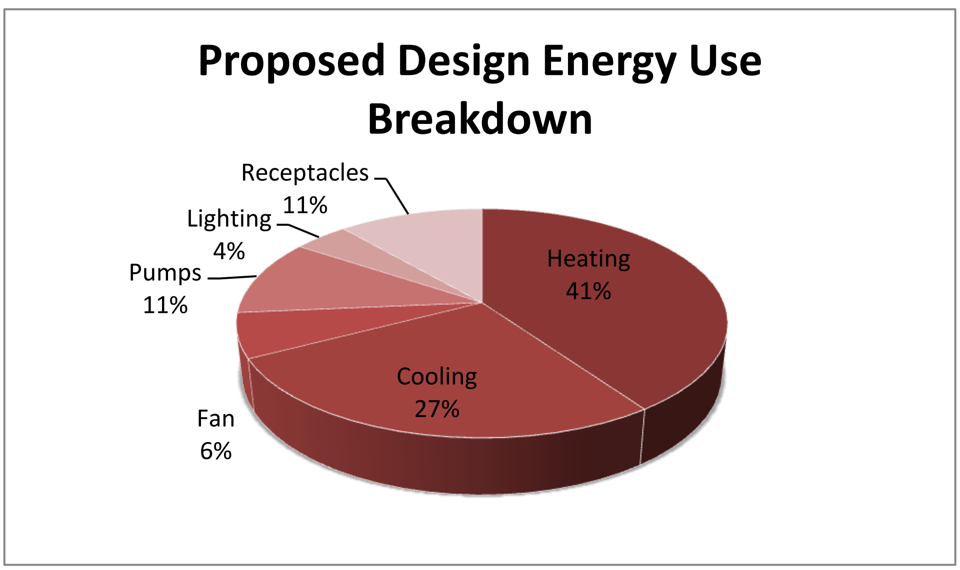


Figure 4.20: Proposed Design Energy Use Breakdown

FUME HOOD OPTIMIZATION

DESIGN CRITERIA

Laboratory buildings consume enormous amounts of energy, largely due to the equipment contained within the buildings. One potential energy saving area is the optimization of fume hoods' face velocities. A single fume hood consumes as much energy as the average household over the course of a year. The Millennium Science Complex will be incorporating 70 fume hoods, with the capacity for additional fume hood as research needs change with time.

Fume hoods contribute to a large portion of the energy usage of a building because they drive the need for airflow within a space. In a typical space, sensible loads, latent loads, or ASHRAE Standard 62.1 ventilation criteria drive airflow needs. In laboratory spaces, airflow is driven by either ventilation for a specified safety air change criteria or make up air needed for fume hood exhaust. The additional air needed for fume hood makeup is usually much larger than that needed to satisfy ASHRAE Standard 62.1. However, this air still needs to be conditioned properly before entering the space. Higher operating costs arise due to large amounts of energy spent conditioning the makeup air.

Currently, all fume hoods are specified to have a face velocity of 100 feet per minute (fpm) or 125 fpm. The effect of changing the face velocity from 100 fpm to 80 fpm on the operating costs of conditioning and delivering the makeup air required was analyzed in this study. It should be noted that this is only a study of the effect of lowered face velocities on operating costs and would any change in face velocity requires the approval of the Industrial Hygiene & Safety Officer of the project before implementation. 80 fpm was chosen as a conservative comparison for analysis. Different agencies have published ranges of acceptable face velocities. OSHA has stated that "hood face velocity should be adequate (typically 60-100 lfpm)." ACGIH has recommended face velocities of 80-100 fpm. For the operating cost analysis of different face velocities, the entire building's fume hoods will be analyzed. In addition, a CFD analysis is provided with 100 fpm and 80 fpm face velocities at open and operating (18 inch opening) sash positions to compare effectiveness containing an area source within the hood from entering occupied space. The CFD model compares different face velocities for a sample fume hood room. The models were evaluated based on the ability to achieve the desired face velocities within the model and the contaminant levels allowed at the fume hood face position.

METHODOLOGY

A smaller quantity of air required for fume hood makeup air will result in lowered operating costs. The specified total CFM of all specialty fume hood exhaust fans, 99,000 CFM, was considered the total makeup air needed for the 100 fpm velocity study. Eighty percent of that, 79,200 CFM was used for the 80 fpm study. Bin data for outside air conditions, from nearby Williamsport, Pennsylvania was used throughout calculations to produce operating costs over a year's duration. The Bin data was applied to calculations to determine the operating costs of cooling/dehumidifying, heating, and humidifying the makeup air.

Bin Data for Williamsport, PA		
Temperature (^{0}F)	Enthalpy (BTU/lbm)	Hours of Occurrence
-13.0	-3.1	1
-8.0	-1.9	4
-3.0	0.0	10
2.0	1.4	23
7.0	2.6	59
12.0	4.2	107
17.0	5.5	191
22.0	7.2	322
27.0	9.0	528
32.0	10.6	846
37.0	12.6	844
42.0	14.3	689
47.0	16.6	652
52.0	18.7	647
57.0	21.4	707
62.0	24.5	747
67.0	27.1	762
72.0	29.3	630
77.0	30.7	456
82.0	32.3	316
87.0	33.9	151
92.0	35.6	52
97.0	36.5	12

However, the bin data cannot be used without alteration to calculate energy costs. The existing VAV system utilizes an enthalpy wheel for air that is delivered to the lab spaces. Therefore, the effect of the enthalpy wheel on the outdoor air temperature needs to be considered before calculations can be made for what energy needs to be expended through the coils. The proposed active chilled beam system will utilize a dual wheel AHU year round to preheat additional ventilation air. This AHU, as mentioned previously will contain an enthalpy wheel to precondition the outdoor air as well as a sensible wheel to provide reheat to air destined for laboratory spaces. The sensible wheel operates to increase the effectiveness of the enthalpy wheel in the summer and provide yaer round preheating of interior laboratory zones. The result is slightly different conditions seen by each AHU's coils. The entering coil conditions are summarized below. For calculation purposes, it was assumed that fan heat accounts for a 3^{o}F rise in temperature before the air enters the sensible wheel in the dual wheel system, and in the other enthalpy wheel only AHUs. A 51% effectiveness of both wheels was used from manufacturer's data to account for unequal supply and exhaust airstreams.

Entering Coil Conditions			
Enthalpy Wheel Only: VAV, 100 fpm		Dual Wheel: Neutral Air+ Chilled Beams, 80 fpm	
Temperature (^{0}F)	Enthalpy (BTU/lbm)	Temperature (^{0}F)	Enthalpy (BTU/lbm)
36.6	14.4	27.7	12.6
38.7	14.9	29.8	13.1
40.9	15.7	32.0	13.9
43.0	16.3	34.1	14.5
45.2	16.8	36.3	15.0
47.3	17.5	38.4	15.7
49.5	18.1	40.6	16.3
51.6	18.8	42.7	17.0
53.8	19.6	44.9	17.8
55.9	20.3	47.0	18.5
58.1	21.1	49.2	19.3
60.2	21.9	51.3	20.1
62.4	22.9	53.5	21.1
64.5	23.7	55.6	21.9
66.7	24.9	57.8	23.1
68.8	26.2	60.8	25.3
71.0	27.4	62.9	26.5
76.0	30.4	65.1	27.4
78.1	31.1	67.2	28.0
80.3	31.7	69.4	28.7
82.4	32.4	71.5	29.4
84.6	33.2	73.7	30.1
86.7	33.5	75.8	30.5

With this data, heating energy calculations for adjusted bin temperatures were made using the following formulas:

$$\left(\frac{Btu}{hr}\right) = 1.1 * (Bin\ Temperature - 52^{o}F) * CFM * Hours\ of\ Occurence$$

$$Therms = \frac{\left(\frac{Btu}{hr}\right)}{10{,}000}$$

$$Steam\ Heating\ Costs = Therms * \$0.82/therm_{steam}$$

The design leaving coil temperature for both systems is 52°F. At near saturated conditions, the enthalpy is 21.5 Btu per pound of dry air. In order to account for the sensible and latent cooling required, operating costs were based on total enthalpy. The calculations for dehumidification (cooling) are listed below:

$$\frac{Btu}{hr} = 4.5 * (Bin\ Enthalpy - 21.5) * CFM * Hours\ of\ Occurence$$

$$Therms = \frac{\frac{Btu}{hr}}{10{,}000}$$

$$Dehumidification\ Costs = Therms * \$1.82/therm_{CHW}$$

It was assumed that during the winter months, the supply air conditions should be kept at the same leaving coil condition. At this design condition, entering air must also have an enthalpy of 21.5 Btu per pound of dry air. The calculations for humidification costs are listed below:

$$\frac{Btu}{hr} = 4.5 * (21.5 - Bin\ Enthalpy) * CFM * Hours\ of\ Occurence$$

$$Therms = \frac{\frac{Btu}{hr}}{10{,}000}$$

$$Humidification\ Costs = Therms * \$0.82/therm_{Steam}$$

The last metric measured was fan power energy. It was assumed that the exhaust fans specified in the schedule could be assigned to 100 fpm face velocities, and 80% of each of these fans CFM capacity would be sized for 80 fpm face velocities. The table below summarizes the changes in requirements of exhaust fans. The HP required for operation was converted into kilowatt-hours, multiplied by 8760 hours, and operating costs were found utilizing OPP's electricity rate for consumption only.

Fume Hood Exhaust Comparison				
Design	Fan Type	CFM	Static Pressure	HP
Existing 100 fpm	(3) Greenheck Vektor MD-33	21,400	5”	50
	(3) Greenheck Vektor MD-33	11,600	5”	25
Proposed 80 fpm	(3) Greenheck Vektor MD-33	17,200	5”	40
	(3) Greenheck Vektor MD-33	9,280	5”	15

All previous calculations were made considering a constant air volume exhaust system operating at full open position continuously over a year. An adjustment factor was found to represent findings as a variable air volume exhaust system and different sash positions. The VAV system was chosen to be applied to 100 fpm and 80 fpm face velocities due to the energy savings achievable with variable exhaust control. A VAV factor was estimated based on 8 hour operation of fume hoods at normal operation position per day, 6 days a week, for all but 14 days of the year. The remaining time was divided between full open (15%) and minimum positions (58%). The VAV factor was found by assigning a Percent Bin to corresponding open positions, and summing the multiples of the Percent Bin and the Percent Hourly Occurrences. The resulting VAV factor, 32%, can be multiplied to the constant volume operating costs to estimate VAV operating costs.

Fume Hood Position- Variable Air Volume Factor				
Percent Open	Percent Bin	Hour Occurrence	Percent Occurrence	Bin*% Occurrence
0-10 (Minimum)	0.05	5100	0.58	0.03
11-20	0.15	0.00	0.00	0.00
21-30	0.25	0.00	0.00	0.00
31-40	0.35	0.00	0.00	0.00
41-50	0.45	0.00	0.00	0.00
51-60	0.55	2384	0.27	0.15
61-70	0.65	0.00	0.00	0.00
71-80	0.75	0.00	0.00	0.00
81-90	0.85	0.00	0.00	0.00
91-100	0.95	1276	0.15	0.14
Totals		8760	1.00	0.32

ENERGY RESULTS

The costs of cooling, heating, dehumidifying, humidifying, and effect on fan power are summarized below. The payback for the increase in cost associated with models designed for lower flows is immediate. By only decreasing the volume of air by 20%, the cooling costs could be anticipated to be around 20%. However, the effect of the sensible wheel and fan power savings increases the operating cost savings 32% The overall cost for operating the Millennium Science Complex was estimated to be $1,501,728 with the VAV system and $1,289,898 with an active chilled beam system. Although the operation of the fume hood accounts for 7% of the operating costs, the yearly operating cost savings are worthwhile if contaminant effectiveness is not compromised.

Summary of Fume Hood Makeup Air Costs and Savings		
Metric	100 fpm VAV	80 fpm ACBs
Cooling/Dehumidification	$233,356.06	$122,597.17
Heating	$6,479.29	$13,447.52
Fan	$110,512.71	$81,042.65
Humidification	$17,610.24	$33,343.69
CAV Operation Costs	$367,958.30	$250,431.03
VAV Multiplier for Operation	0.32	0.32
Adjusted Operation Costs	$116,704.95	$79,428.95
Percent Savings		31.94%

Price Comparison of Fume Hoods						
Fume Hood Size (feet)	Existing Fume Hoods: Labconco Premier Fume Hoods			Proposed Low Flow Fume Hoods: Labconco XStream Fume Hoods		
	Unit Price	Quantity	Total Price	Unit Price	Quantity	Total Price
4	$7,360.00	2	$14,720.00	$7,480.00	2	$14,960.00
5	$8,380.00	14	$117,320.00	$8,650.00	14	$121,100.00
6	$8,920.00	52	$463,840.00	$9,270.00	52	$482,040.00
8	$12,350.00	1	$12,350.00	$13,220.00	1	$13,220.00
		Total	$608,230.00		Total	$631,320.00

Model information on low flow fume hoods can be found in Appendix 4.H

CFD ANALYSIS

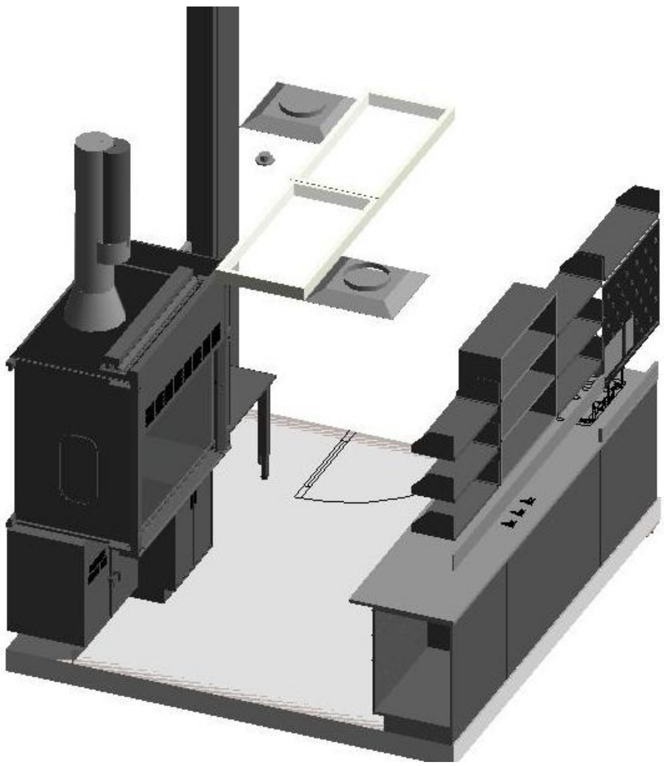


Figure 4.21: Revit Architecture view of W324A-Hot Room

Computational Fluid Dynamics (CFD) is an emerging tool in the HVAC industry that can predict the movement of air distribution of temperature, concentration levels, and pressure gradients within a modeled space. The movement of air throughout a space is extremely complicated and governed by the Navier-Stokes equations. Solving the Navier-Stokes equations is not practical for modeling indoor air flow conditions. Turbulence modeling, or the prediction of turbulent effects on fluid flow, requires much less time and computing power. Turbulent models can produce simulations to an acceptable level of detail for indoor air flow and other fluid flow modeling.

An advantage of producing an accurate CFD model is the ability to predict design alternatives without assembling mock up conditions and experimentally collecting data. While the experimental method provides reliable and easily attainable results, it is extremely costly and often unpractical. CFD modeling, the numerical prediction of data, can be faster and more affordable. However, the modeling interface requires an understanding of the basics of turbulent modeling and how the modeling software produces results to efficiently prepare models and analyze model outputs.

In order to compare the effectiveness of different face velocities, CFD modeling was based off of W324A-Hot Room, shown in Figure 4.21. Within the Millennium Science Complex, there are varying fume hood conditions. W324A-Hot Room was chosen because of its size and to the time needed to produce an accurate CFD model. The components of the room were dimensioned from the Revit Architecture model, converted to metric units, and re-modeled within Phoenics 2009 software.

The purpose of this CFD model is to analyze the effect of changing the amount of air the fume hood is required to exhaust and in turn, the face velocity required. The effectiveness of 100 fpm and 80 fpm face velocity conditions' ability to contain a contaminant source will be reported. ASHRAE Standard 110: Laboratory Fume Hood Performance Testing's tracer gas containment test will be the basis for the CFD models. Measurements were taken to analyze fume hood containment effectiveness. The energy savings previously mentioned are not worthwhile if the lowered face velocity does not adequately protect a human operator from contaminant leakage.

For the room chosen, the following elements have been modeled in Phoenics 2009:

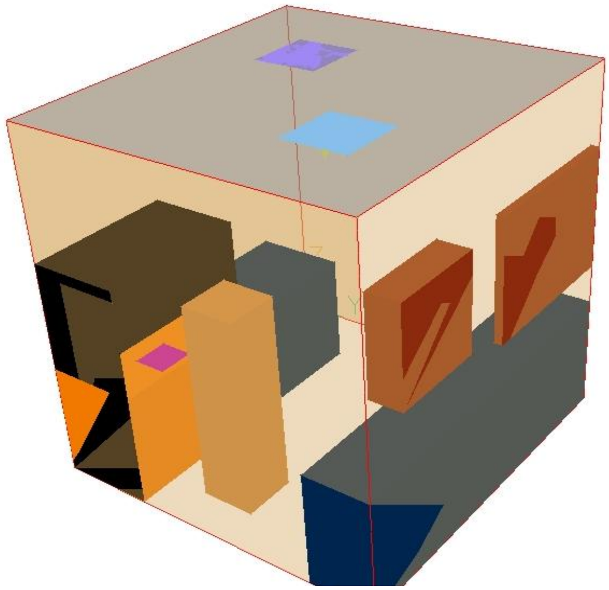


Figure 4.23: CFD Model of Fume Hood Room

1. Four walls, ceiling, and floor
2. Human operator at fume hood
3. Table adjacent to the fume hood
4. Fume Hood
5. Table
6. Cabinet
7. Wallboard
8. General Exhaust
9. Square Ceiling Diffuser
10. Contaminant Source Inlet
11. Fume Hood Outlet

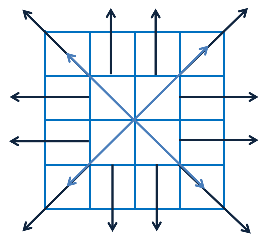
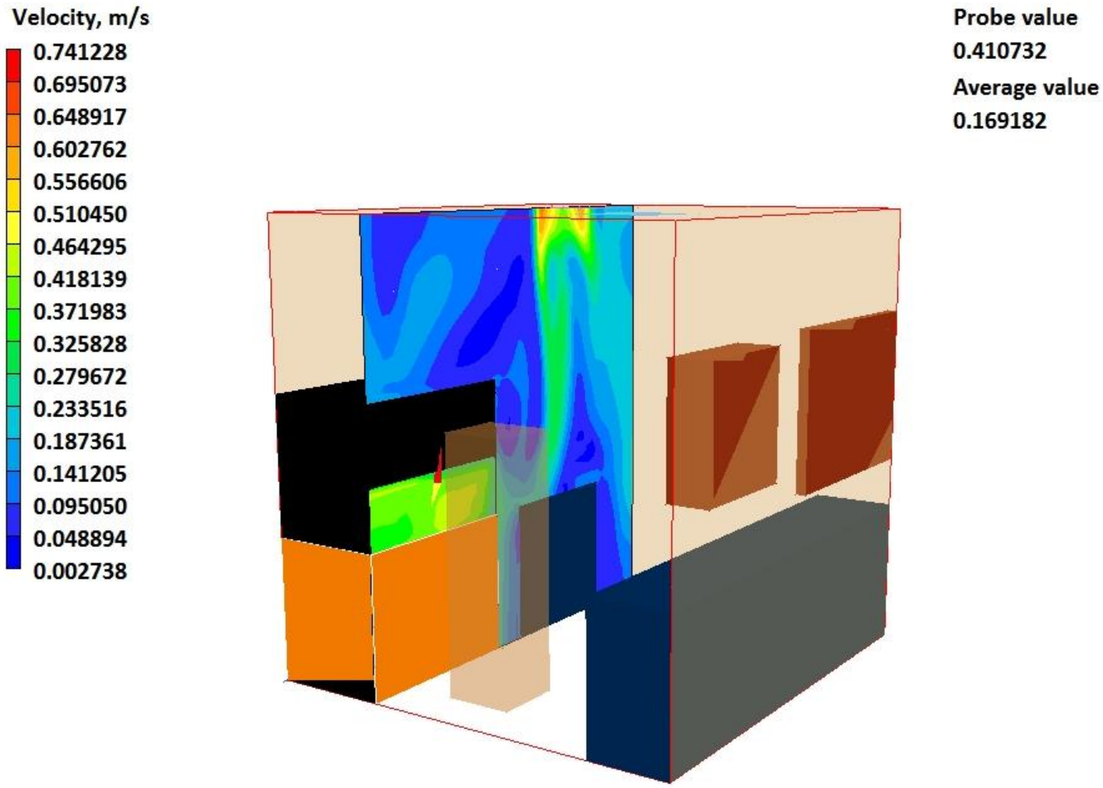


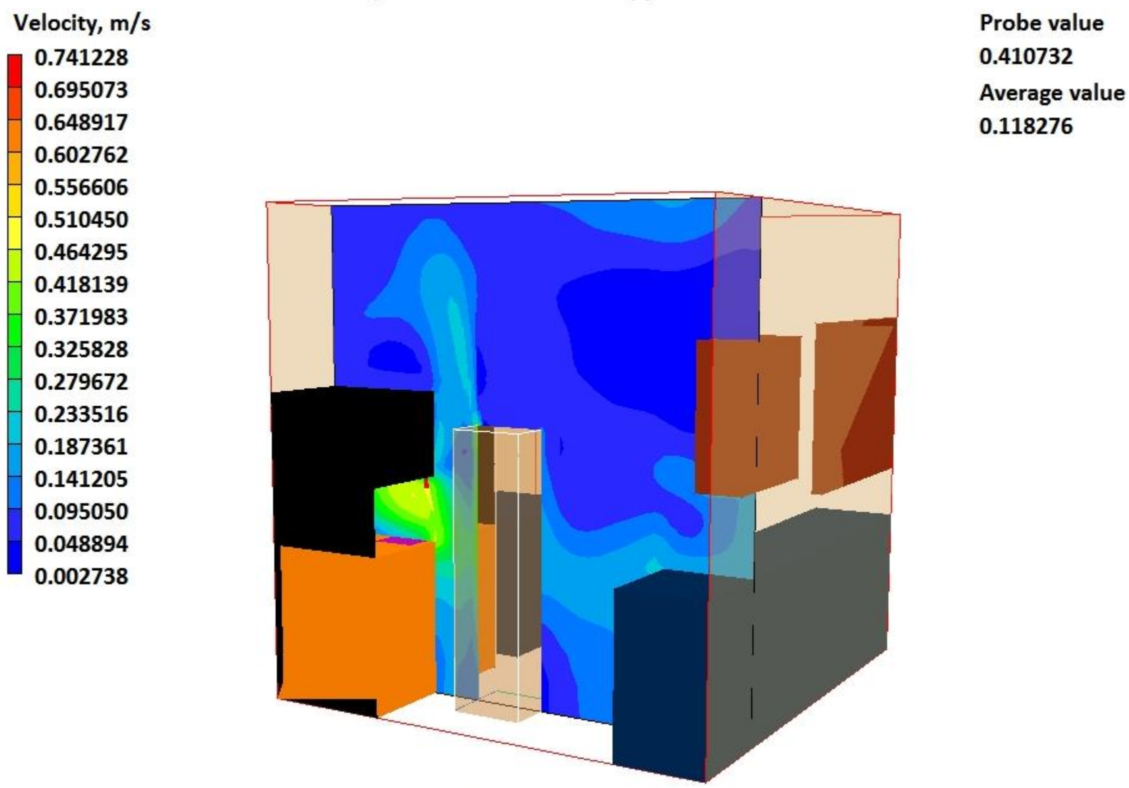
Figure 4.22: Momentum Method applied to Supply Diffuser

To accurately model airflow from a diffuser in a CFD model, the diffuser must be input as a series of inlet components. The 2' x 2' diffuser (light purple figure in Figure 4.23) was split in 16 inlet conditions. The varying CFMs induced into the model were equally spilt between each section. Each inlet section contained a velocity in the negative Z direction and additional components in the X and Y directions to produce flow in different directions. Figure 4.22 depicts how the velocity components of the 16 inlets were broken down according to the momentum method for modeling diffusers. The outlet conditions for the fume hood were specified with an exhaust velocity according to the require face velocity fpm and the sash position. The general exhaust (light blue in Figure 4.23) contained unspecified conditions and will allow mass to flow in or out. If the exact airflow conditions are specified, the model will be over prescribed and forced to converge. In modeling simulations, this could allow potential airflow problems to be overlooked. The general exhaust allowed for the simulations to gradually reach convergent, accurate results. The grid created automatically by the program was altered slightly around the diffuser to improve accuracy.

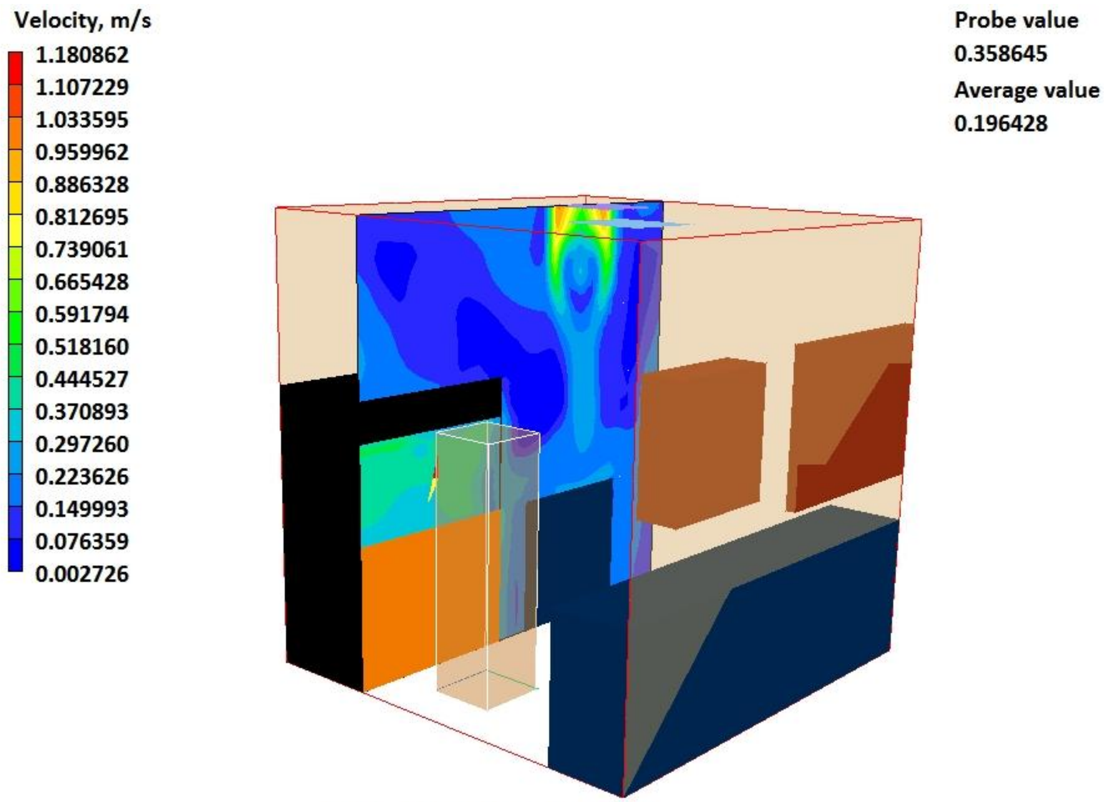
Four model simulations were reported. The existing 100 fpm face velocity condition was modeled at an 18" operating sash position and an open 30" sash position. The proposed 80 fpm face velocity condition was similarly modeled at those sash positions. For each simulation, only the inlet air quantity and the specified fume hood exhaust quantity were altered. To test containment potential, a 0.3m x 0.335m inlet condition was modeled on the fume hood face (pink in Figure 4.23). The inlet velocity was modeled at 4 L/min per ASHRAE Standard 110 and the scalar concentration inlet was set at 1000. The inlet flow was specified to have a density five times denser than air to replicate a typical tracer gas, SF_6. The probe measured the concentration value at the fume hood face and quantities will be compared. The models were run numerous times with small and large iterations to test accuracy. Ultimately, precise boundary inlet and outlet conditions were specified and all models were run to approach convergence before results were analyzed. The following pages provide screen shots of highlighted results. More CFD information can be found in Appendix 4.I.



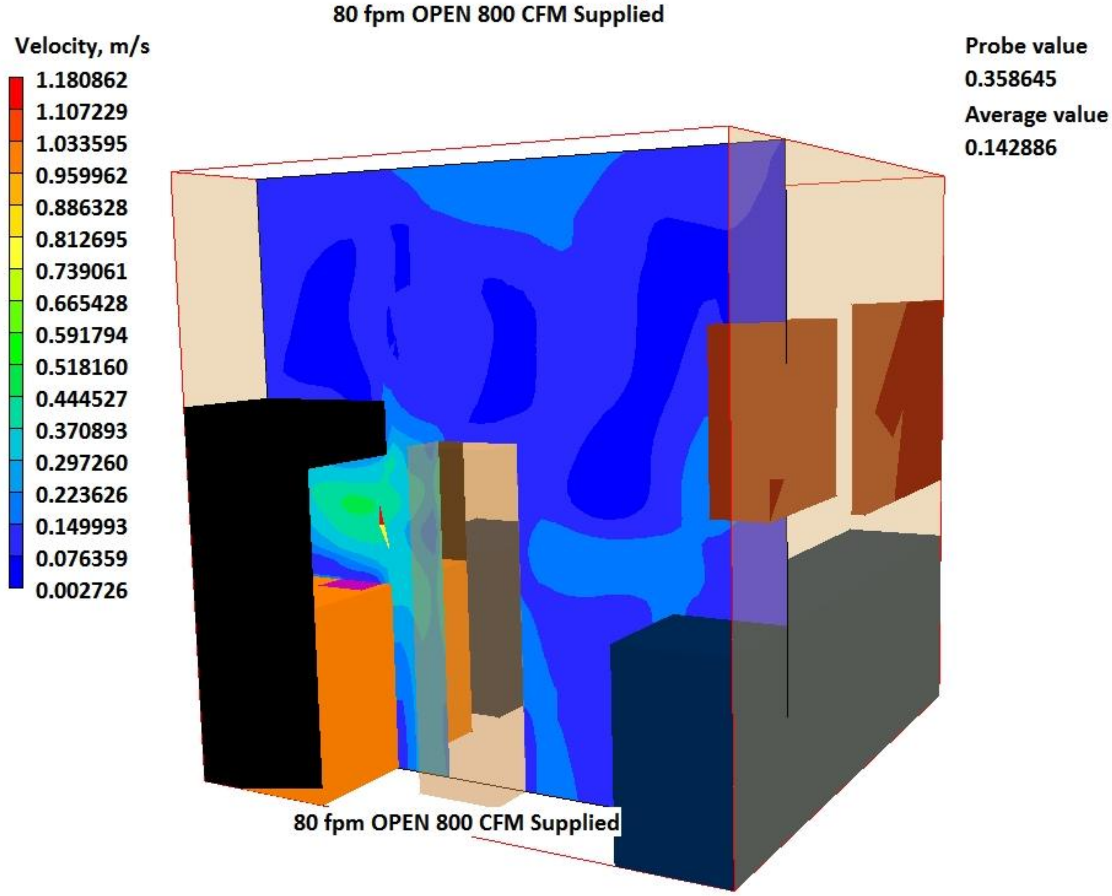
80 fpm 18" Sash 500 CFM Supplied



80 fpm 18" Sash 500 CFM Supplied



80 fpm OPEN 800 CFM Supplied



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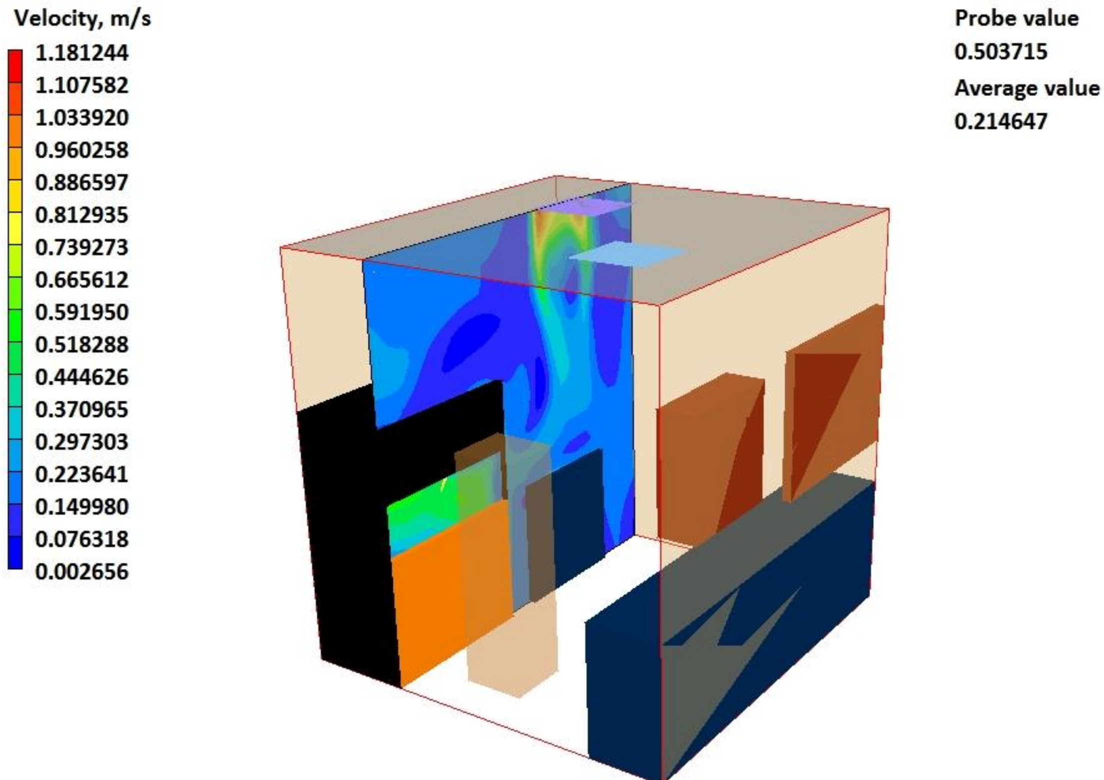

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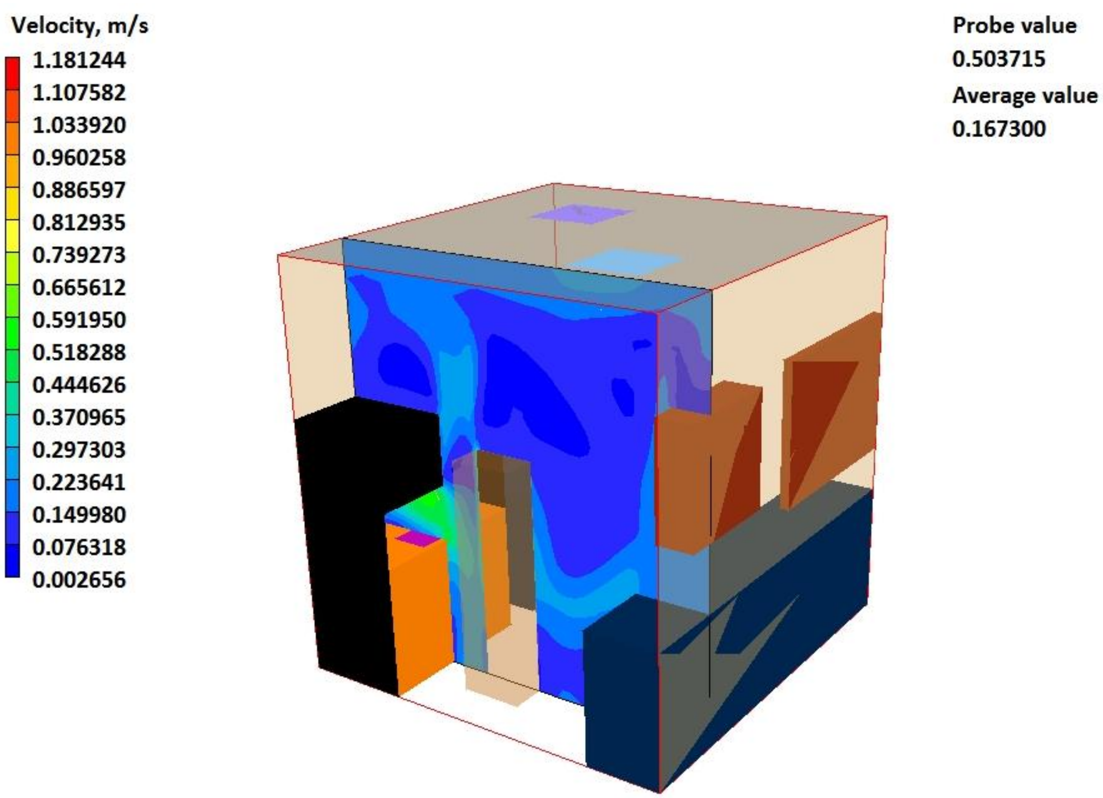
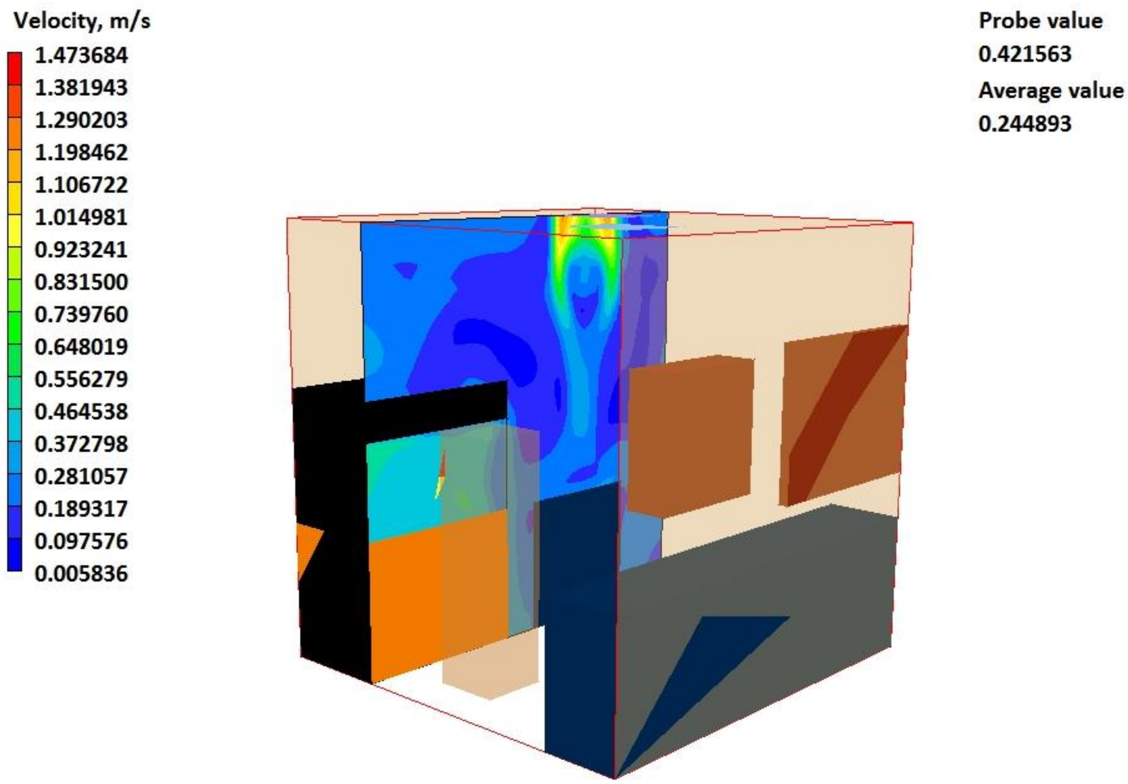
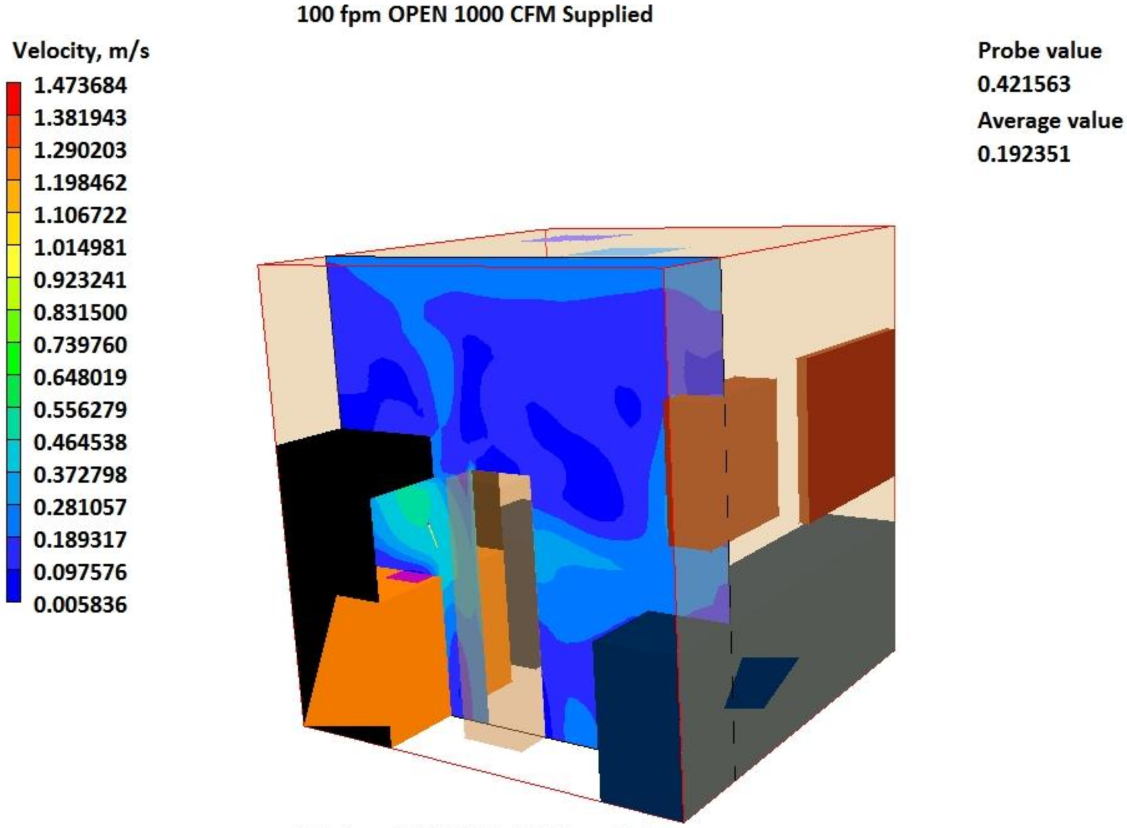


100 fpm 18" Sash 600 CFM Supplied



100 fpm OPEN 1000 CFM Supplied



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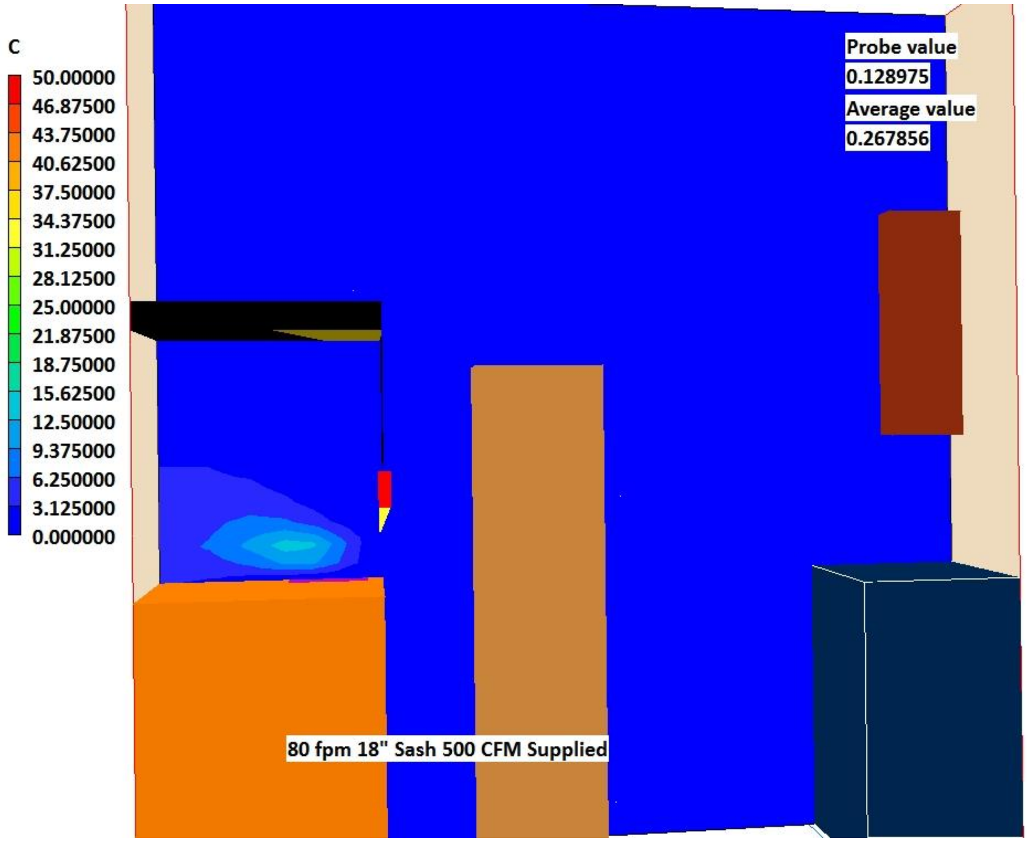
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18.75000
15.62500
12.50000
9.375000
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Probe value
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Average value
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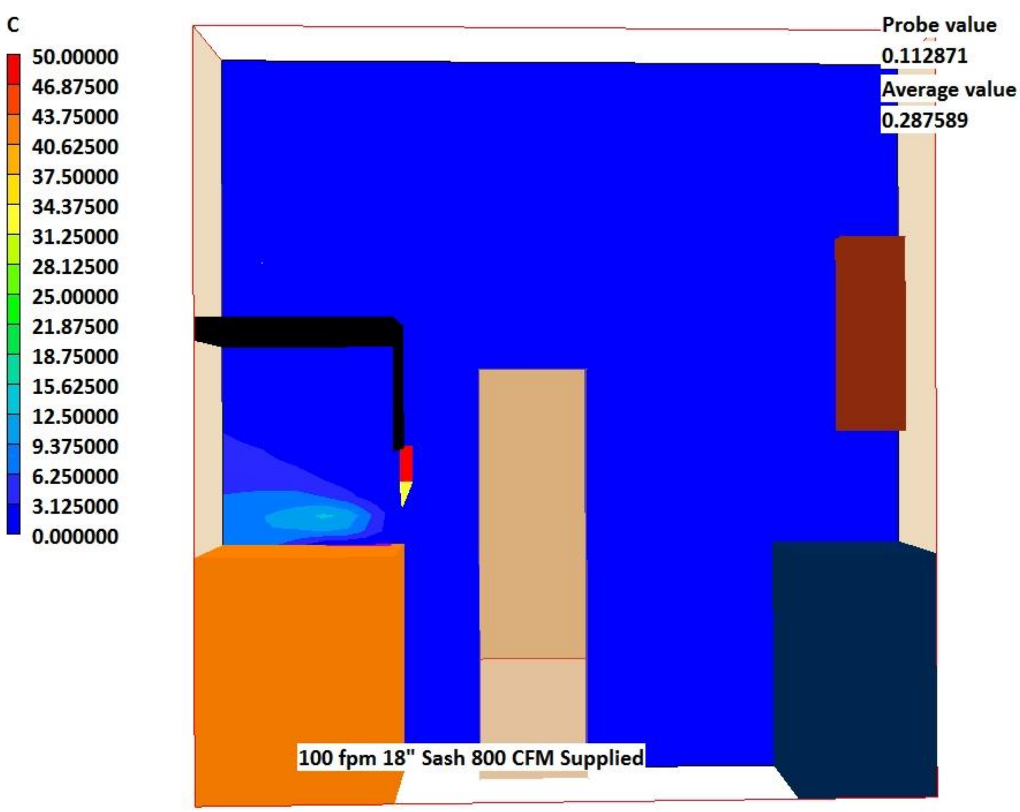
80 fpm 18" Sash 500 CFM Supplied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Average value
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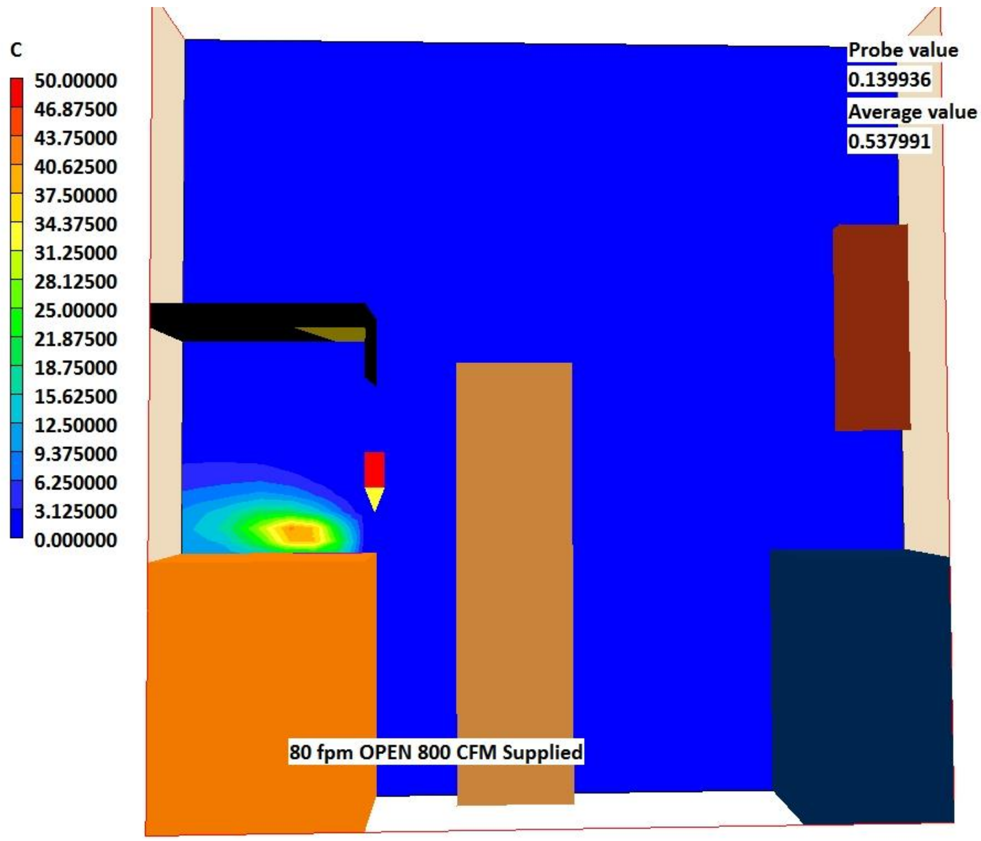
100 fpm 18" Sash 800 CFM Supplied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15.62500
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Average value
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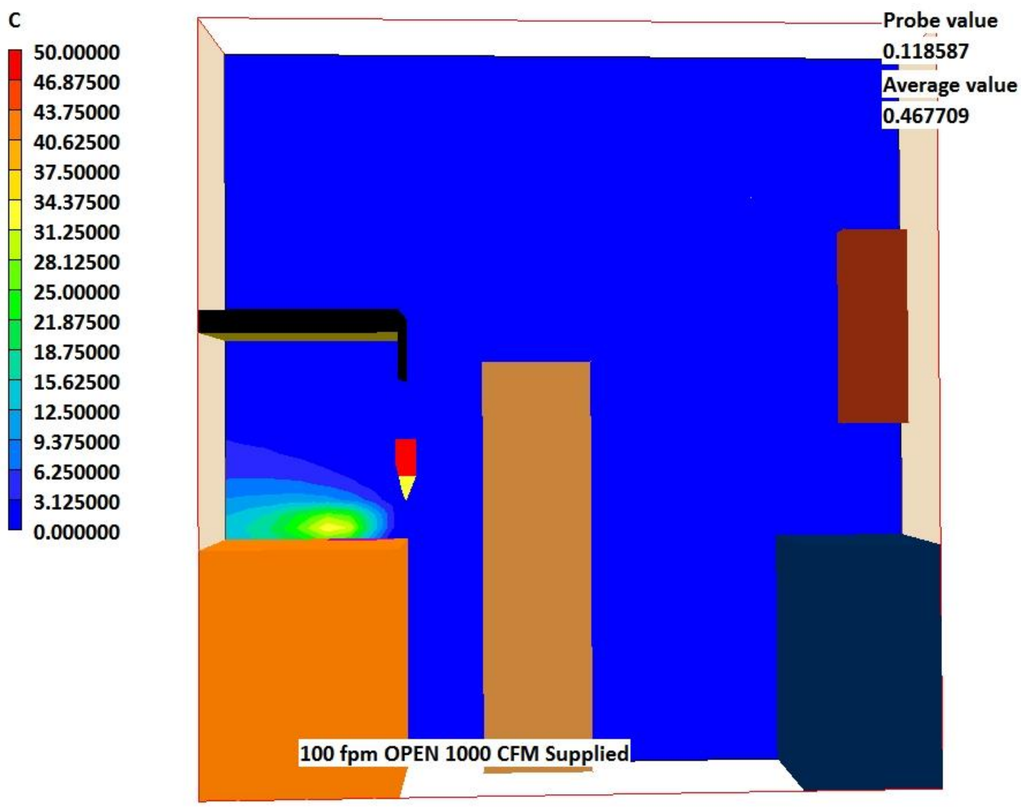
80 fpm OPEN 800 CFM Supplied


C
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43.75000
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37.50000
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31.25000
28.12500
25.00000
21.87500
18.75000
15.62500
12.50000
9.375000
6.250000
3.125000
0.000000
Probe value
0.118587
Average value
0.467709
100 fpm OPEN 1000 CFM Supplied

CFD RESULTS

All simulations were run at 4,000 iterations with the k-ε Chen turbulence model and hybrid differencing scheme. The effects of gravity were turned on and temperatures were assigned to the objects and inlet air conditions. The mass residual criterion was 0.1%. Simulations were not run to meet the criteria due to time constraints and seemingly accurate results. A 55 x 45 x 42 grid was used in all models.

CFD Results: Comparison of Different Scenarios					
Scenario	Specified Outlet CFM	Face Velocity (2.7, 0.85,1.27)	Concentration: Face (2.7, 0.85, 1.27)	Percent Increase in Concentration	Mass Residual
100 fpm, 18" Sash	675	0.5037 m/s	0.11287	-	1.01%
80 fpm, 18" Sash	540	0.4107 m/s	0.12898	14.2%	0.63%
100 fpm, 30" Sash	1125	0.4215 m/s	0.11856	-	1.60%
80 fpm, 30" Sash	900	0.3586 m/s	0.13994	18.0%	1.11%

The previous pages depict the conditions listed in the tables. A cross section in the X and Y planes were provided at the middle of the fume hood (2.7, 0.845, 1.27) to prove the achievement of different face velocities. 0.51 m/s and 0.40 m/s are equal to 100 fpm and 80 fpm face velocities respectively. Additional images show the dispersion of the contaminant into the exhaust of the fume hood. A point value is provided at the face of the fume hood positioned (2.7, 0.85, 1.27).

CONCLUSION OF FUME HOOD STUDY

Within the CFD models, face velocity conditions for 18" sash positions were able to be mimicked in the 100 fpm and 80 fpm models. However, when the sash positions were set to 30" open position, the fume hood face velocity was lower than desired in both cases. This may be due to an over simplified modeling of fume hood geometry.

The specified inlet contaminant area had a scalar quantity of 1000 assigned for contaminant source and was the only source of contaminant in the model. Despite increases of concentration seen at the face of the hood of 14.2% and 18.0% for 80 fpm conditions, the overall effect of contaminant is very similar. Concentrations at the face of the fume hood were all less than 0.015% percent of the source and decreased dramatically as the probe approached the human operator.

From energy analysis and CFD studies, fume hoods with 80 fpm provide a comparable environment for safe operation and save 32% annually in operation costs. The first cost difference in lower flow models does not deter the installation of lower flow fume hoods. Therefore, it can be concluded that the energy savings seen by reducing the face velocity of a fume hood to 80 fpm are worthwhile due to comparable containment effectiveness in this scenario. Further analysis of other conditions would need to be done to ensure lower face velocities can be used in other conditions.

LEED & LABS 21 EVALUATION

The United States Green Building Council has promoted the rating of building's performance with the use of LEED rating systems. The rating systems scale performance based on multiple categories including, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation in Design Process. The increase in energy savings from the existing design, compared back to ASHRAE Standard 90.1's baseline design resulted in the attainment of 3 additional credit points for EA Credit 1: Optimize Energy Performance. The Millennium Science Complex would be awarded LEED Gold Certification with the proposed design as well.

LEED Credit Breakdown		
Category	Achieved/Possible Points	
	Existing Design	Proposed Redesign
Sustainable Sites	11/14	11/14
Water Efficiency	3/5	3/5
Energy & Atmosphere	5/17	**8/17**
Materials & Resources	5/13	5/13
Indoor Environmental Quality	12/15	12/15
Innovation & Design Process	5/5	5/5
TOTAL	41/69	**44/69**

The LEED Rating systems are becoming more popular and many areas require minimum LEED performance in the construction of new buildings. LEED has different rating systems for new construction, existing building renovations, operation and maintenance upgrades, schools, and homes. However, these breakdowns may not address the sustainable aspects of all projects. For the Millennium Science Complex, the LEED New Construction rating system was utilized. However, the same rating system applies to the new construction of different types of buildings such as offices. Labs 21, an organization sponsored by the Environmental Protection Agency and the Department of Energy, has analyzed the existing LEED rating system and provided additional credits for laboratory buildings. The Labs21 Environmental Performance Criteria (EPC) rating system addresses laboratory buildings specifically for their impact on the environment. It is intended to be supplemental to the LEED rating system and does not provide certification. However, the EPC provides additional guidance for designing an environmentally conscious lab facility. A summary of the supplemental credits is located in the following table.

Labs21 Additional Credits	
Credit	Intent
SS EPC Credit 1 Safety and Risk Management for Air Effluents	Minimize the environmental, safety and health impact of laboratory exhaust on neighboring buildings and the site.
WE EPC Prerequisite 1 Laboratory Equipment Water Use	Reduce water use by restricting the use of potable water for "once-through" laboratory equipment unless it is required as direct contact process water
WE EPC Credit 1 Process Water Efficiency	Reduce process water use and process wastewater generation
EA EPC Prerequisite 1 Asses Minimum Ventilation Requirements	Optimize minimum ventilation requirements in laboratories based on user requirements, health/safety protection and energy consumption.
EA EPC Credit 1 Improve Laboratory Equipment Efficiency	Save energy with efficient laboratory equipment
EA EPC Credit 2 Right-size Laboratory Equipment Load	"Right-size" mechanical equipment by improving estimates of heat-gain from laboratory and process equipment
MR Prerequisite 1 Hazardous Material Handling	Track and manage hazardous materials stream
MR Credit 1 Chemical Resource Management	Reduce potential harm to the environment and people through improved management of chemicals
EQ EPC Prerequisite 1 Laboratory Ventilation	Ensure that minimum requirements for IAQ and safety are met
EQ EPC Prerequisite 2 Protection and Notification Systems	Ensure health, safety, and awareness of employees
EQ EPC Credit 1 Laboratory Air Flow Analysis	Ensure health and safety of laboratory occupants

Information obtained from Labs21 website, EPC criteria: http://www.labs21century.gov/pdf/epc_3-0_508.pdf

KGB Maser has found the existing design follows most, if not all, of the criteria listed by the EPC credits. Equipment was right sized, ventilation rates were optimized, monitoring and control of fume hoods was incorporated, and alarm systems were provided. During the redesign process, CFD analysis was provided to demonstrate the effect of altering the face velocity of fume hoods. CFD analysis is one method discussed in EQ EPC Credit 1 for verifying laboratory air flow conditions. The Millennium Science Complex, although it does not achieve the maximum rating of LEED Platinum from the LEED rating system, is a laboratory facility that is designed to minimize the environment impact of its scientific processes and provide a safe environment for its occupants.

LIFE CYCLE COST: MECHANICAL SYSTEMS

A life cycle cost analysis is provided to compare the costs of installing, operating, and maintaining the existing mechanical distribution system against the proposed mechanical system. 14.1% energy savings of the proposed system comes at a higher upfront cost. A life cycle cost of the effect of the energy savings over the lifespan of the system is required either to promote or dismiss the proposed system. If the chilled beam system has a lower Net Present Value over 30 years than the existing VAV system, the initial increase in cost will be overcome. The utility data for the plant varies differently than the utility data used in the calculation of the building's operating cost. Coal, the existing primary fuel used at the plant, and natural gas, were used to compare the Net Present Value of each system. The inclusion of natural gas as a primary fuel is in reaction to the Board of Trustees at Penn State's approval of a plan to shift the campus coal plant to natural gas. In their analysis, the high cost of improving the emitted pollution from the coal and lower coal fuel prices was relatively equal to low conversion to natural gas costs and higher future fuel prices for natural gas. The heating energy for the building was used for natural gas and coal calculations while the cooling and electric needs were used for electricity calculations. In one analysis, a real discount rate of 3% was applied and does not include the effect of inflation. Other analyses were done with low (2%) and high estimates of inflation (5%). Reference Appendix 4.J for additional information on rates used. The proposed system, despite costing $1.852 million more than the existing system proved to be a quality investment when considered against inflation rates and if the switch to a natural gas plant is made. When inflation is not considered, the existing condition design is favored if a coal plant remains at Penn State. Natural gas prices are predicted to continually go up while costs of coal show a steady downward trend. Based on changes to the façade and the mechanical system, the life cycle cost analysis shows that the redesign will be worthwhile investment. Further savings can be realized if Penn State approves lowering the fume hood face velocity based on CFD modeling of further fume hood spaces or further experimental data to ensure safety of human fume hood operators.

Life Cycle Cost Summary						
	Coal Plant			Natural Gas Plant		
	Real Rate	2% Inflation	5% Inflation	Real Rate	2% Inflation	5% Inflation
VAV	$54,813,916	$63,883,395	$63,856,220	$64,693,985	$77,435,022	$90,744,775
ACB	$55,346,191	$62,693,273	$62,647,108	$59,478,486	$69,307,263	$69,259,831
Percent Savings	-0.97%	1.86%	1.89%	8.06%	10.50%	23.68%
NPV Differential	($532,275)	$1,190,122	$1,209,111	$5,215,499	$8,127,758	$21,484,944

Note: Operating cost savings from reduction in fume hood velocities were not included in this study.

MAE COURSEWORK INTEGRATION

AE 559

AE 559: Computational Fluid Dynamics in Building Design has been the source for all information applied to the CFD study of different fume hood face velocities effect on contaminant levels in a space. The course provided background information on turbulence modeling and the operations CFD simulations perform to assist in the study. Without knowledge of the intricacies of CFD programs, modeling could have produced erroneous results and negated the purposed of the analysis. It was crucial to use CFD modeling to back up energy saving claims of lower flow fume hoods.

AE 557,558

Knowledge gained from AE 557: Central Cooling and Distribution Systems and AE 558: Central Heating and Distribution Systems was referenced throughout the mechanical distribution analysis. Both classes assisted in identifying alterations necessary to existing flow diagrams to allow the proposed system to run efficiently with minimal impact on the campus plant. Information from these courses assisted in equipment resizing as well. Life cycle cost estimating learned in AE 558 was applied to existing and proposed designs to compare the two different strategies over a 30 year lifespan.

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April 7th, 2011

UNIT 5: STRUCTURAL REPORT

KGB Maser

Management. Engineering. Consulting.

IPD/BIM TEAM #3

JASON BROGNANO | MICHAEL GILROY | DAVID MASER | STEPHEN KIJAK

Dr. Mistrick | Dr. Jelena Srebric | Dr. John Messner | Dr. Andres Lepage

STRUCTURAL EXECUTIVE SUMMARY

The purpose of this report is to detail the process of structural analysis that was used to redesign the floor system, façade, and cantilever of the Millennium Science Complex. This laboratory building is located at the corner of Pollock and Bigler in University Park, PA. The existing design will be evaluated, and redesigned based on the goals of KGB Maser in an effort to engineer a system that functions as an integral part of three systems while maintaining economy and constructability.

The current floor system of the Millennium Science complex uses a lightweight, composite floor system to meet a strict vibrational criterion. Lightweight concrete on top of 3-inch metal deck is used with 24-inch deep girders in order to retain a certain level of rigidity. The proposed design replaces these wide flanges with 30-inch deep cellular beams to increase stiffness while preserving low mass.

An analysis was performed in SAP in order to calculate the existing floor's vibrational velocity. The results of this analysis were used to size the cellular beams that would replace the current wide flanges. It was found that strength, rather than stiffness controlled the new design, although stronger concrete was used to largely increase performance for a relatively low cost.

The façade was identified by KGB Maser as a point of interest due to its exisiting weight of 36 thousand pounds. In order to decrease the weight of the panels, and subsequently the amount of materials, the team investigated decreasing the profile depth.

After an analysis was completed on the strength of the current panels, the face depth of each panel was decreased to 5 inches from 6. That analysis revealed it was also possible to decrease the flange depth, decreasing its profile depth a foot. Thin brick was used to further decrease the weight of materials at its face.

The existing cantilever stretches 154 feet unhindered by support over a landscaped plaza at the North West corner of the building. This cantilever is a large source of structural costs and was considered by KGB Maser as an opportunity to reallocate money for more practical purposes. The redesign proposed two columns that would sit between two intersections of the four main trusses in order to reduce stresses in their members and eliminate unnecessary diagonals.

The trusses were completely redesigned, eliminating all but one floor of web members in the overhang. The existing base columns were able to be reduced in weight and several bays of bracing, previously purposed to resist the cantilever's inherent overturning moment, beyond the overhang's base were removed.

A lateral system analysis was also completed. This analysis confirmed the strength of the current lateral system using ETABS to check shear, story drift, and maximum displacement. Due to a torsional irregularity, panel zone shear and cracked concrete sections had to be considered in the analysis of the analytical model.

For a complete IPD/BIM discussion, please refer to Unit 1. The following explains only the structural depth of KGB Maser's redesign.

TABLE OF CONTENTS

FLOOR SYSTEM

Of the revisions proposed, the floor system was the first system to be changed. Due to the projected time required to complete the analysis, three weeks were allotted to entirely redesign the floor system. It took four and a half weeks in total from initially researching vibrations to the point at which a final SAP model was completed and run to move on to the next structural system.

EXISTING CONDITIONS

The existing floor system utilizes steel beams and girders to support a composite deck in square, 22' x 22' bays. Wide Flange, 21 inch deep beams frame into 24 inch deep girders in typical fashion, as seen in the figure below, throughout the Life Sciences and Material Sciences wings (please note the orientation of the center row of bays in each wing as it is oriented 90 degrees from the direction of the adjacent bays). Strict vibrational criterion necessitates the use of heavier beams and lightweight concrete in areas where labs and offices are located. To minimize weight while maintaining stiffness, the engineers used 3000 psi lightweight concrete on top of 18 gauge 3" metal decking for a total floor height, including girders, of about 30 inches, as shown in Figure 5.3. Normal weight concrete is used elsewhere, in varying thicknesses, in locations not regularly populated by indoor traffic.

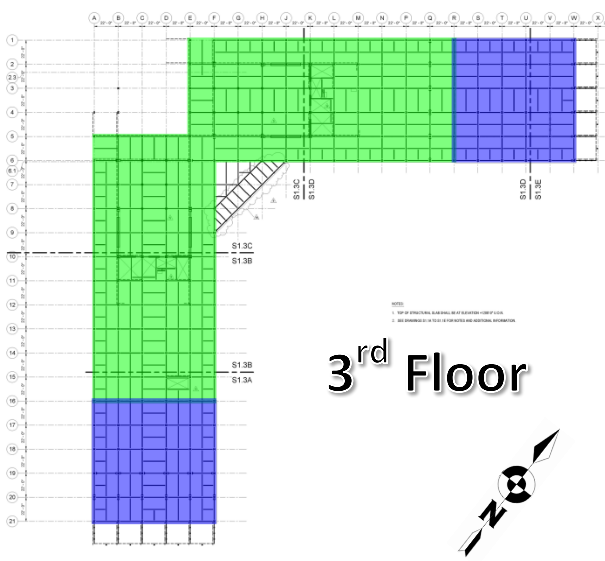


Figure 5.1: Plan View of the Third Floor

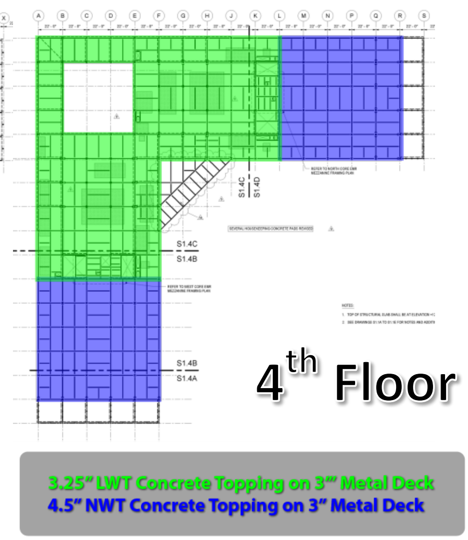


Figure 5.1: Plan View of the Fourth Floor

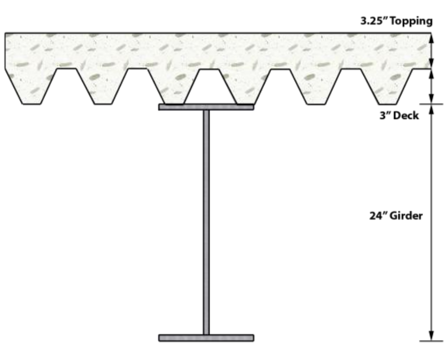


Figure 5.2: Typical Floor Profile

Figures 5.1 and 5.2 show a plan view of the 3rd and 4th floors, respectively. It must first be explained that KGB Maser chose the 3rd floor to focus on rather than the entire building, as that would have been a massive undertaking requiring time the teams were not afforded. Since the 3rd floor plenum is the area being studied by the Mechanical and Electrical/Lighting disciplines, the 4th Floor was studied in order to coordinate their systems through the 4th floor structure. The structure of the 3rd floor was also redesigned with an emphasis being placed on vibrational impedance to accommodate the vibrational criterion required of this floor. Also shown in figures above, are green and blue areas representing slab variants as well as defining the different areas of green roof, in blue, and office/lab space, in green. The area in blue on the 4th floor represents the most congested space in the plenum of the 3rd floor; this area was given special focus by the mechanical and structural disciplines during their research.

PROPOSED DESIGN

A preliminary gravity analysis was conducted on the existing floor system to confirm member sizes in each wing. It was found that the members were two to three times stronger than required by strength or deflection. Information garnered from an information session courtesy of Thornton Tomasetti revealed that the members were, in fact, oversized due to a vibrational criterion of 4000 and 2000 micro inches in the Life Sciences and Material Sciences wings, respectively. With this information, it was posited that a different solution could be used to meet vibrational requirements while relieving congestion in the third floor plenum.

Figure 5.3: Example castellated beams coordination with distribution systems from ArcelorMittal

Since frequency is dependent on mass and stiffness, the proposed alternative had to be either stiffer or lighter. Replacing the existing wide flanges with cellular beams was proposed thereby decreasing mass while maintaining stiffness. This solution also provided a convenient alley by way of the beam's inherent voids through which mechanical equipment could snake as demonstrated in Figure 5.4. The deck and concrete topping would remain unchanged, as would the W14 columns and lateral system.

Although this solution would have actually increased the cost of the floor system, it was anticipated that it would have allowed the plenum space to shrink, decreasing floor to floor heights. The amount of material saved by decreasing story heights would have, theoretically, offset the increased cost of the floor system.

ANALYTICAL PROCESS

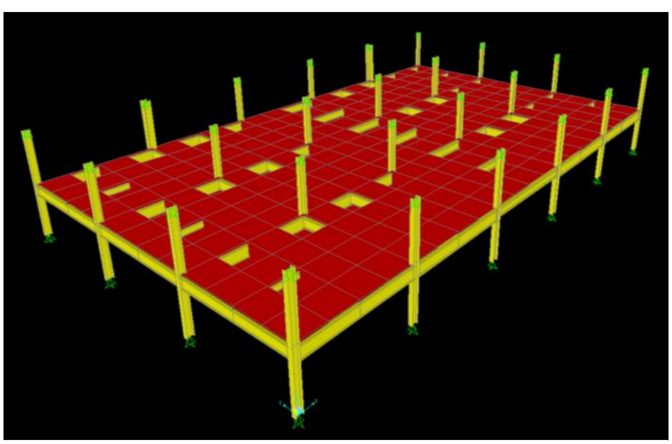


Figure 5.4: Final SAP Model (the seemingly protruding beams are a result of an error in rendering the extrusion in SAP)

Determining the stiffness of the existing floor system was the first step in the redesign process. The vibrational benchmark was given to us by Thornton Tomasetti, but numerical stiffness of the existing system was unknown. Initial research was conducted by reading AISC Design Guide 11 to both learn the evaluation process of stiffness in a floor system and to gather a general list of elements which would be needed to complete a vibrational analysis.

As per chapter 6 in Design Guide 11, the equation $[V = U_v \Delta_P / f_n]$ determines the velocity of a system based on a footfall impulse parameter $[U_v]$, its deflection $[\Delta_P]$, and its frequency $[f_n]$ acquired from another, separate equation. With this information, a model was begun in SAP2000 to determine the maximum deflection, when subjected to a concentrated load, of the existing floor system. The results of this procedure would set the bar for future redesign alternatives.

EXISITING CONDITIONS SAP MODEL

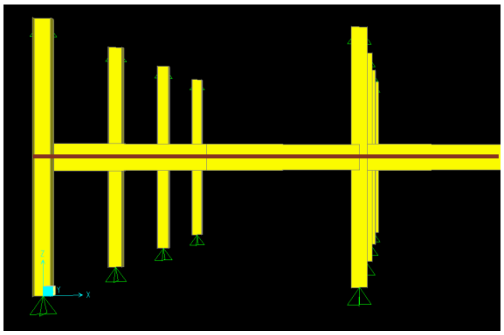


Figure 5.5: Initial SAP Model

The most costly procedure in this process, in terms of time, was building an accurate existing conditions analytical model. Rather than modeling the entire 3rd floor, it was chosen to use a representative section using 15 bays, 5 wide and 3 long as seen in Figure 5.5. All dimensions were taken directly from the structural drawings including the column and beam sizes. The columns were placed ten feet above and below the slab, fixed with pins on either end where moments are assumed to be zero due to the bending curvature of the element. The beams and girders were then modeled and released from moment at their connections, assuming shear connections only. Each bay was given its own slab, modeled as a shell thin, which was assigned modified material properties due to its behavior differing in one direction versus the other. To account for this behavior, due mainly to the ribs, the shell's modulus of elasticity was increased by a factor of 1.5 the direction in which the deck spanned.

An issue arose when trying to mimic composite action inside SAP. Since SAP, by default, places every element on a gridline by its centerline, as shown in Figure 5.6, it was necessary to offset the beam or slab to attain the correct depth, and therefore inertia, of the floor structure. In the figure, the yellow elements represent wide flanges and the red horizontal line penetrating the center of the beams represents the default placement of the shell element. A question was brought up regarding the accuracy of simply using insertion points to gain composite action of the slab and beam, leading to an investigation of composite beam action in SAP.

Four options were explored during this investigation. The first option simply offset the top of the beam, using insertion points, to 4.625" below the centerline of the slab. The second option did exactly the opposite, offsetting instead the slab above the top of the beam. The third option was a blend of the first two, exploring different combinations of offsetting both the beam and slab while maintaining a distance of 4.625" between them. The fourth option used rigid elements to connect the slab and the girder, which were placed on different gridlines at different elevations from one another. A series of trials were conducted using every method to determine the most accurate way of modeling a composite floor system.

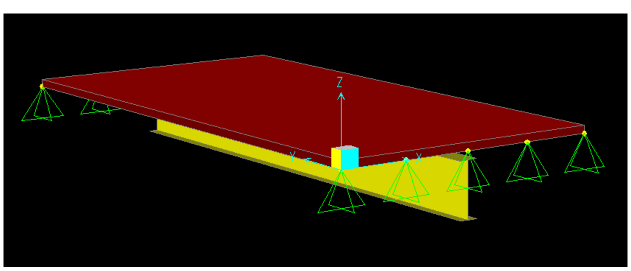


Figure 5.6: Composite Floor System Trial

To set up these different trials, a simple bay was used, 8 feet wide and 20 feet long, and a beam was drawn across it. A 3" slab was used and pinned at the edges to prevent bending in two directions. The beam was first offset, followed by the slab, and finally both were offset at intermediate values between 0 and 4.625 inches, while still maintaining a constant distance of separation. Through all these trials, inconsistent results were being returned as beam size and weight changed. One combination of offsets would return an accurate deflection (corroborated by hand calculations) for a particular beam, however when the beam was changed, a different combination of offsets was needed to return the same amount of accuracy. Not only did this prove to be inconvenient when attempting to replicate it on a larger scale, the results were inconsistent with hand calculations performed using a transformed moment inertia and a basic deflection equation. It was found, after searching through SAP's included manual, that in order to return results which match those of a simple deflection equation, the simply supported beam had to be determinate. Pinning both ends of a simply supported beam, and using insertion points to offset the beam below the grid line, created an invisible line of tension that resulted in a lower deflection than what was predicted. After using a roller on one end of the beam and discretizing the frame as well as the slab, deflections closely aligned with what was foreseen (within 10%). Insertion Points were used in the final existing conditions model, offsetting the beams and girder below the grid line, 3 inches below the bottom of the slab as seen in Figure 5.8.

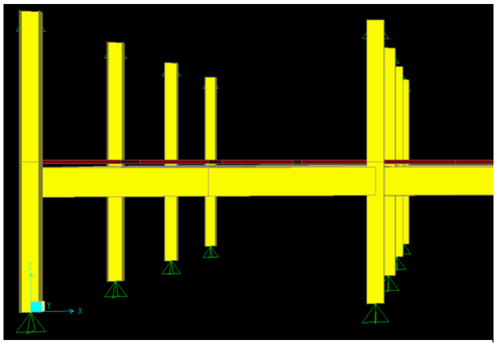


Figure 5.7: Final Existing Conditions Model with Insertion Points

Completing the model was fairly straight forward from that point onward. A point load was assigned to critical points in each bay of relevance. The slab was divided up and then discretized further in order to properly distribute mass as assumed by vibrational calculations. Figure 5.9 illustrates where loads were placed with green, blue and red circles. These points produced the most deflection when subjected to a point load and are representative to the behavior of the remaining bays.

VIBRATIONAL ANALYSIS OF EXISTING CONDITIONS

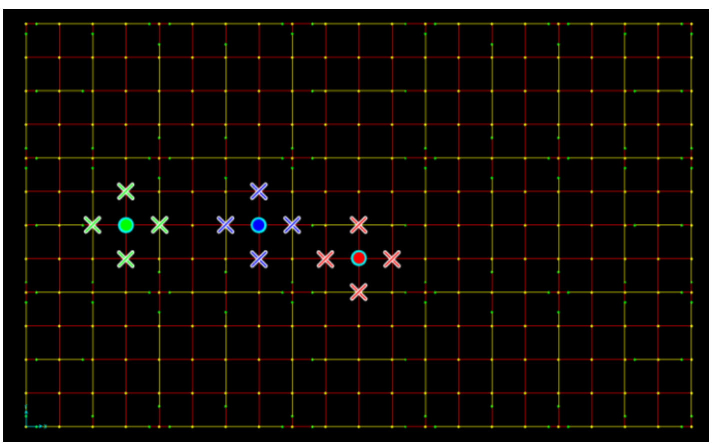


Figure 5.8: Plan View of SAP Model - Deflection Due to Point Loads

Once the model was complete with all necessary elements and loads, it was run for deflections. These deflections were used to calculate an approximate fundamental period of each bay which would then be used to calculate velocities. The equation and factors used for this analysis was taken directly from Design Guide 11 and is as follows:

$V = U_v \Delta_P / f_n$; where $U_v = 5500\ lb.Hz^2$ for moderate walking.

Using SAP to find the fundamental frequency would have required averaging different modes, whose shapes do not always reflect the period of one particular bay. A more straight forward method was used to calculate the fundamental frequency by way of Rayleigh's Method. His equation is as follows:

$\frac{1}{2}\omega^2\Delta^2 m = \frac{1}{2}P\Delta$; Solving for frequency yields $T = 2\pi\sqrt{\Delta^2 m / P\Delta}$; where $P = 100k$, the point load applied, and m is the mass of the bay.

The procedure of steps follows the table below from left to right. First each bay's mass was calculated by adding the total weight of the slab and beams in one bay and dividing by 484 square feet, the area of each bay, to obtain a distributed load. The nodes in three bays (those to which point loads were applied) were then renamed and used to gather the deflections at each of these 25 points. Weight was distributed to each node by way of tributary area and then multiplied by the square of its deflection as per Rayleigh's Method; this value was then divided by the product of the 100 kip point load and the deflection of the node where it was placed. After the period was calculated, the equation garnered from Design Guide Eleven was used. This equation uses the floor's maximum deflection from a unit point load to calculate velocity. In day to day use, deflections will not be caused by a single point load, rather it will be caused by a human foot walking on the weakest part of the slab over more area than a single point. A weighted average of the deflection at the point of the unit load and its neighboring nodes was therefore used, out of practicality, as depicted in Figure 5.9 by "X's". Sample calculations detailing the bias given to each point used in the calculation of Δ_P can be found in Appendix A.

SPAN	Lx	Ly	t	w	Wslab	Wbeams	NODE	Wi	Δ	Wi.Δ^2	P.Δ	Tcalc	T(SAP)	Vel
	ft	ft	in	ksf	kip	kip		kip	in		P=100 k	sec	sec	μ in/sec
SPAN-A	22.0	22.0	3.3	0.049	23.619	4.103	1	0.533	0.0012	0.0000	178.6212	0.0639		3916
							2	0.902	-0.0195	0.0003				
- due to load at A13							3	0.902	-0.0330	0.0010				
							4	0.902	-0.0195	0.0003				
							5	0.533	0.0012	0.0000				
							A1	0.902	0.0551	0.0027				
							A2	1.640	0.0596	0.0058				
							A3	1.640	0.0774	0.0098				
							A4	1.640	0.0596	0.0058				
							A5	0.902	0.0552	0.0027				
							A6	0.902	0.0913	0.0075				
							A7	1.640	0.2216	0.0805				
							A8	1.640	0.2886	0.1366				
							A9	1.640	0.2217	0.0806				
							A10	0.902	0.0914	0.0075				
							A11	0.902	0.0614	0.0034				
							A12	1.640	0.6814	0.7615				
							A13	1.640	1.7862	5.2335				
							A14	1.640	0.6818	0.7624				
							A15	0.902	0.0614	0.0034				
							A16	0.533	0.0052	0.0000				
							A17	0.902	0.0818	0.0060				
							A18	0.902	0.1219	0.0134				
							A19	0.902	0.0826	0.0062				
							A20	0.533	0.0051	0.0000				

Figure 5.9: Calculation of Vibrational Velocity

As illustrated by the table above, velocities were very close to what was required of the building. The values calculated from the existing conditions served as a baseline for the redesign.

REDESIGN ANALYSIS

The existing analytical model served as the base for redesign. Since design changes were minimal, the existing model was simply updated by replacing the unaltered wide flange sections with modified W21 sections. Initial sizing of members was done by matching the inertia values of the existing beams and girders with inertia values of particular cellular beams obtained from RAM SmartBeam. The cellular beams were then checked for strength by using an excel spreadsheet taken from a steel manufacturer's website and increased in weight as necessary (see Appendix A for spreadsheet and manufacturer). By using W21 members in the model, the components which comprise a 30" cellular beam, the weight of the cellular members were maintained. The shear areas of these wide flanges were reduced by roughly 10 percent and their inertias were increased twofold in order to mimic the behavior of an actual cellular beam. The updated model was then run and its results were used in the spreadsheet created for existing conditions; only the beam weight per bay had to be changed. These results were then compared to the ones gathered before and member sizes and decking were re-evaluated and changed as appropriate to exceed those conditions set by the existing conditions model.

COLUMN CHECK

After changing the floor system, a column check was conducted in order to confirm the sizes of the existing conditions. Loads were quantified based on the categories listed in the Figure below. Columns were sized for loads every two to three floors, splices lying between the 2nd and 3rd floors.

Column Check								
	Occupancy	Area	Dead Load (lbs.)				Live Load	Totals
			Slab	Beams	Panels & Column	SDL	(lbs.)	(lbs.)
Roof	Roof	484	24200	1804	0	12100	8580	59452.8
Floor 4	Mechanical	484	53240	3817	1755	12100	72600	201254.4
Floor 3	Green Roof	0	0	4559.5	1620	0	0	131319.4
	Office	0	0			0	0	
	M.S. Labs	0	0			0	0	
	L.S. Labs	484	24200			14520	48400	
	Corridors	0	0			0	0	
	Elevator Lobbies	0	0			0	0	
Floor 2	Green Roof	0	0	6303	1620	0	0	78851.6
	Office	484	24200			14520	14300	
	M.S. Labs	0	0			0	0	
	L.S. Labs	0	0			0	0	
	Corridors	0	0			0	0	
	Elevator Lobbies	0	0			0	0	
Floor 1	Plaza Landscape	242	26620	3476	1800	72600	24200	231875.2
	Office	0	0			0	0	
	M.S. Labs	0	0			0	0	
	L.S. Labs	0	0			0	0	
	Corridors	242	16940			7260	24200	
	Mech. Mezzanine	0	0			0	0	
	Elevator Lobbies	0	0			0	0	

Floors Three and Four	W14X61	392.0	k	
	A=	17.9	in.2	
	k=	1.0		
	l=	18.0	ft.	
	r=	2.5	in.	
	E=	29000.0	ksi.	
	Fy=	50.0	ksi.	
	k*l/r=	88.2		
	Fe=	36.8	ksi.	
	Fcr=	28.3	ksi.	
	ϕPn=	456.3	k.	OK
Floors One Two and Three	W14X90	702.8	k	
	A=	26.5	in.2	
	k=	1.0		
	l=	20.0	ft.	
	r=	3.7	in.	
	E=	29000.0	ksi.	
	Fy=	50.0	ksi.	
	k*l/r=	64.9		
	Fe=	68.0	ksi.	
	Fcr=	36.8	ksi.	
	ϕPn=	876.7	k.	OK

Figure 5.10: Column Check at the Intersection of Grids 9 & C

RESULTS

When a first analysis was run in SAP with preliminary cellular beam sizes, the results showed surprising deflections. When these SAP results were inserted into the excel sheet that translated their values, the resulting velocities were actually slightly higher than those of the existing conditions. Shear deflections were not considered a major factor with the design in SAP up until this point. The decreased area of the area resulted in larger shear deflections than the existing wide flanges, and even despite their doubling of inertia, the cellular simply deflected more. To solve this issue, the cellular had to become heavier in order to increase their stiffness.

As these changes were being made to account for shear deflections, a mistake was realized with the strength calculations. The loads on each beam had been miscalculated, and they had to be sized up due to strength. Given that development, the beams being sized up as a consequence of strength, the model was run again with the new beams in place. The results that were returned gave deflections aligning more along the lines of those of the existing conditions. They were still slightly higher than the existing conditions, but their weights, although only slightly less, brought down the floor’s vibrational velocity to within a few percent of the existing conditions.

Velocity Comparison			
	Existing Conditions (μ.in./s.)	Redesign (μ.in./s.)	Percent Change
Span A	3916	3099	20.86%
Span B	3317	2737	17.49%
Span C	4063	3458	14.89%

From the onset of the analysis, it was desired that the floor system exceed the existing system's performance. Two options were then considered. The current vibrational velocity would suffice, so the system could be left as redesigned, or the floor could be made stiffer in order to gain a more desirable velocity.

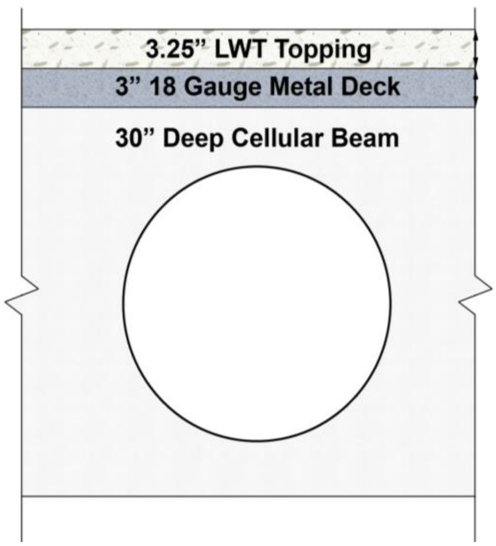


Figure 5.11: Cellular Beam Profile

It must be noted that a discovery was made in the midst of this process. Allegedly the material sciences wing suffers from a stricter vibrational criterion than the life sciences wing. However, when the material sciences wing was modeled in SAP, the members that were needed to be changed were few in number and lacked any significant strength advantage over the life sciences wing's members. When the deflections were run through excel to calculate velocities, the results did not represent a floor that was stiff enough for the criteria required of it.

It was chosen to increase the concrete strength rather than upsize the beams. This increase from 3000 psi to 4000 psi added $5 per cubic yard to the price of lightweight concrete (or 4.2%). The model was run again with 4000 psi concrete in order to gauge the value of the change. Velocities decreased 20% in each bay with the added strength, so the change was made permanent.

A large consideration for this floor type was cost. Cellular beams are more expensive than traditional w-shapes for the same weight. Since they are made from the two halves of a wide flange, they retain the cost of the original w-shape on top of the added cost of manufacturing. It was chosen therefore to only use this system where congestion in the plenum is heaviest. This occurs mainly at the end of each wing where the laboratories require large quantities of ventilation. For this reason, only two beam sizes were needed for the entire 4th floor. And also, as a consequence of this lack of size diversity, the bays weigh relatively the same and are also mostly lighter than the existing conditions. Though this does not account for much in the way of velocity performance or lateral forces, it is nonetheless an improvement.

Because the beams were placed every eleven feet, the system was very uniform. Nearly every beam uses the same amount of tributary area so the loads experienced by each are nearly identical, and the same can be said of the girders. Different layout schemes were considered, but ultimately disregarded

Figure 5.12: Cellular Beam Layout

due to cost and incompatibility with the mechanical system. If, for example, the beams were placed every 7 or so feet, deflection would most likely decrease enough so that shallower beams could be used while still meeting velocity requirements. The smaller beams, however, would use smaller voids and prevent most of mechanical equipment from using that space. If the beams were again increased in depth, 3000 psi concrete could be used, but the cost of the extra beam in every bay would far offset the savings in concrete cost. The current layout, it seems, uses the most efficient spans it can, given the size of the bays.

Choosing cellular beams over a concrete system was done in light of the collaborative effort between disciplines. An integrated design process calls for decisions to be based on the consequences of multiple systems, rather than basing them on a solely structural objective. Thus the analytical process was completed in order to realize a larger goal of mechanical integration with the structural system. The system, in this way, finds success in being a true alternative because it functions as a participant of a larger machine.

FAÇADE

The façade was designed as an ongoing study of panel alternatives throughout the entire semester. The façade was constantly referenced as keys points of study for the mechanical, construction management, and electrical/lighting disciplines. The design that resulted from the structural analysis was also influenced by the other discipline's systems analysis. For more information on this topic, please refer to Unit 1.

EXISTING CONDITIONS

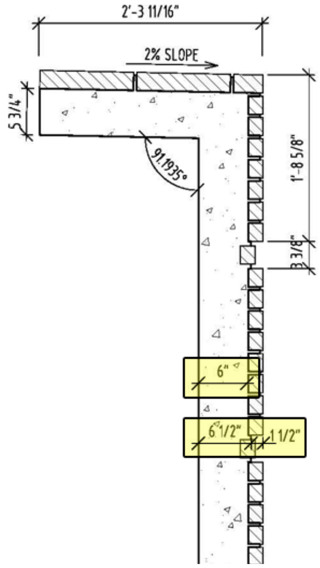


Figure 5.13: Existing Facade Panel

The existing panels weight in at 36 thousand pounds apiece. They impart all of their weight onto the exterior columns, which are then needed to be sized up in order to resist the additional force. It was proposed from the start of this project that the panels were needlessly heavy and could be thinned in some way to achieve better economy of materials and to reduce the forces on the superstructure.

This enormous weight is derived from sheer volume. The panels are 6 inches at their faces, which are embedded with 2-inch, masonry half-brick, as illustrated by the diagram on the left. The shape they take, a "C", is due to a cantilevered slab at the edge of the building. They also sport flanges that flank all four edges of each panel. These flanges shoot 2 feet from the rear of the panel towards the building and are used to resist bending under the panel's self-weight. Each panel stretches 22 feet across the exterior frames to connections at each exterior column. Two bearing connections are used along with two lateral connections, which brace the panel against wind and seismic loads.

In order to begin the redesign process, the existing panel dimensions were analyzed for strength. It was understood that each panel needed to remain uncracked in order to maintain the illusion of a real brick façade, so analysis was conducted for a stress of 477 psi, derived from the strength of an uncracked section of 5000 psi concrete.

	Precast Panel Dimensions		
	Panel Height	141.125	in.
	Panel Depth	4.25	in.
	Brick Depth at Face	2	in.
	Flange Height	5.75	in.
	Brick Height at Flange	2.25	in.
	Flange Depth	27.6875	in.
	Panel Width	263.25	in.
	Return Thickness	14	in.
	Return Depth	21.4375	in.
	Return Height	129.625	in.
	Volume Concrete	173.9579	ft.3
	Weight Concrete	26093.68	lb.
	Volume Brick	61.9801	ft.3
	Weight Brick	7437.612	lb.
(factored)	Total	46943.81	lb.

Figure 5.14: Existing Facade Dimensions

The dimensions were first taken from the construction documents, and inserted into a table made in excel, on the left. This spreadsheet related these various measurements to volumetric dimensions and, by multiplying these volumes with the density of a particular material, weight was found. The weight calculated did not match the values given by the precast manufacturer, who presumably evaluated each panel in more detail, and with more accuracy. However, as information was limited on the process by which they found those weights, the weight by way of the method as described above was used.

The largest panel was chosen to be evaluated for various loading cases. These loading cases included the panel sitting on its connections as part of the façade, the panel laying down

	Cracking Stress		
(factored)	477.2971	psi	
Self Weight Check Prone			
Weight/in.	8.53125	lb./in.	(factored)
Inertia of Strip	76.765625	in.4	
Moment	16695.94	lb.in.	
Stress	462.17134	psi.	OK

Figure 5.15: Self-Weight Inducing Moment of Existing Panel

at the site before assembly, and it subjected to wind pressure. As shown in the above table, the controlling load case for the existing conditions was gravity in the case of the panel being laid prone before construction.

The biggest surprise during the analysis process was the panel's self-induced moment, as shown in the Figure on the left. Previously it had been assumed that the panel was 6 inches thick merely for architectural reasons, but as discovered from the strength calculations, the required thickness, based purely on a maximum uncracked stress, is 4.25 inches at the face. 6 inches, while conservative, was reasoned based on quality control which could fall short during the transportation and erection processes. Surprisingly the controlling factor in this case was gravity rather than wind.

REDESIGN

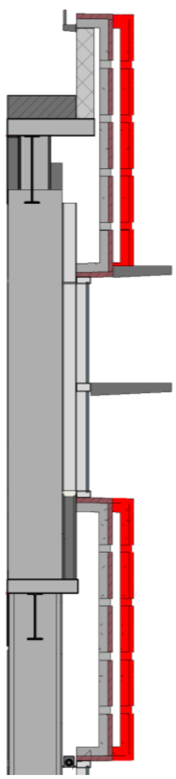
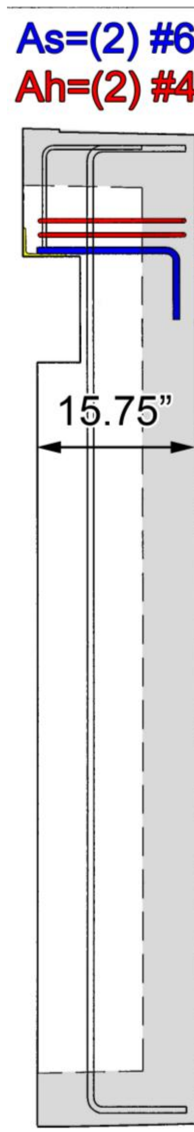


Figure 5.16: Redesigned Panel - Existing in Red

As it was desired to make the panel profile thinner, the most susceptible element of the panel to change, given its conservative construction, was the flange. 1 foot was immediately removed from the flange profile, shrinking the entire panel depth to 15.75 inches while also removing one inch from the panel face thickness. The new dimensions shifted strength control from gravity to wind.

Although the concrete was dimensioned appropriately for strength under bending, connections still had to be considered. Two types of bearing connections were investigated. The first connection analyzed was a dap steel type, which places the connection in the middle or towards the bottom of the panel. The connection was first evaluated for required steel in order to properly identify rebar sizes. These rebar sizes were then used to calculate development length into the façade panel. It was found that ## inches of development were needed for strength, ## inches more than what was available. KGB Maser was unwilling to enlarge the profile beyond what was decided, so another connection type was considered.

A corbel was chosen instead of a bottom bearing connection. Reinforcement was calculated for the specific Vu, and rebar was sized based on the required steel. Development length was once again checked. By moving the connection to the top of the panel, the development length criteria is changed, requiring less development into the concrete, 9 inches versus the aforementioned ##. This option fit the desired panel depth so the connection was chosen.



PCI was constantly referenced throughout the entire process providing the appropriate equations for each bearing type connection. The precast manufacturer has also provided their drawing and sample calculations for reference. A quick check of their numbers confirmed the veracity of the above calculations.

CANTILEVER

Redesigning the cantilever fell at the middle of the overall analytical process. It was projected that the entire analysis, including an investigation of the existing conditions, would take two weeks. The entire redesign was completed in a week and a half, including changes made on a Revit model to reflect those member sizes which changed due to the analytical process.

EXISTING CONDITIONS

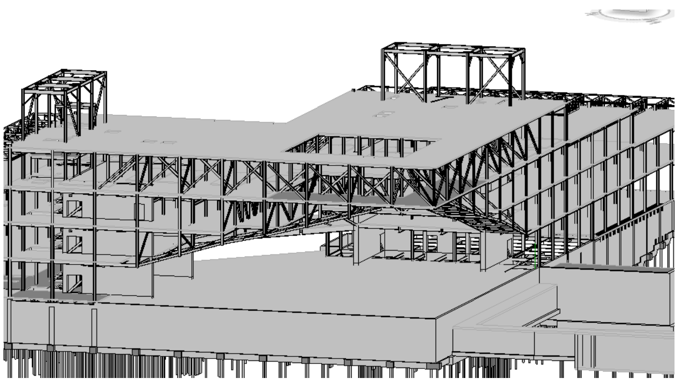


Figure 5.17: Existing Cantilever 3D Model

Situated at the corner of the Millennium Science Complex, a 154 ft. cantilever stretches out over a landscaped plaza. This architectural feature, conceived out of a purely aesthetic goal, adds an enormous amount of money to the overall cost of the superstructure. And on top of the expensive construction, the space inside the cantilever is mostly unoccupiable, including the last 88 ft. of the overhang. Its trusses crowd the mechanical penthouse with web members making placement of mechanical equipment inside the fourth floor even more difficult than it already is.

The cantilever is entirely supported by four main load bearing trusses which occur at grid lines 2, 5, B and E. Forces are collected by diagonal web members which then transfer loads into large wide flange columns and into the foundation by way of enormous pile caps, as seen in Figure 5.14 (Blue members represent compression whilst red ones represent tension). An overturning moment develops out of this cantilevered action, which is resisted by two more bays of trusses extending beyond a 30 inch thick shear wall, shown in yellow below. This shear wall was not used in the initial design of the cantilever. Its inclusion occurred later in the design process, when a vibrational consulting firm suggested it as a necessary factor in damping vibrations from the cantilever. Although it adds stiffness to the entire truss, it did not participate in the analytical model drawn up by Thornton Tomasetti, the design firm on this project. A deflection limit was given by the design firm of 2 inches at the tip of the overhang which greatly increased the cost of the cantilever, as truss members had to be both moment connected and sized based on stiffness rather than strength, as it may have been if deflection had meet code requirements of L/180 or 10 inches.

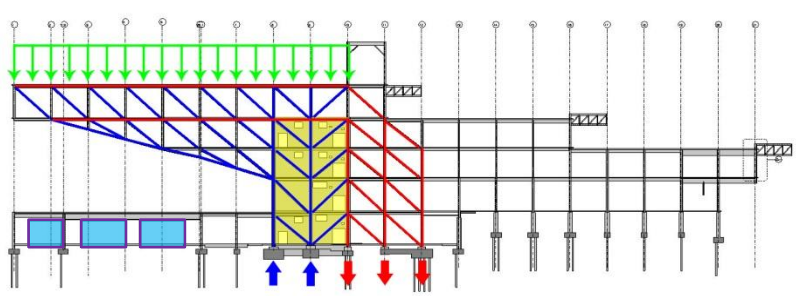


Figure 5.18: Existing Cantilever - Distribution of Forces

One of the main advantages to using a giant cantilever over the plaza, is its minimal interference with the basement level below. This level houses three laboratories, show in blue boxes on the left, each of which are subjected to strict vibrational criterion. Each lab sits on a 2 ft. thick slab completely separate of the surrounding foundation, poured independently of any other slab, as shown in Figure 5.14. The laboratories were designed for a vibrational velocity of 130 micro inches per second, achieved by its seclusion from any potential vibration inducing source.

PROPOSED DESIGN

It was a goal of KGB Maser's to reduce the structural cost of the building in order to afford the Mechanical and Lighting/Electrical disciplines more freedom with their energy efficient designs. The most obvious way of reducing the cost was to reduce the amount of materials used in the superstructure. Since most of the cost is concentrated in the cantilever, it was suggested that a column be placed at the end of it, thereby reducing the large stresses experienced by the existing truss members and allowing their weights to therefore be decreased.

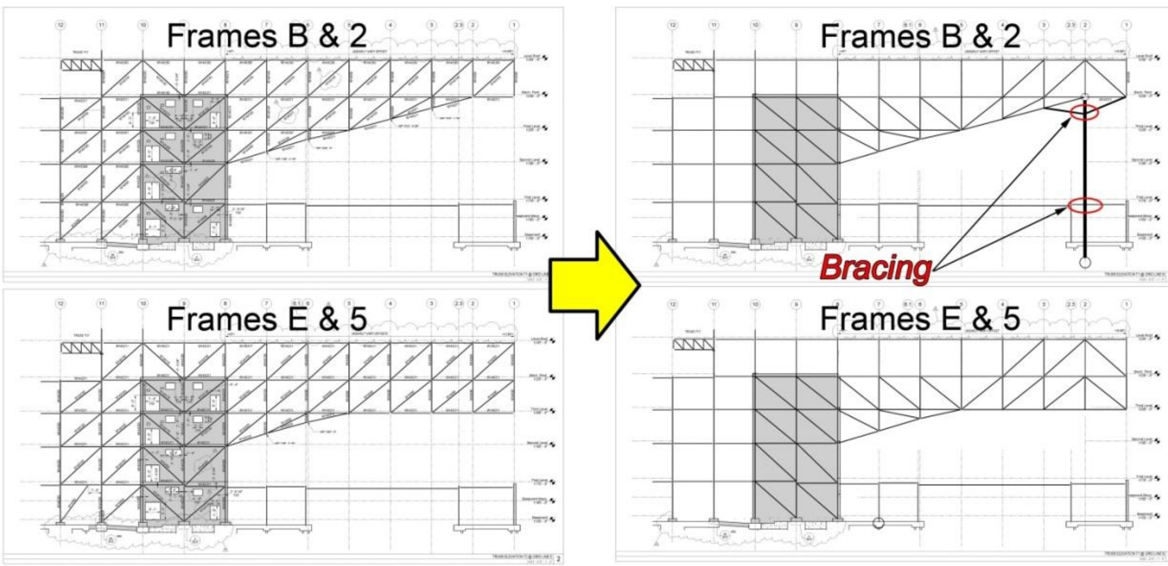


Figure 5.19: Initial Truss Layout

Initially one column was proposed, situated between the intersection of trusses 2 and B. A new web design had to be created, and since the information up until that point had led KGB Maser to believe that the existing truss's members were pinned, it was assumed that the redesign would be as well. By eliminating the cantilever, the trusses needn't be as stiff and therefore need be less encumbered by braces. The resulting design was anticipated to rid the mechanical penthouse, as well as the two bays beyond the shear wall, of diagonal bracing. However the new design also required a restructuring of the basement level due to interference with the isolation laboratories.

A column that would support the end of the cantilever would also need to penetrate through the plaza level and travel directly through the laboratory floor based on the existing layout. To reduce direct vibrational propogation through the slab, it was posited that the column could be, itself, isolated from the laboratories. By creating a premeditated hole in the floor of the laboratory and allowing the column to travel, unobstructed, through the slab, the isolation laboratory could retain some of its vibrationally resistive integrity. This column would also cause a disturbance, not only in the labs, but also in the visual experience created by the architect, Rafael Vinoly. These two factors ultimately shaped the resulting plan visually and schematically of the cantilever redesign.

ANALYTICAL PROCESS

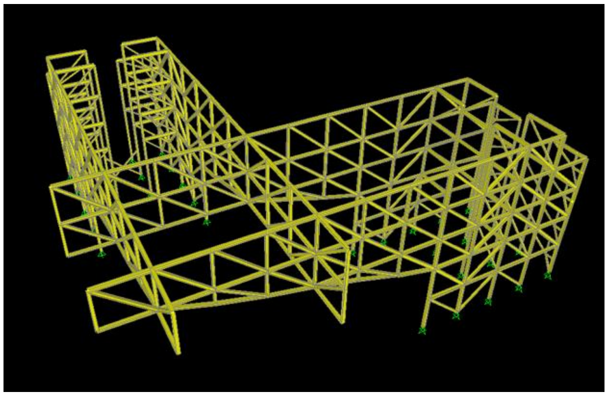


Figure 5.211: Initial SAP Model

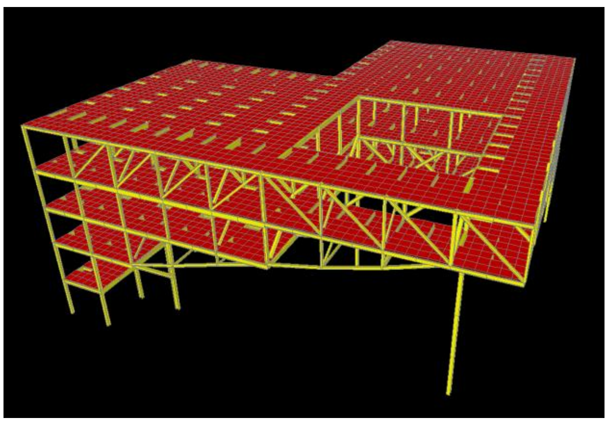


Figure 5.202: SAP Model Iteration

It was first decided that an analysis of the existing cantilever would lend some insight into the method of force distribution throughout the truss, so a SAP gravity model of the existing truss design was begun, seen in the Figure to the left. The model was based on the structural drawings and from an existing Revit model complete with member sizes. Only the four main trusses were modeled, as it was assumed that a simplified distributed load derived from a scheme of tributary areas would suffice over a complete modeling of the floor and its loads. After a rough plan of tributary area was created, it was realized that a more accurate way of approximating the actual loads experienced in the building would be to model everything, including the floor system through the end of the truss, as seen in the Figure to the left. After modeling the majority of components inside the truss, it was realized that the proposed redesign would be completely changed, from a cantilever to a simple truss spanning from one support to another; thus the existing conditions would have proved to be of little use to do its limited relevance to a simply supported truss. Although fundamentally, the analytical process had changed, the existing conditions continued to be modeled as it was decided that only the design of the four trusses would be altered. The frames which depend on these four mains for support were designed for loads which will remain unchanged. It was assumed that the transfer of forces from these dependent frames into the four main trusses will remain as is, where only the behavior of the forces through the independent trusses will be changed. The model was completed with the addition of two columns at the far and near corners of the window box, as shown in Figure 5.16; the theory behind using two columns being the more, the better.

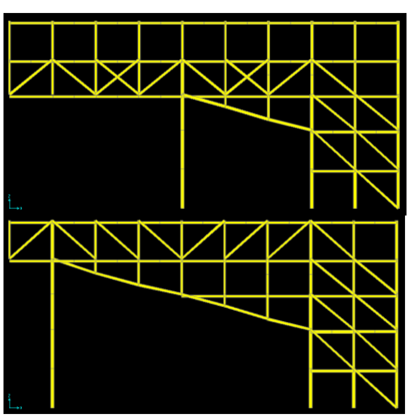


Figure 5.22: Frames B & E First Iteration

Preliminary sizing was based on a truss layout inspired by a basic Pratt truss where all members are in tension, as illustrated on the left, and would therefore need the very least amount of steel area. These members were also pinned rather than moment connected, as they are in the existing truss, a discovery made late in the analytical process which had little bearing on the redesign or its results although relevant to the modeling of existing conditions. W14X90's were chosen for web members and diagonal bracing inside the base of the truss. The chords and columns were left alone, to be sized after a first analysis.

The results of the first run revealed a stable model which behaved relatively identical in both the North/South and East/West directions. This was expected due to entire model being symmetrical, but it did lend credence to the accuracy of the model and its results. Members were resized based on this first run, changing the diagonal, horizontal and vertical elements. Changes in one truss reflected changes in its counterpart, revealing the redesign was successful in balancing forces. Deflection did not control at any point during the process of redesign, although multiple iterations were required due to strength.

A last check of was conducted based on beam-column interaction. Results gained from SAP were plugged into an Excel spreadsheet, seen above, which calculated each member's bx, by, and p or ty/tr based on its unbraced length. Being that the spreadsheet took into account bending around both major and minor axis, some member sizes were increased over the changes made via hand calculations. The columns were initially sized as W14X550's on the basis of an assumption of unbraced length and later checked based on the actual unbraced length acquired from the finished architectural feature used to mask them. Around seven iterations were completed in order to arrive at a completed model whose members met all strength requirements.

RESULTS

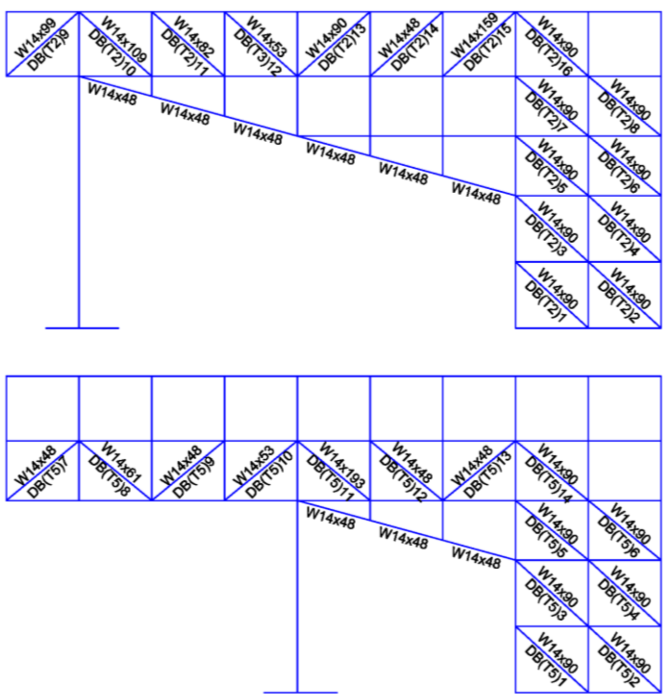


Figure 5.234: Final Truss Design

Ultimately, the truss redesigned truss was a success. Bracing was removed in two entire bays, previously necessitated in order to resist the overturning moment which has now been eliminated. The braces that remain were switched to tension, since stiffness was not a controlling factor in the redesign, and greatly reduced in size. Nearly all the members, were, in fact, reduced in weight. The columns at the base of each truss still need to carry half the load of the cantilever, so they were the biggest members besides the two columns added in the redesign. These members were all able to be downsized by the removal of the deflection limit. Since a large cantilever no longer exists, the required stiffness to limit deflection is greatly reduced to the point of strength controlling every member. The limit on deflection was 2 inches over a 154 foot cantilever set by the design firm; the allowed deflection of the new design, over a span of 66 feet in the interior truss is 2.2 inches in accordance with L/360. A maximum deflection of 0.83 inches was reached in the interior truss, well below its limit.

As described above, each member in the truss was put into an excel spreadsheet which checked the results returned from SAP by way of a unity equation, as seen on the following page. Shear was assumed not to have controlled at any point in the design process; a quick check of the largest shear of any truss versus the capacity of the smallest member in shear, reveals that it exceeds the maximum shear verifying that assumption. The only point at which forces required the addition of structure outside what was structurally proposed is in the two supporting columns at the end of the cantilever.

TABLE: Element Forces & Unity Equation

Frame	Station	OutputCase	P	V2	V3	M2	M3	FrameElem	ElemStation	Section	Length	Length	Interaction
Text	in	Text	Kip	Kip	Kip	Kip-in	Kip-in	Text	in		in	ft	
CL(T2)1	0	All Factore	-2566.34	2.013	-0.485	-1.1E-14	-2.3E-13	CL(T2)1-1	0	W14X283	240	20	0.87
CL(T2)1	120	All Factore	-2562.6	2.013	-0.485	58.154	-241.525	CL(T2)1-1	120	W14X283	240	20	0.88
CL(T2)1	240	All Factore	-2558.87	2.013	-0.485	116.307	-483.049	CL(T2)1-1	240	W14X283	240	20	0.90

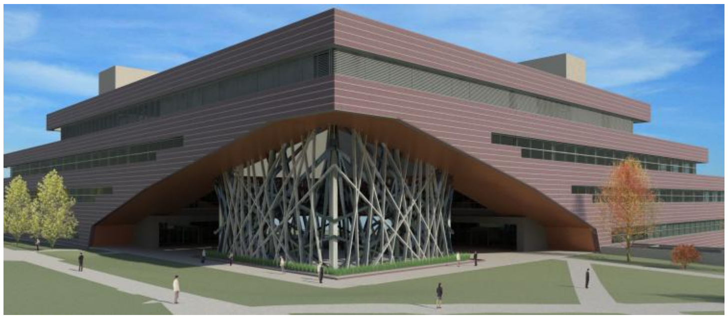


Figure 5.245: Bird Cage Rendering

The exterior column, or the column located at the intersection of the two outermost trusses, experiences 3400 kips over an unbraced length of 56 feet whilst the other, interior column experiences a larger load of 3900 kips. Extra bracing needed to be given to the columns lest the size and weight of them go up dramatically. It was originally proposed to mask the presence of a column with an architectural feature. This feature, or bird cage as it appeared to be, behaved dually both drawing attention away from the presence of the columns, and to bracing them intermediately. The unbraced length shrunk to 32' by using HSS tubes designed to resist 2% of the axial load of the column. These tubes, which appear as part of a mass of intertwined cage members, feed back into the truss for support and are braced, themselves by other members participating in the architectural feature.

The redesigned truss succeeded in alleviating congestion in the mechanical penthouse, it eliminated web members and turned the ones remaining into tension members reducing material and therefore cost. By virtue of two supports on each truss, the overturning moment present on the existing design becomes irrelevant to the new design and removes the need for bracing beyond the shear wall. However, with the presence of a column comes the need to resolve axial force via pile caps in the foundation. The location of the columns coincides with the location of the isolation laboratories, as shown on the left, requiring these foundation pile caps to be placed directly under the isolation slabs. This is an issue as the labs are under a 130 micro inch per second limit on vibrational velocity. Although no calculations were performed to verify the concept, a rational solution to this problem was proposed. The column pile cap would be placed several feet below the bottom of the isolation slabs. This depth of earth would provide impedance to any vibrational propagation initialized in the column. The column would be constructed first, and the isolation slab would be poured around it, allowing for an inch or so gap. This gap would then be filled with a compressive material to further mitigate vibrations. The frames of the plaza at the first floor would simply attach to the column. This method would be used for both columns.

Figure 5.256: Isolation Lab Interference

LATERAL SYSTEM

A check of the existing lateral system was the last process of the structural depth. This analysis was begun with a cooperative model between 2 other structural engineers, concluding with an individual check of the lateral elements. The entire analysis was completed in a week and a half.

EXISTING LATERAL SYSTEM REVIEW

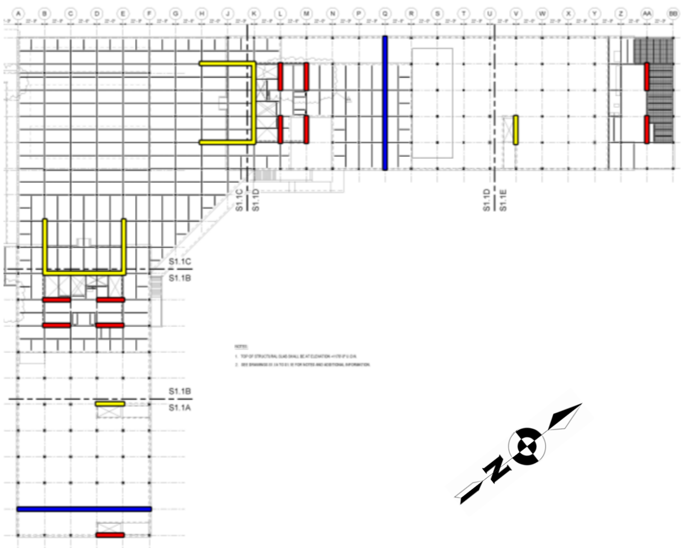


Figure 5.267: Plan of Lateral Elements

The existing lateral system is made up of various frame types throughout each wing. Shear walls, moment frames, braced frames, and gravity trusses, purposed for the cantilever, all partake in resisting the lateral loads. Most of the forces are taken by 3 shear walls toward one end of each wing, whose original designs were not meant to participate in the lateral system; rather they were included to dampen vibrations from the cantilever.

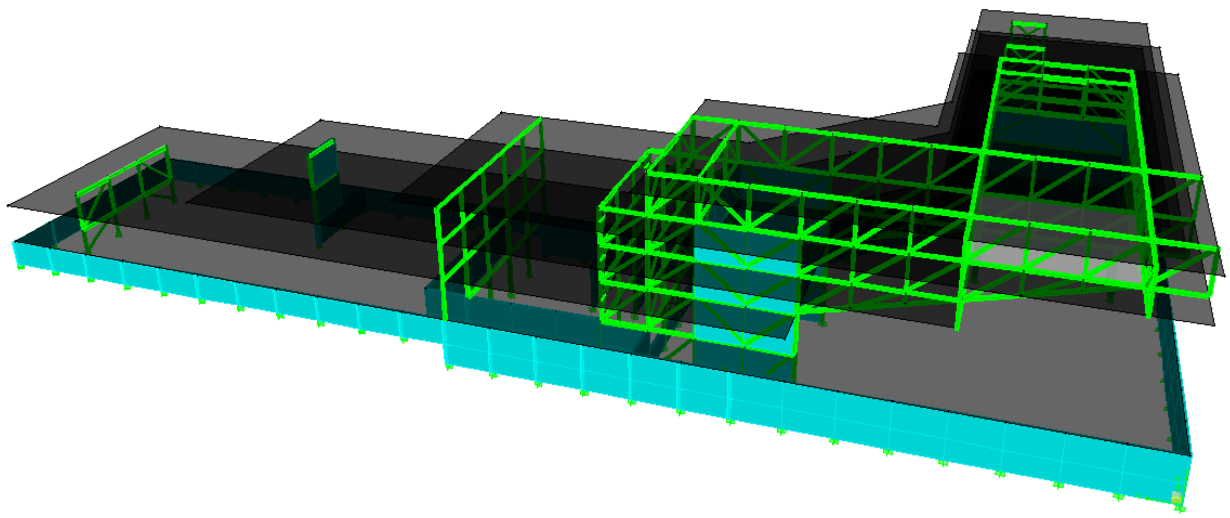
The plan on the left shows the placement of the various types of lateral resisting elements. They are staggered in such a way that force should be distributed evenly throughout each wing. Moment frames are shown in blue, shear walls in yellow and braced frames in red. The shear walls, and adjacent braced frames located closest to the Northwest corner of the building are also part of four large trusses that support the 154' cantilever at that end of the building.

As the floor system redesign was developed, the lateral system was continuously changed to fit the appropriate floor system type. It ended up that the floor system was changed relatively minimally. The existing lateral system had been presumably designed correctly for the current layout, so it was thought that with only minor changes being made on the floor system, that the lateral elements needn't be changed. An analysis was performed to confirm that the existing system did indeed meet code strength and drift requirements. The entire lateral system was replicated in ETABS and run through a series of checks.

When the redesigned floor system was being modeled, the lateral elements were avoided in being changed. It was guessed that due to the relatively low area for its depth that the cellular shapes would perform poorly in shear. The areas where beams were moment connected to their columns, the floor remains precisely as it was before the redesign. It was aimed to limit the amount of interference with the current lateral system as much as possible to retain the same integrity.

Where the lateral system did definitively change is in the cantilever trusses. Since the trusses were completely revamped, their diagonal members were downsized drastically. This of course led to reduced stiffness in these frames. And although these frames are mainly purposed to support the cantilever, they play a major role in the lateral system, so any changes could have been significant. If the shear walls were not present in these trusses, the lateral system would have needed to be completely redesigned, but these shear walls lend a tremendous amount of stiffness to each truss frame. It was proposed that the lateral system be left as is, changing only the diagonal members inside the base of each truss. This change, of course, would be trifle due to the 30 inch thick shear that encases the truss frames at their base as proved later by an analysis of the existing conditions.

LATERAL SYSTEM ANALYSIS



First the entire lateral system of the millennium science complex was replicated in ETABS. The entire Northwest corner of the building had already been modeled in SAP for a gravity analysis and it was anticipated to simply export this model to ETABS to serve as a base for assembling the lateral system. However, the amount of gravity members that were modeled in SAP would have simply burdened ETABS with superfluous information, slowing its analysis and lengthening load times. It was also feared that errors would inevitably occur in the process leading to a lengthy period of correcting mistranslated information. Area properties as well as member properties would have needed to be altered to fit a lateral analysis and it was believed that creating a new model from scratch in ETABS would have been longer, but it would have caused less frustration and ultimately produced a model with less oversights.

Therefore each lateral element was recreated in ETABS. The floors were modeled as rigid elements and constrained to move with the lateral elements. Some of the frames required special joints to be placed off grid, especially those in the truss. The shear walls were modeled as shell elements, which were discretized for accuracy. There is also a diagonal foundation wall that was modeled at the interior corner of the meeting of the two wings. This shear wall required the creation of new elevations so it could be placed at the right location. The entire model's elements were placed even before the lateral loads and floor weights were corrected from the previous semester's calculations. In fact, the model was nearly complete from the start of the semester, but analysis was left to the end because of other priorities, including the cantilever, façade and floor system redesigns.

Floor weights had to be slightly corrected due to errors made when inserting floor areas into excel. These weights had a cascading effect on the rest of the seismic load calculations, whose story forces depend not only on ground acceleration, but of the floor masses as well. These new forces were corrected and applied to the model in two seismic load cases. Wind forces were inserted into the model based on story forces as well, with 8 load cases being necessary to cover all combinations of wind direction and moment due to eccentricity. The façade panel weights had to be applied to the model as point loads on the exterior columns. These weights were taken from construction documents created by the precast manufacturer.

RESULTS

After all necessary steps were taken to complete the model, an analysis was run. As was expected, seismic values controlled as they produced the largest story forces. In fact, seismic base shear was 1.5 times greater than the base shear produced by wind alone.

The analysis also revealed peculiar behavior in the distribution of forces. Forces were concentrated in the shear walls, taking over 90% of the load between four walls, three of which are located towards one end of each wing. This result could be explained by describing the size of each shear wall. The wall experiencing the most force is 16" thick and 66 feet long, an incredible amount of area over which shear can be distributed. It is no wonder that these walls take an inordinate percentage of lateral forces.

Another result that was, at first, perplexing was the amount of force in one of these walls. Looking at the layout of the lateral elements leads one to believe that the shear walls are favored towards one end of the building. In reality, the floor footprint is shaped like an "L" so the visual center when considering only the lateral elements in one direction appears farther from the actual center of mass. And since the story forces are applied at the center of mass, the shear wall that takes the most force serves as a fulcrum for the other three walls in that direction.

The period of the analytical model was then checked to corroborate the one calculated for seismic loads. Unfortunately, this period was much higher than what was calculated by seismic analysis, on the level of 3 seconds. Clearly a mistake had been made with the model, so loads were once again checked. The floor weights had been overestimated, and were far higher than should've been, so they were re-calculated and inserted back into the model.

One issue that could not be readily explained was with total amount of shear collected in all the elements. This total did not match the total base shear, being 6% lower than what was applied to the building. This was discovered when section cuts were used on all the modeled elements, in both direction, for seismic loads in the East-West direction. The first floor was chosen as the plane across which these section cuts would be used. Forces in each frame were separated into loads received by the columns, braces, and shear walls individually. Once their values were tallied, it was found that this total did not quite equal the amount of force that was applied to the building. One explanation that was proposed, involved the participation of an out-of-plane element. There exists a 45 degree foundation wall at the corner of the building that was thought to have been interfering with the results. Taking a section cut of this wall revealed that 20 kips were being taken in along its major axis. It was believed this force was the missing component of the total base shear, however even when added to the total, the forces still did not amount to a number equal to the base shear. After further consideration it was decided that this 20kips was due to more to eccentricity than from direct shear and was hence discarded as the problem.

Story Drift						
		Disp. (in.)	Disp. (in.)	Average	Max./Avg.	
Quake: East-West	Roof	0.041235	0.067931	0.054583	1.244545	
	Mech.	0.027331	0.027255	0.027293	1.001392	
Quake: North-South	Roof	0.067717	0.042757	0.055237	1.225936	
	Mech.	0.026746	0.028852	0.027799	1.037879	

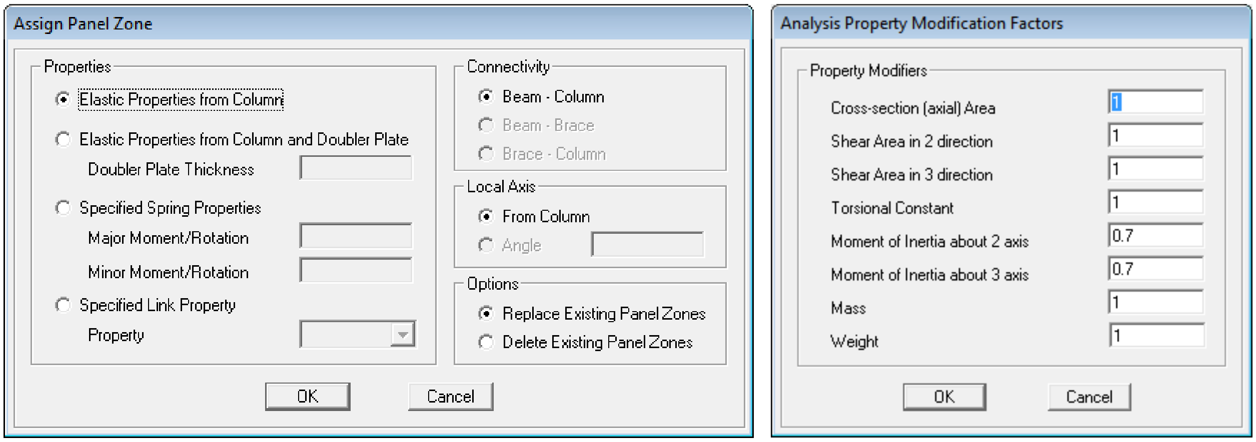


Figure 5.28: ETABS Torsional Irregularity Property Modifiers

Drift was also considered. The building was found to have torsional irregularity when subjected to seismic loading in both directions. According to ASCE7-05, the building falls under seismic design category B, and therefore, when classified as having a torsional irregularity, is required to be modeled mathematically. This had already been done with ETABS and its members were therefore checked for strength as per code. The mathematical model had to conform to a certain criteria; it had to be modeled in 3D, considering cracked section properties for concrete, and panel zone deformations for steel moment frames. All these requirements were easily met, and used to check for lateral element strength.

As was mentioned previously, lateral forces in the non-shear wall frames were small and ultimately piffling in the grand scheme of things. These forces totaled less than 10% of the base shear. Time constraints did not allow for detailed checks of the braced or moment frames, but checking them by hand against the beam-column interaction equation showed they exceeded strength requirements. Story drift was last checked, revealing a maximum story drift, including the Deflection Amplification Factor, of 0.00056, far below the allowable drift.

MAE COURSEWORK INTEGRATION

AE597B

A complete redesign of the existing cantilever was performed on the Millennium Science Complex. Methods of solving for chord and web forces, learned in Historical Methods of Structural Analysius, were used in creating a preliminary redesign for the four trusses of the cantilever. Using a design inspired by a Pratt Truss, web members were oriented so that they performed in tension. Due to different loading conditions, the live loads may cause these web members to experience a reversal in axial force, switching them from tension to compression in certain bays of the truss where dead load cannot supersede the influence of the live load. This was taken into consideration in the preliminary design with counters in bays near the midspan of the truss, between the column and the truss base. After an analysis was completed, it was decided that these counters were not needed as the live loads were too small to reverse the shear in the center bays.

AE 597A

Extensive use was made of computer modeling software including SAP and ETABS. SAP was used for redesigning the cantilever and floor system. The composite floor system was modeled by using normal wide flanges offset from the slab, whose material properties were edited to behave differently in different directions depending on the orientation of the deck span. The floor system also needed to be checked for vibrations, so it was analyzed for specific periods of vibrations. The cantilever was modeled using every beam, column and brace in the Northwest corner of the building to accurately depict the distribution of forces through its truss members. The lateral system was also modeled in detail with the relevant lateral force resisting elements. Loads calculated from an evaluation of seismic and wind forces were applied to the model and it was run to check member strength in those relevant structural elements. For a more in depth review of the model building process, please refer to the appropriate chapters above on the floor system and cantilever.

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