SCHEMATIC DESIGN & CONSTRUCTION PLANNING:
ALTERNATE SYSTEMS DESIGN REVIEW

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EXECUTIVE SUMMARY

KGB Maser is one of three IPD/BIM Senior Thesis Teams for the 2010-2011 Senior Thesis. In the second year of Penn State Architectural Engineering Department's IPD/BIM Thesis, KGB Maser hopes to provide insight into Integrated Project Delivery methods and Building Information Modeling programs throughout the course of their investigation of Penn State's Millennium Science Complex. The team consists of Jason Brognano, Michael Gilroy, Stephen Kijak, and David Maser. Collectively, KGB Maser has analyzed redesign options that not only improve the building, but impact each team member's disciplines. The team consists of a lighting/electrical engineer, mechanical engineer, structural engineer, and a construction manager.

The major points of emphasis the team has decided to focus on in the following report are as follows:

I. *Façade Redesign*
II. *Reduction of Energy Consumption*
III. *Value Engineer systems to Fund Alternate Systems*

Redesigns of the existing facade will focus on improving the façade's function, constructability, and its impact of the façade on the structural system. Lighter precast panels will be investigated to evaluate the impact on the schedule. The lighter precast panels' impact on the thermal envelope and the load on the structural system will be considered. The use of phase changing material (PCM) in glazing and wall construction could potentially be an innovative way to design a sustainable yet passive envelope. Additional daylighting and glazing redesigns of the façade are also detailed in this report.

Reducing the energy consumption of a laboratory building is a daunting task. Laboratories spaces within the Millennium Science Complex necessitate stricter HVAC parameters and invoke higher energy consumptions than other buildings such as office buildings. 100% outdoor air requirements increase the energy needed to condition incoming air in extreme weather conditions. Fume hoods within the labs are connected to a dedicated exhaust system which drives the cooling loads of the spaces. The primary redesign of the HVAC system to reduce energy usage involves the replacement of the current variable air volume system (VAV) with a dedicated outdoor air system coupled with chilled beam cooling and radiant floor heating. This system will replace the Office VAV AHUs and will be investigated in the future for application within the labs.

The final point of emphasis during KGB Maser's proposal process is to value engineer current systems for the most efficient design and analyze applying savings to the funding of alternate systems which may have higher initial costs but economical payback periods.

The following report summarizes the initial ideas of each discipline and their impact on the Millennium Science Complex as well as points of coordination with other systems within the building. Integrated Project Delivery methods of inter-disciplinary communication, discussions, and decision making will lead to successful redesigns. Building Information Modeling is a tool that KGB Maser plans to use to further develop the suggested redesigns to determine the most effective, holistic solution.

EXISTING CONDITIONS

Façade Existing Design

The architectural precast panels that are used on Millennium Science Complex consist of split face brick, backed with 6" of 5000 psi concrete. A drawing for sample precast panels can be found attached in Appendix A. The 5000 psi concrete is specified in Specification 03451 Section 2.09 Mix, under Design Mix. Specification 03451 is attached in Appendix B.

The precast panels are attached to the structure through two types of connections. The gravity load of the panels is attached to the steel structure through a seat connection, and the panel is also connected through a threaded connection so that there is also a connection to prevent the panel from shifting in and out. Both connections are pictured in the details below.

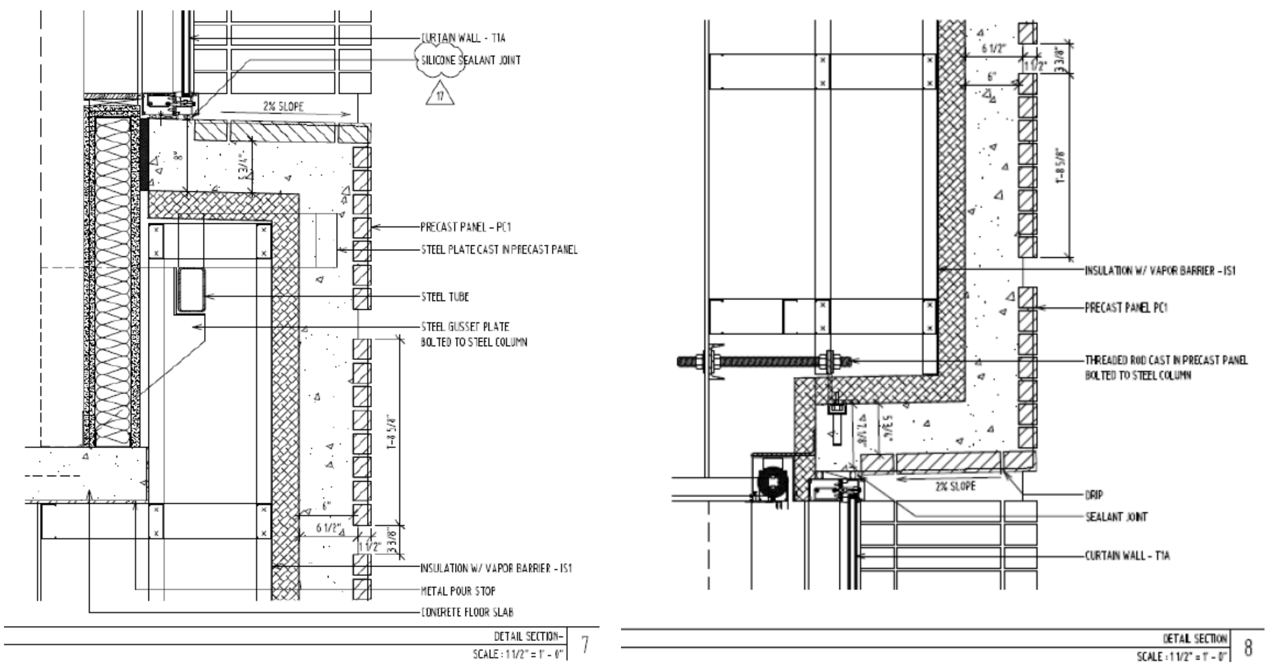


Figure 1: Precast Panel Connection Details

The architectural precast panels are being fabricated in York, PA and shipped to Millennium Science Complex via tractor trailer, one at a time. When the panels arrive on site they are lifted off of the truck and lifted directly in place. This method is able to help eliminate extra staging space for the material. The scheduled output of each day for hanging the precast was 10-16 pieces per day. One of our goals is to increase this rate per day. Figure 2 is an image of the precast panels being lifted off of the trailer and directly into place. Currently, the panels do not occupy the entire length of the trailer, and we see this as room to improve the design of the panels.

Figure 2: Precast Panel Site Delivery & Installation

The current architectural precast panels have a few standard sizes, with the nominal panel being 12'X22' in a "C" shape design that weighs 23,000 lbs. One of the issues regarding the precast panels is the sheer weight of the panels. Each panel is a total depth of 1'-5" with the thickness of the "C" shape being 6". In order to reduce the weight of the panels, three different design options will be investigated. Shown below is a picture of the mock-up that was built for the building enclosure systems.

Figure 3: Enclosure Mock-up

Daylighting Existing Conditions Review

In its current state, the Millennium Science Complex employs three daylighting tactics – fritted glazing, overhang usage, and dimmable electric light. The fritted glazing consists of 70% transmissive glass with ceramic circles baked into the surface, which further decreases transmittance of the glass. It is unclear on which surface the frits are mounted and they interact with occupant view to the outside. The use of overhangs appears in two places – recessed glazing and a louver. The glazing is mounted toward the inside face of the exterior wall to utilize the underside of the panels above. This trims away very high angle direct sun. The louvered overhang is used similarly to the recessed glazing. It blocks high angle direct gain for each façade. Upon further investigation, however, it is apparent that the louver has more of an architectural use than a daylighting use.

The glazing as well as the addition of an interior light shelf will be examined for this report. We will examine the current shading situations, examine the effects of a different glazing option for both the view glazing and clerestory glazing, and examine the addition of a light shelf on the inside of the glazing. Each of these options has impacts on other disciplines within the building process. These interactions will be discussed throughout each design alternative.

Current Shading

The building is oriented approximately 52° counter clockwise from magnetic north. State College, PA is in a region of the United States that is approximately 11° from true north. These rotations work out to the Millennium Science Complex being oriented in the following fashion:

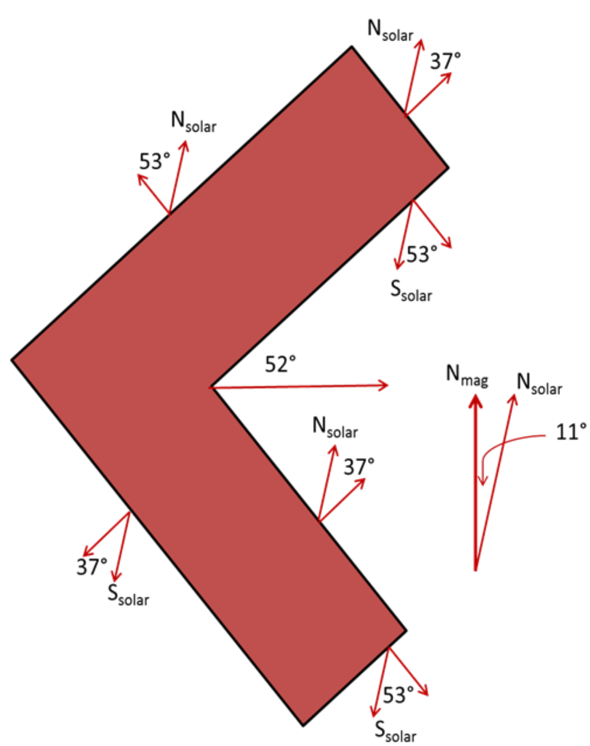


Figure 4: Building Orientation

The worst shading conditions are in the following images. One feature of the ends of each wing is the large trellised overhang. This overhang proves useful in summer months as it blocks higher angle sunlight from penetrating the building, but has no real use outside of summer months.

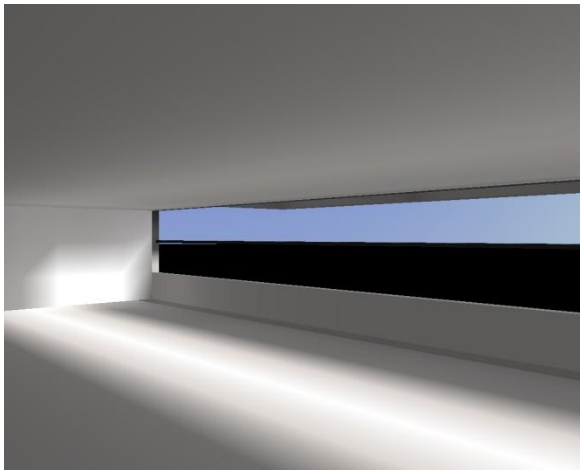


Figure 5: Material Science End Summer – 6/21 6:00AM

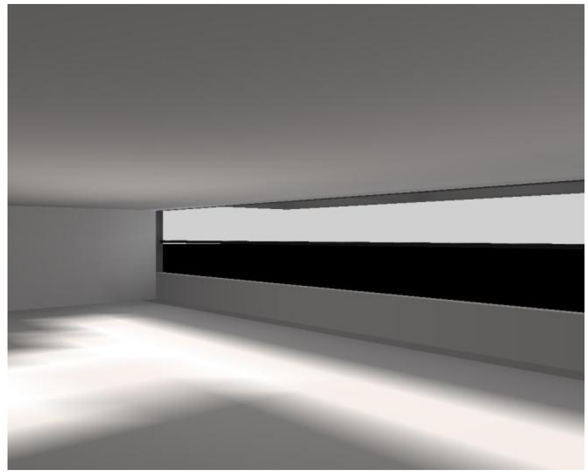


Figure 6: Life Science End Summer – 6/21 6:00AM

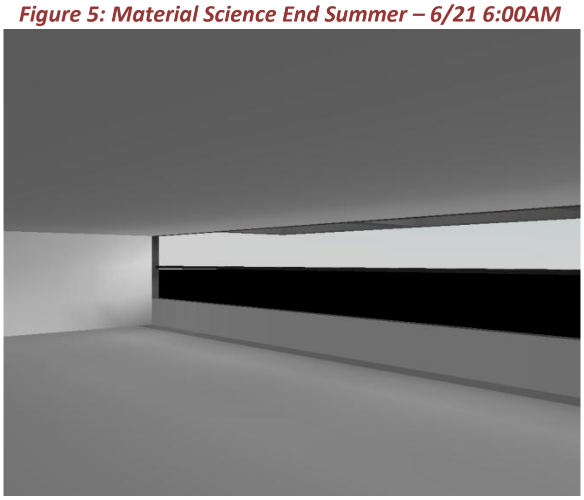


Figure 7: Material Science End Winter – 12/22 9:00AM

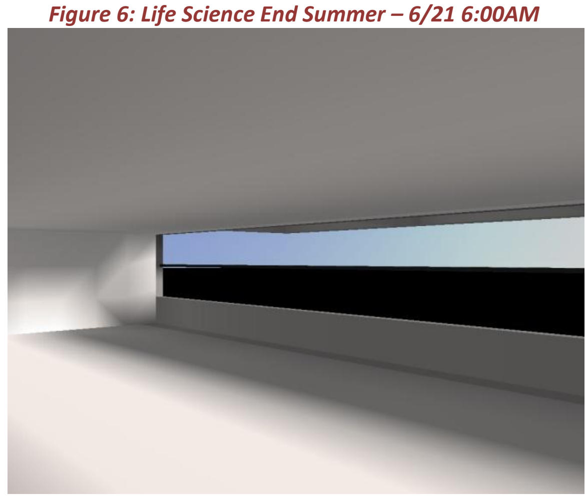


Figure 8: Life Science End Winter – 12/22 10:00AM

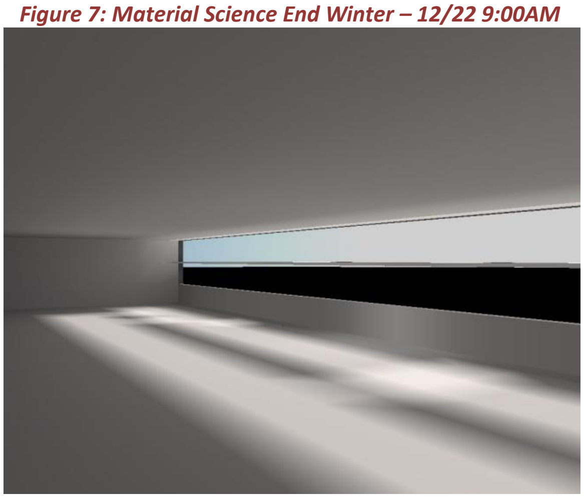


Figure 9: Material Science Corridor Summer – 6/21 7:00AM

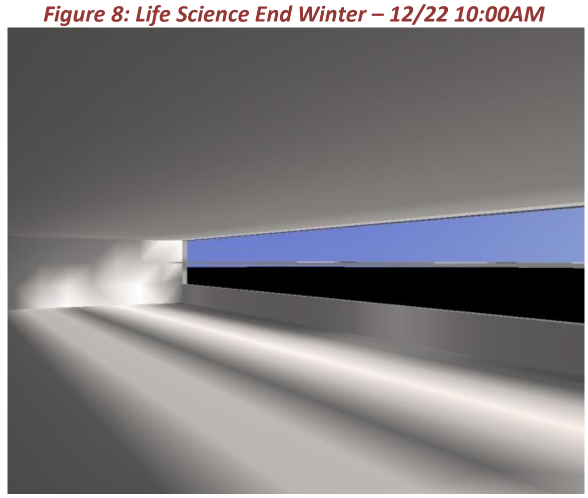


Figure 10: Material Sci. Corridor Winter – 12/22 11:00 AM

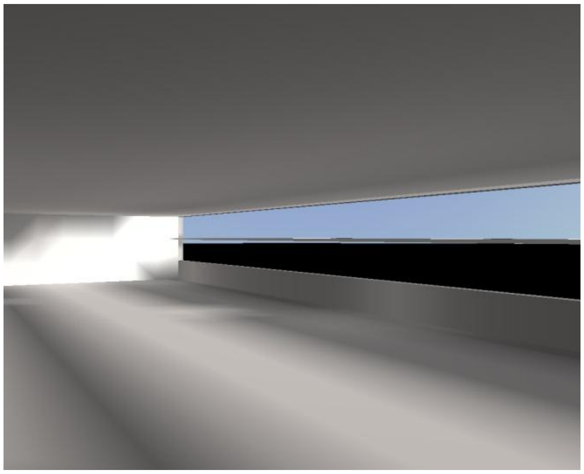


Figure 11: Life Science Corridor Summer – 6/21 6:00AM

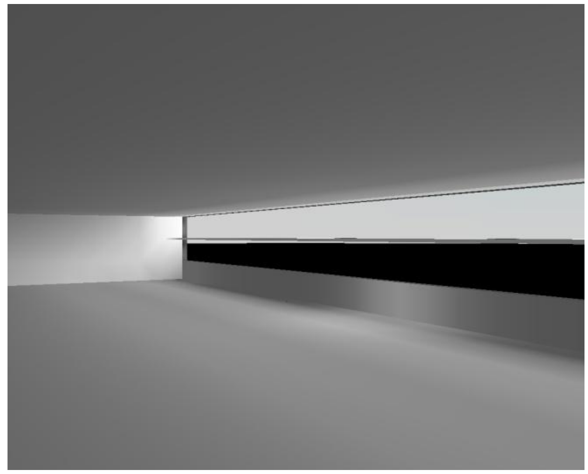


Figure 12: Life Science Corridor Winter – 12/22 9:00AM

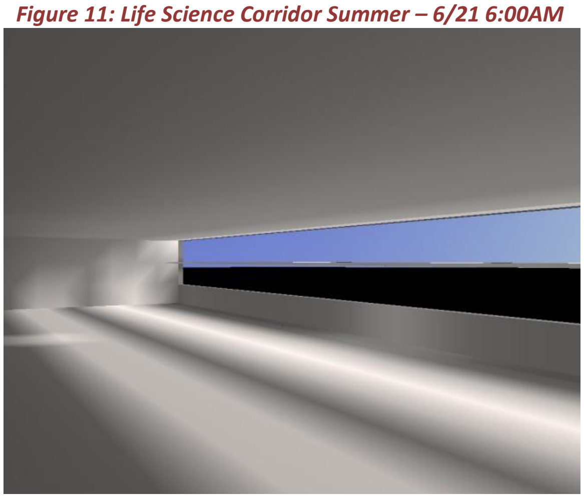


Figure 13: Café Summer – 6/21 7:00AM

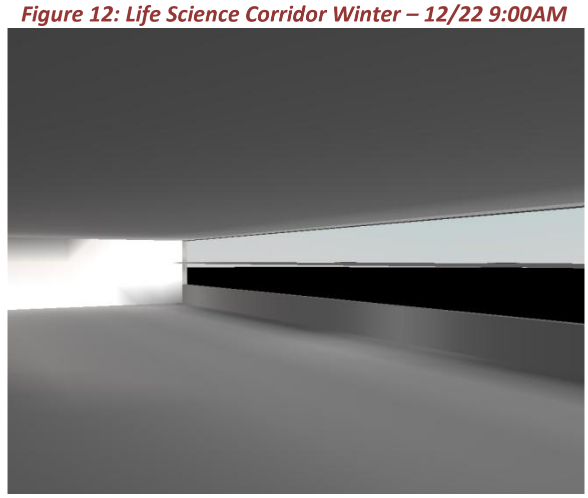


Figure 14: Café Winter – 12/22 9:00AM

Secondly, the louvered overhang does not provide much protection from high angle sun on long sides of the building. As seen in the images below, daylight still penetrates into the space even on the highest altitude and profile angle days. The large trellised overhang does block these high angle rays, but it is not perfect.

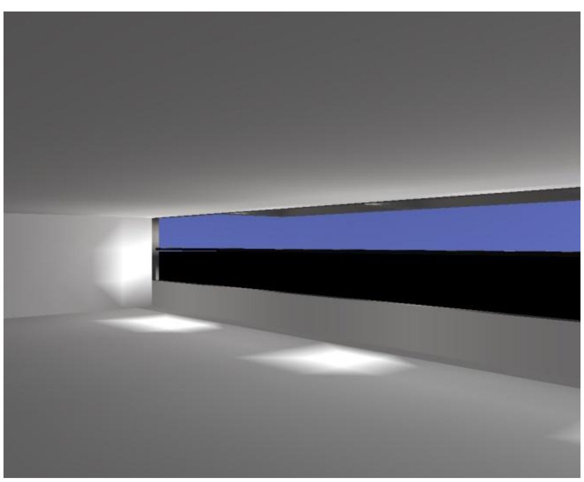


Figure 15: Material Science end high profile angle block

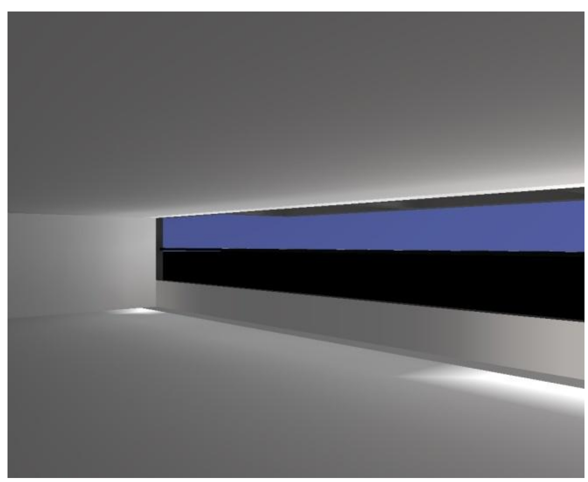


Figure 16: Life Science end high profile angle block

Existing Mechanical System Review

The Millennium Science Complex is equipped with an efficient, reliable, and energy conscious mechanical system. Campus steam and chilled water lines are used as the source of heating and cooling. This eliminates the need for spacious equipment such as boilers and chillers that consume large amounts of energy. Steam pressure is reduced from the incoming pressure of 140 psi to medium pressure steam at 60 psi and low pressure steam at 15 psi. Steam is used for sterilization, other process loads, and in heat exchangers that create the hot water used in VAV reheat-coils. Three variable speed split case pumps are used in junction with a jockey pump to deliver chilled water throughout the building.

Air is distributed to the laboratories from a 100% outdoor air VAV system. There are a total of five laboratory AHUs, each sized at 50,000 CFM. Laboratory spaces were required to have 100% outdoor air in order to help ensure that ongoing experiments were not altered or tainted by recirculated air. Similarly, the animal holding facility areas and clean room are served by 100% outdoor air AHUs to ensure proper indoor air quality. Phoenix venture valves are used to ensure proper ventilation and pressurization with these systems.

Enthalpy wheels were used to recover energy from laboratory exhausted air and heat recovery coils were used on the animal holding and clean room AHUs. A dedicated fume hood exhaust system removes contaminated air from laboratory fume hoods and directs them straight out of the building. Three other 40,000 CFM VAV systems serve the supporting office and common area spaces. These areas do not require 100% outdoor air therefore office AHUs are specified to use 15% outdoor air.

An initial space-by-space Trane TRACE energy model was constructed for solely the third floor of the building to provide a baseline model for future comparisons. The graph and table below break down the energy usage from the third floor.

Table 1: 3rd floor Existing Energy Data

	Existing Design
Electricity (kWh/yr)	684,280
Purchased Chilled Water (therms/yr)	28,705
Purchased Steam (therms/yr)	24,119
Energy Intensity ($kBTU/ft^{2-}$ yr)	172.2
Operating Annual Cost	$123,754

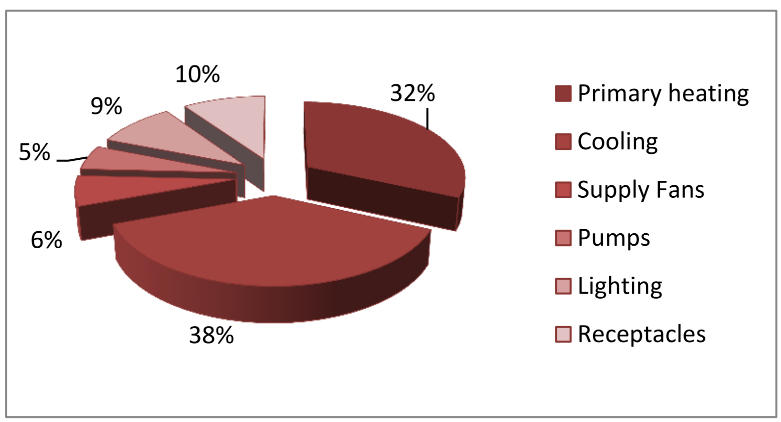


Figure 17: Existing Energy Breakdown

Existing Structural Design Review

Foundations

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

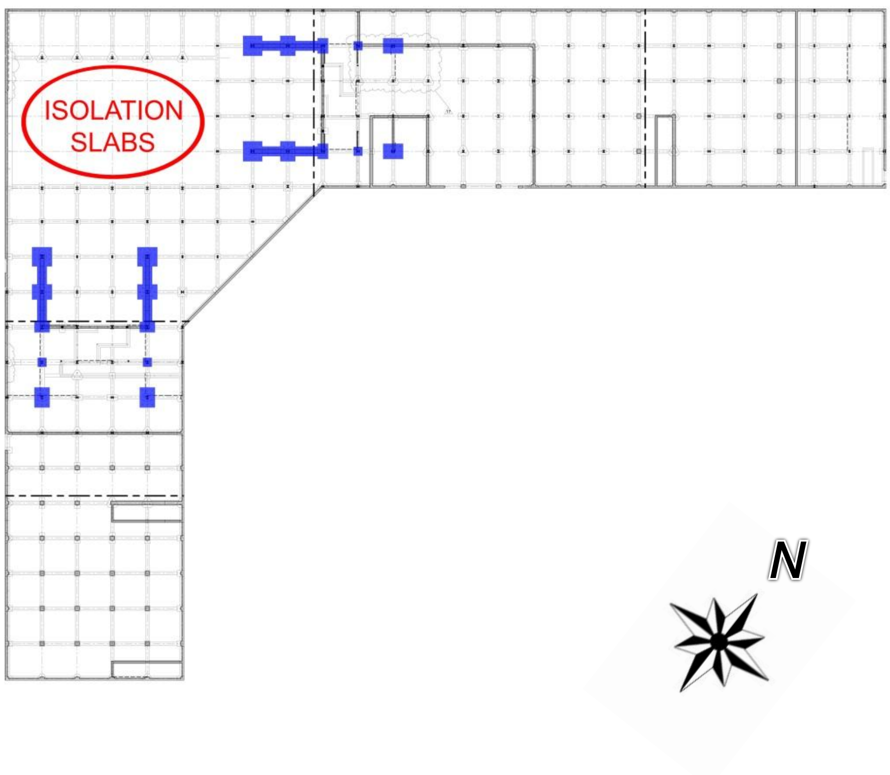


Figure 18: Foundation Grid showing Pile Caps and Grade Beams

Figure 18 shows pile caps positioned at every grid line corresponding to the location of the columns. Columns transfer their load into these pile caps and then into micropiles. Grade beams connect the pile caps in a grid pattern. Several of these pile caps are enlarged and highlighted in blue; they serve to distribute the load from the cantilever. Also seen here is a section circled in red which does not contain pile caps due to the presence of three isolation slabs.

Floor System

A composite floor system with typical 22 foot square bays forms the floor system for the Millennium Science Building. A typical floor layout for the wings contains a centralized corridor surrounded by rooms on either side. Those perimeter spaces are generally divided into either laboratories or offices. The floor loads are handled by three types of composite decking used throughout the building, highlighted in figure 19, the most common of which is a 3 inch 18 gage deck with 3¼ inch light weight concrete topping. The concrete decking is supported by W21 beams and W24 girders which frame into W14 columns, at the intersection of each grid line. Beyond the typical dead and live loads, there are specialty loads from the green roof, mechanical equipment, and the pedestrian traffic at the entrance which call for increased slab strengths. A 3 inch metal deck is used with a 7 inch normal weight concrete topping immediately below the cantilever where pedestrian traffic is heaviest as people enter and exit the building, and a 4½ inch normal weight topping is used to support each green roof. These hallways call for a slightly higher ceiling so W18 beams are used in the center bay of each frame.

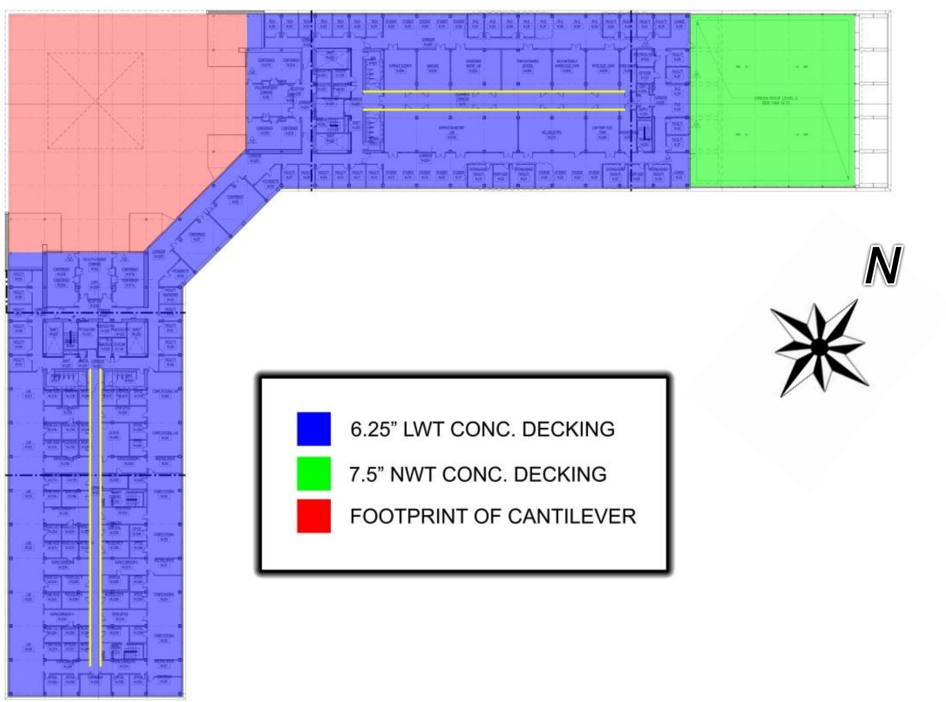


Figure 19: Typical Floor Layout

Seen above is the second floor plan of the Millennium Science Building. Highlighted in green and blue are the different decks used on occupied floors; they represent the green roof and interior floor, respectively, of the second floor. This plan is used as an example of a typical layout, being lightweight concrete used for the accessible spaces and normal weight concrete used for areas with specialty loads such as the green roof or mechanical penthouse. The area highlighted in red represents the plaza landscape under the cantilever. The yellow lines running through the center of each wing call out the central corridor.

Specialty Systems

To cope with the massive stresses induced by the 150 foot overhanging cantilever, a truss design was used to handle the gravity forces. Gravity loads start from the tip of the cantilever and are transferred into the diagonal compression members. Continuing on the load path, the truss feeds into a 30" shear wall integral with the truss frame. The loads from the diagonal compression members get carried into the shear wall and transfer into the foundation. The load is handled by 10 points in the foundation; one of the two identical frames is shown in figure 20. These enlarged pile caps and grade beams act in compression and tension on the soil, using the micropiles as an anchor.

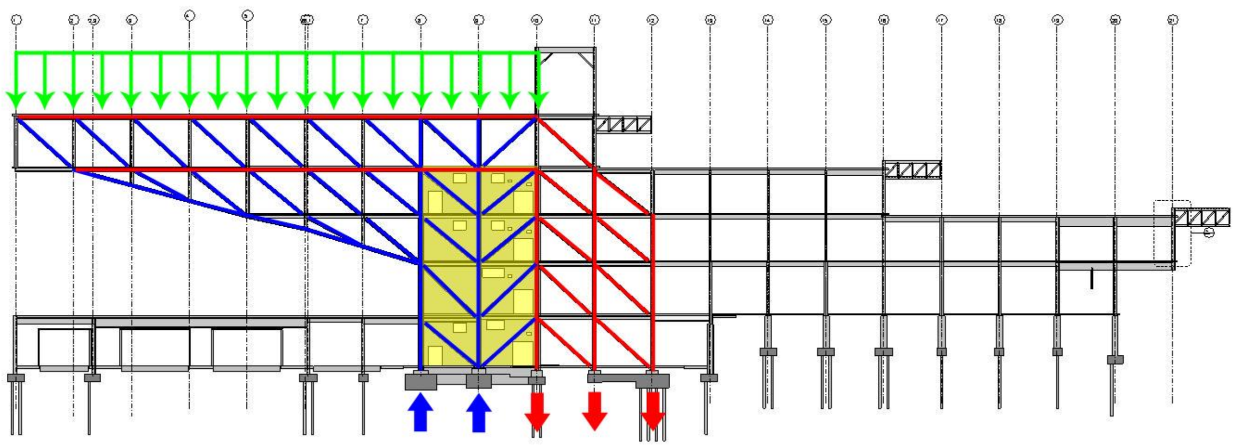


Figure 20: Special Systems load distribution

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

PROPOSED INTEGRTAED SOLUTIONS

KGB-Maser has identified redesign goals that revolve around holistic improvements to the Millennium Science Complex. The main challenge of the redesign is to produce holistic and sustainable solutions. Communication and teamwork among the four disciplines, construction management, structural engineering, mechanical engineering, and lighting/electrical engineering will be crucial to the success of alternate systems.

The following topics expand on the overall goals of the redesign. Each discipline's expertise has and will continually be involved in each redesign focus.

FAÇADE REDESIGN

Precast Panel Redesign

The current design of the façade and architectural precast panels is not the optimum configuration from a constructability standpoint, for daylight utilization, or solar shading in some cases. The redesign of the façade will require the attention of all group members.

With the architectural precast panels being investigated, any changes to the façade will have to be examined with respect to upfront direct costs, life cycle cost analysis, potential maintenance issues, and how the redesign will affect constructability and schedule. It is vital to realize that many systems may cost more up front, but provide benefits to the owner within a payback period. It is up to the owner to decide on an acceptable payback period for which they desire to invest in.

It is important to the Millennium Science Complex and The Pennsylvania State University that the building maintains its appearance as a signature building on campus. Any redesign of the façade will keep in mind the goal of creating a modern, signature building as well as utilizing a brick appearance to match the surrounding architecture of the campus. There are three main options that KGB Maser will use to lighten the precast panels of Millennium Science Complex.

The first option that will be investigated to lighten the precast panels is the redesign of each panel. The precast manufacturer will be consulted with to find the minimum thickness that the panels need to be, in order to hold the split face brick and to withstand the wind loads. This will limit the weight of each panel, which will have a direct impact on the structure, thermal envelope, and could have an impact on the schedule.

The second option that will be investigated to lighten the precast panels is the use of a foam core in the precast panels. If the panels were to have a foam core inside of the "C" shape panel, this would severely lighten to the weight of the panel and have the same effects as option one.

The third option that will be investigated to lighten the precast panels is the use of a lightweight concrete mix. Currently the panels are being made with 5000 psi in accordance with Specification 3400. The precast panels are simply a gravity dead load on the structure, and they do not need to have high strength concrete for wind loads.

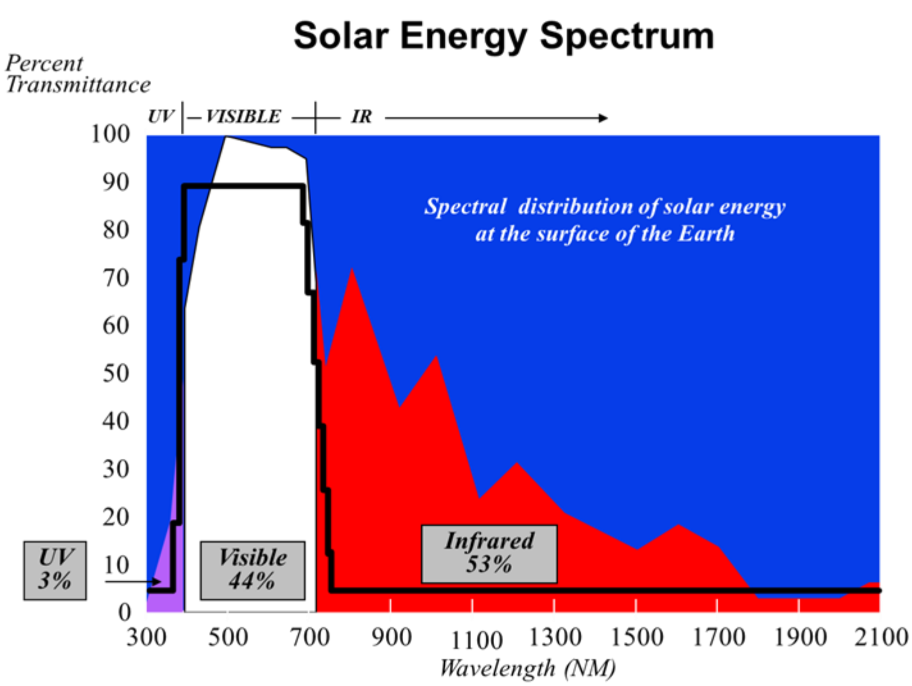
The three options above will be consulted with precast panel manufacturers and structural engineers for consideration. It is possible that any of these three options will be used in the final proposal, or a combination of one, two, or three of them.

After completing extensive research, consulting with industry professionals, and developing designs, it is believed that a precast split face masonry system will be able to be designed that will lighten the structural loads, provide energy saving benefits, help with constructability/schedule, and architectural appeal.

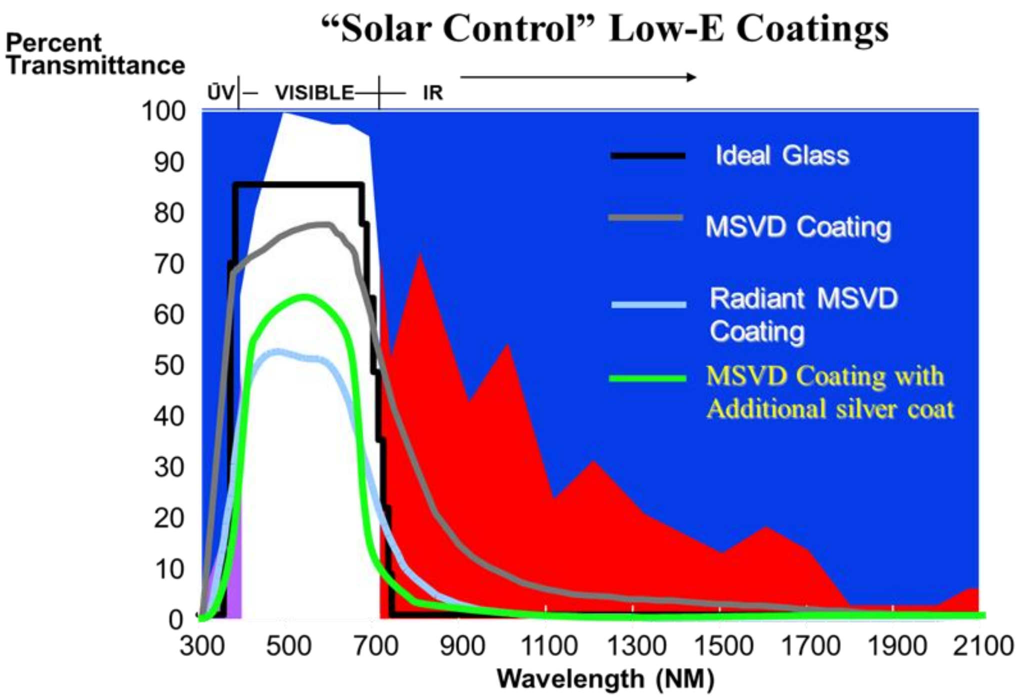
Daylighting Redesign

Glazing Option: Spectrally Selective

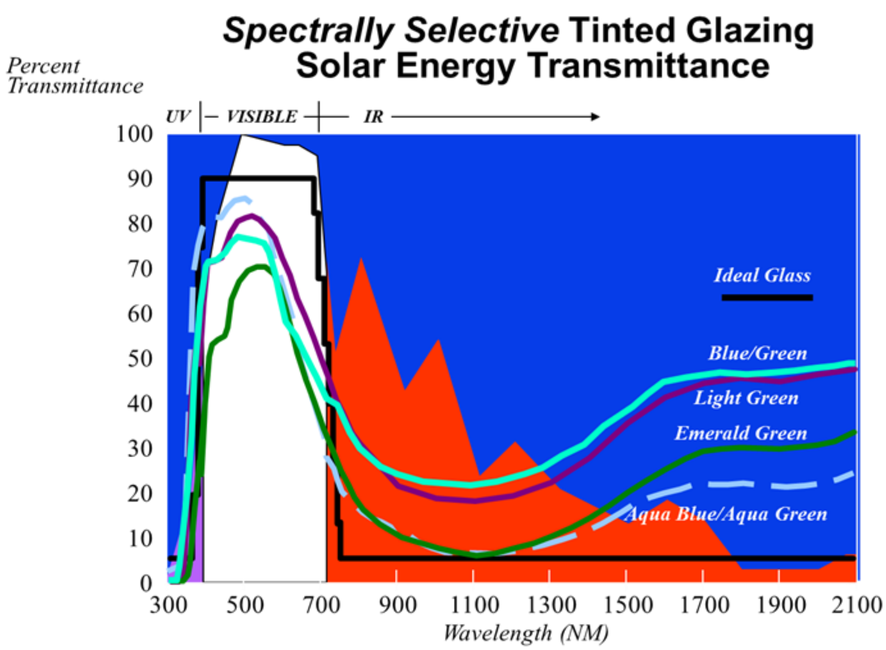
The ultimate goal of architectural glazing is to be spectrally selective. This means all possible visible light enters through the glazing and none of the long wavelength (infrared) or short wavelength (Ultraviolet) radiation enters the building. The graph below illustrates the ideal glazing.

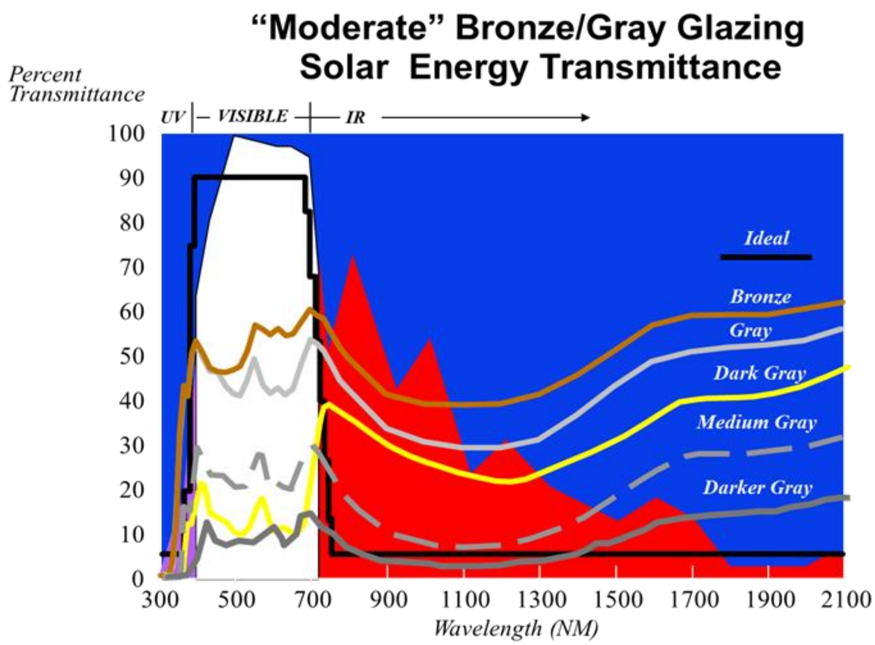


Products are available that compare to the ideal curve shown above. However, there are sacrifices made when manufacturing glazing that is close to the "ideal" curve. Most of the costs appear in the visible transmittance of the glass. The following graph shows "solar control low-e coatings" for three types of magnetic sputtered vacuum deposition (MSVD) coatings



When compared to tinted or "moderate" spectrally selective glazing, the "solar control low-e" glazing more closely matches the ideal glass type transmission curve. The graphs for tinted and "moderate" spectrally selective glazing are shown below.





One glazing option under investigation includes PPG Triple Silver Solar Control Low-e glass. The glass properties are as follows:

Winter U-Value – 0.28
Visible Light Transmission – 64%
Solar Heat Gain Coefficient – 0.27
Light to Solar Gain Ratio – 2.37

This glass outperforms traditional glazing types and does not have frits that decrease view for the occupant. A study of environmental performance criteria for both coated and uncoated glass by PPG is summarized in the following table:

Table 2: Energy and Environmental Performance Criteria

Glass Type	Winter U-Value	VLT	SHGC	LSG
Uncoated Glasses				
Clear Glass	0.47	79%	0.70	1.13
Ultra-Clear Glass (Low-iron glass)	0.47	84%	0.82	1.02
Blue/Green (Spectrally Selective) Tinted Glass	0.47	69%	0.49	1.41
Coated Glasses				
Pyrolytic Low-E (Passive Low-E) Glass	0.35	74%	0.62	1.19
Triple Silver Solar Control Low-E	0.28	64%	0.27	2.37
Tinted Solar Control Low-E	0.29	51%	0.31	1.64
Subtly Reflective Tinted	0.47	47%	0.34	1.39
Blue/Green Reflective Tinted	0.48	27%	0.31	0.87

This study also included switching from dual pane tinted glass to triple silver glass for an office building and a school in each of twelve different cities. The buildings examined have the following characteristics:

270,000 square-foot, eight-story office building
Punched window
Total window area: 33,418 ft^2
Total wall area: 56,640 ft^2
Window to wall ratio: 59% glass
Window wall
Total window area: 50,976 ft^2
Total wall area: 56,640 ft^2
Window to wall ratio: 90% glass

200,000 square-foot, one-story school
Punched window
Total window area:18,863 ft^2
Total wall area: 63,520 ft^2
Window to wall ratio: 30% glass
Window wall
Total window area: 45,027 ft^2
Total wall area: 63,520 ft^2
Window to wall ratio: 71% glass

The variables in each energy model are:

- *Total Electric Consumption (kWh)*
- *Total Natural Gas Consumption (therms)*
- *Peak Cooling Load (tons)*
- *Peak Heating Loads (kBtu/hr)*
- *Total Supply Airflow (cfm)*
- *Total Electric Cost ($)*
- *Total Natural Gas Cost ($)*
- *Total Building Energy Consumption Cost ($)*
- *Cooling Equipment Capital Cost ($)*
- *HVAC Equipment Capital Cost ($)*
- *Total Cooling HVAC Capital Cost ($)*

The results of this study are summarized in the following tables:

• City	Annual HVAC Operating Expenses		Annual Savings	Total HVAC Equipment Costs		Immediate Equipment Savings	1st Year Savings
	Dual-Pane Tinted	Triple Silver		Dual-Pane Tinted	Triple Silver		
Atlanta	$680,456	$597,772	$82,684	$2,115,464	$1,697,686	$417,597	$500,281
Boston	$853,450	$756,001	$97,539	$2,326,967	$1,928,086	$398,881	$496,420

City	Electricity (KwH Savings)	Gas (Therm Savings)	Annual CO_2 Reductions (Tons)	40-Year CO_2 Reductions (Tons)
Atlanta	455,841	18,829	417	16,699
Boston	432,301	26,618	354	14,163
Chicago	434,777	29,644	502	20,087
Houston	473,971	14,199	422	16,889
Phoenix	469,246	6,170	411	16,451
Seattle	328,567	29,588	250	10,018

The results are based on the eight-story glass-walled office building in major cities. The total glass area is 50,967 ft^2 and the total floor area is 270,000 ft^2. This is not an exact comparison to the Millennium Science Complex, but does show what glazing changes may be able to achieve. In Boston and Atlanta, two very different climates, the Triple Silver coating saved around a half of a million dollars in total energy costs for the year. The environmental impact can also be seen in thermal energy savings and CO_2 reductions. Further and more in-depth investigation will be completed should KGB Maser pursue this change. The energy characteristics of this glass can be assessed by both the electrical and mechanical engineers. This new glazing compounded with shading devices that operate from the bottom up (rather than top down) will preserve the benefits of daylight in the space and ensure only the undesired light be shaded.

Diffuse Glazing Addition

The addition of diffuse glazing will prevent direct rays from falling on occupants, thus causing discomfort. KGB Maser plans to investigate the use of phase change materials in clerestory glazing applications – more specifically above the louver and view glass. The application of DELTA®- COOL 28 phase change glazing will be investigated for both daylighting and mechanical purposes. It was applied in translucent PMMA panels in a glass facade system of a zero energy office building in Kempen, Switzerland shown in the images to the right. The phase change material will absorb the low angle light that penetrates beyond the overhangs and reradiate the energy later in a second phase change. This reradiating occurs later in the day when the building would normally be heated around the perimeters at the fenestration. Only applying it above the louver will be beneficial to occupants as head-height direct sun will be eliminated from the perimeter of the building as seen in the images below. Low level sun still penetrates below the louver, but will stay closer to the perimeter as the sun reaches higher profile angles. More in-depth calculations as to daylight availability and mechanical load depreciation will be undertaken should KGB Maser pursue this option for daylight delivery and mechanical change.

Figure 21: Phase change glazing images from www.cosella-dorken.com

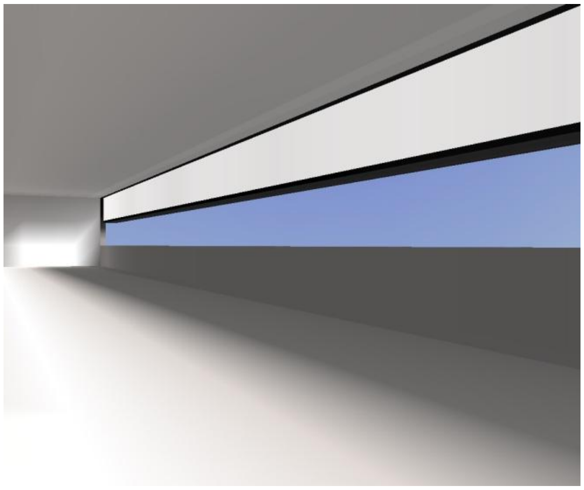


Figure 22: Material Science Low Summer Sun Angles

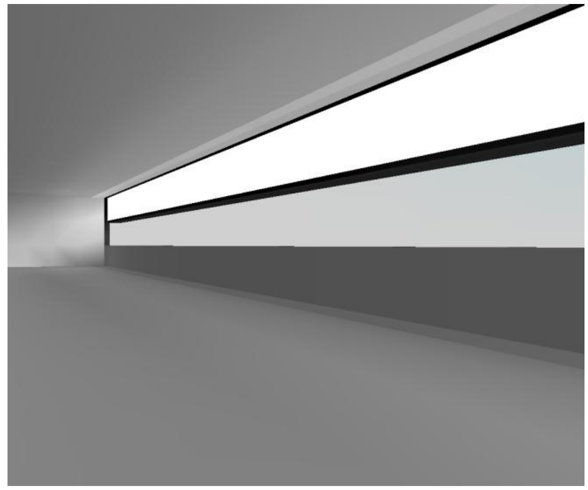


Figure 23: Material Science Low Winter Sun Angles

One major issue with this application, as with all of the proposed applications, is the minimal direct gain on the wing ends of the Material Science section of the building. The phase change material may prove to be non-cost-effective once further analysis is performed. This application would also most likely only be on northeast and southeast facing façades. The western facing façades must interact with adjacent buildings and will not receive sufficient direct gain to be effective.

Light Shelves

The addition of light shelves will shield occupants of perimeter offices and study spaces from deep penetrating daylight and direct sun rays. They will also diffusely send light to the deeper areas of the spaces. The following images illustrate the use of light shelves in the various orientations of the Millennium Science Complex. They employ a simple three food deep light shelf.

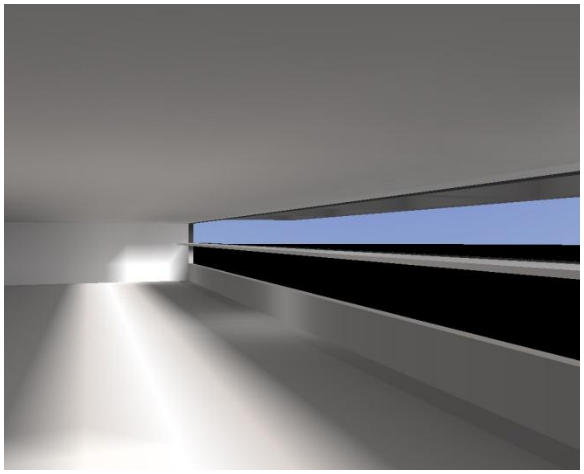


Figure 24: Material Science End Summer Morning

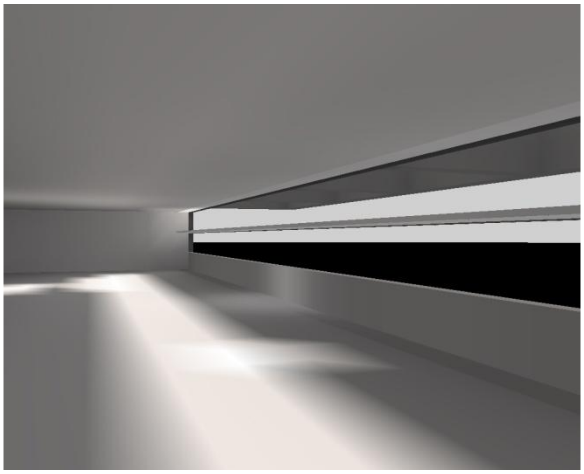


Figure 25: Life Science End Summer Morning

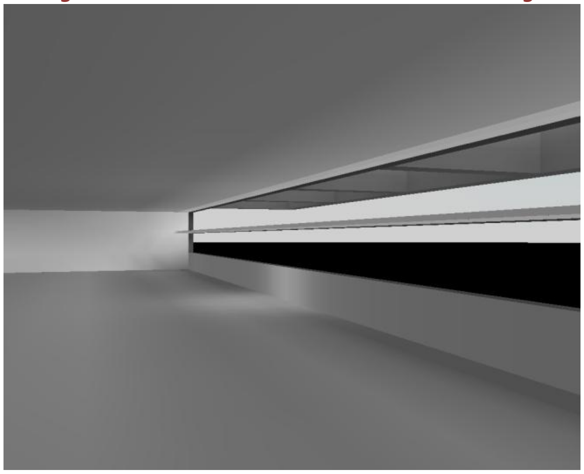


Figure 26: Material Science End Winter Morning

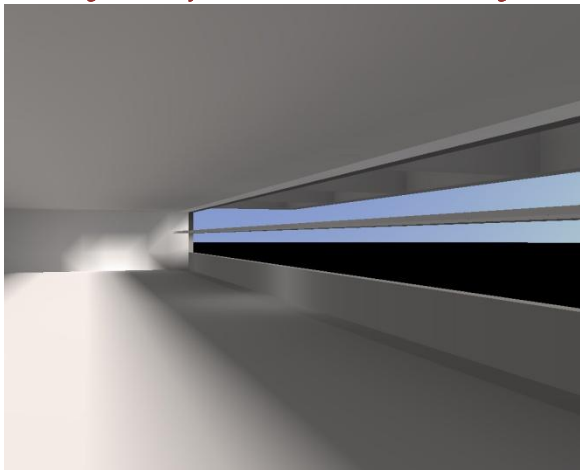


Figure 27: Life Science End Winter Morning

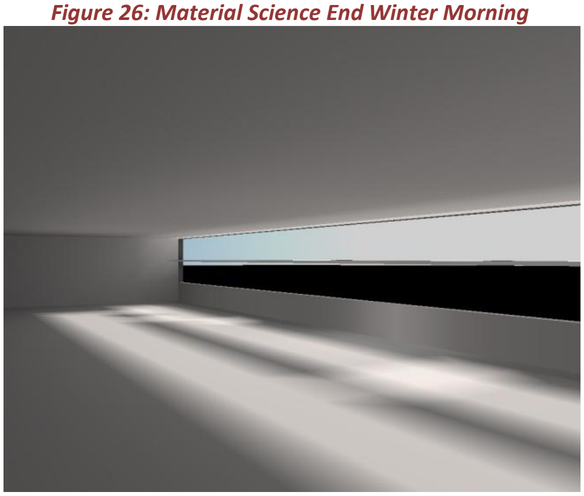


Figure 28: Material Science Corridor Summer Morning

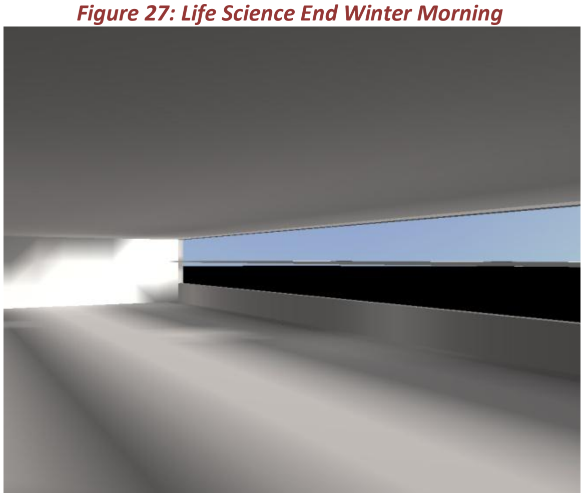


Figure 29: Life Science Corridor Summer Morning

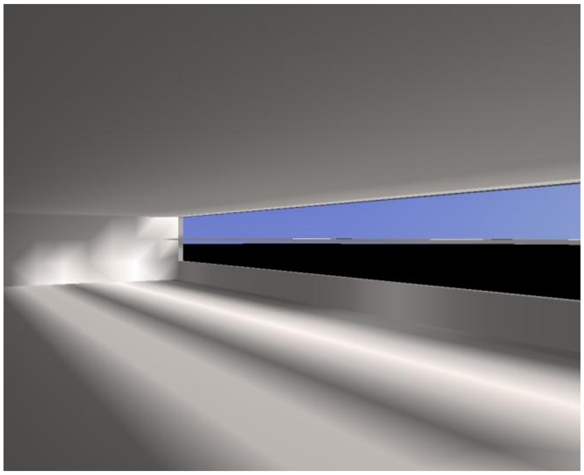


Figure 30: Material Science Corridor Winter Morning

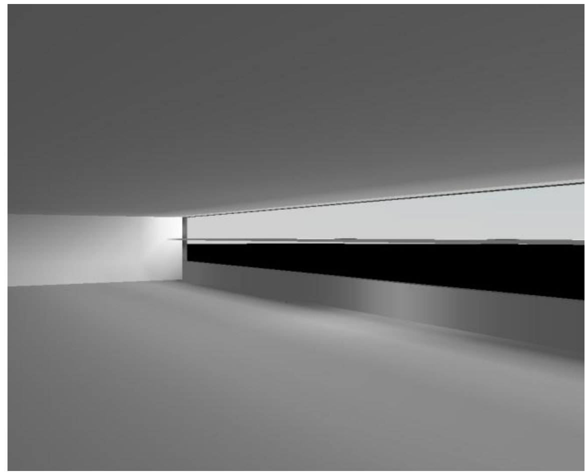


Figure 31: Life Science Corridor Winter Morning

The shelf removes direct rays, in combination with the large overhang at the ends of the building, so that direct light will mostly strike walls deeper into the space. This may include office-corridor interfacing walls, or if no walls are present, the occupant walking by will not be blinded at head level. The largest challenge with light shelves is sizing exactly how deep they can penetrate into the space. For this reason as well as interaction with mechanical equipment, light shelves will need much more analysis. At this point, its prevention of effective perimeter heating is a major obstacle keeping KGB Maser from pursuing light shelves as daylighting integration.

Major issues also arise when the large trellised overhang is not present. Without this geometry, the sunlight passes by the small louvers and causes large amounts of direct sun light. Also as with other daylight applications, the Material Science wing end does not see much direct gain in winter months. Overall, light shelves do not appear to have much improvement over the current daylight delivery system.

Phase Changing Material Drywall Façade Integration

KGB-Maser has chosen to look at the façade of the building from a hollistic point of view. The thermal envelope of the building impacts loads within the space and HVAC system sizing. The components of the façade need to be selected to balance costs and bearing on the mechanical system.

A study of using phase-change material (PCM) will be incorporated into the façade redesign. Two types of PCM strategies have been investigated, PCM drywall and encapsulated PCM. The drywall application can cover a large surface area and has more heat storage capacity due to its ability to be installed on exterior and interior walls. Encapsulated PCM is mixed with the concrete and could be mixed into the precast panels of the Millennium Science Complex. However, placing PCM in the façade concrete eliminates the potential for renovation due to advances in PCM technologies. PCM drywall may be a better alternative than encapsulated PCM in concrete because it allows for updated PCM drywall to be installed over the lifespan of the Millennium Science Complex. Phase change drywall is comparable to standard drywall in weight and thickness and should not have a constructability concern.

National Gypsum has produced a ThermalCORE Panel that contains high purity paraffin wax. The wax is designed to change phase at 73^{o}F. When the temperature falls within a space, the drywall will begin to release heat into the space. The desired effect is a more stable room temperature throughout the day. The manufacturer data claims the drywall comes in 4 foot by 8 foot sheets and has a 22 BTU per square foot latent heat capacity. The ThermalCORE Panel product is not currently on the market, but similar phase-change drywalls are available. BASF, The Chemical Company has its own Micronal PCM drywall that is very similar and close to application in the United States as well. Phase change drywall from manufacturers such a BASF and National Gypsum could be used in the Millennium Science Complex to help reduce peak loads in building spaces.

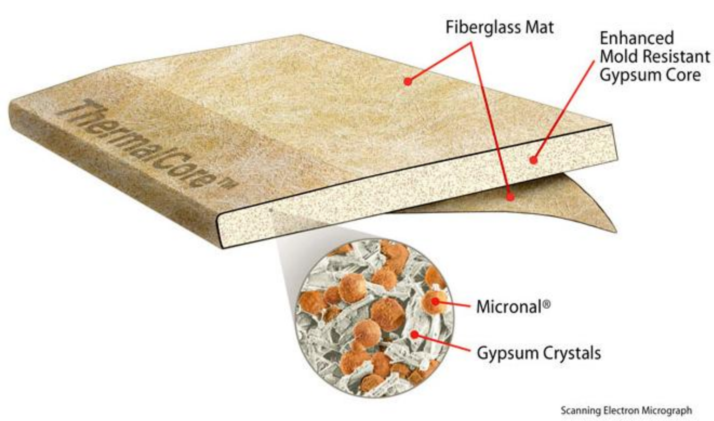


Figure 32: Thermal CORE Panel from National Gypsum

REDUCTION OF ENERGY CONSUMPTION

Reducing the energy usage of the Millennium Science Complex is a common goal for KGB-Maser. The mechanical systems of the building can be considered the focal point of energy improvements because adjustments to the building can affect mechanical loads. The analysis of the existing design conditions from previous reports has led to the investigation of the following improvements.

The proposed alternatives are intended to aggresively attempt to decrease the energy consumption of the Millennium Science Complex. Laboratory buildings consume more energy than many other types of buildings. The focus of the energy use optimization redesign is to evaluate options that could save energy and be economically feasible. The use of Building Information Modeling (BIM) will be used to effectively model and communicate suggestions between disciplines. Careful management of associated costs and schedule impact, and coordination with disciplines will be crucial to arriving at the best integrated energy saving solution.

DOAS + Chilled Beam + Radiant Floor Heating

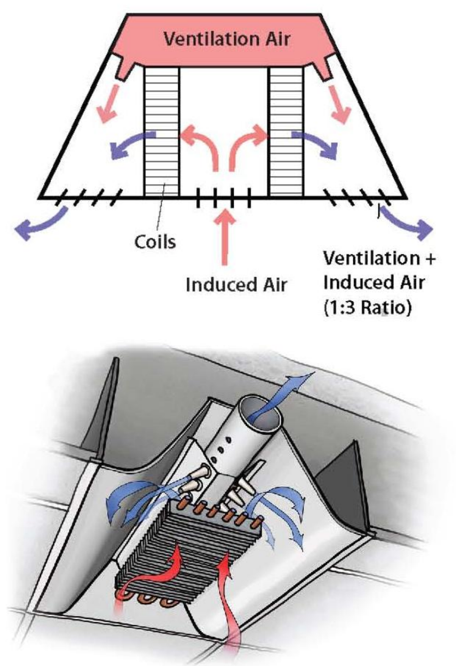


Figure 33: Proposed Active Chilled Beam. From Labs21: Chilled Beams in Laboratories

Thermal comfort and indoor air quality are two key components needed to produce a productive envrionment. It has been proven that buildings with poor indoor air quality can affect the health and in turn the productivity of building occupants. In order to ensure that all occupants of the Millennium Science Complex are thermally comfortbale and experience indoor air quality a dedicated outdoor air system (DOAS) with chilled beams and radiant floor heating can be recommended to replace the existing office VAV systems. This system has been proven to save energy in annual operating costs in comparison to forced air systems.

Dedicated outdoor air systems deliver a specified amount of air to handle the required ventilation or latent loads. A DOAS requires supporting heating and cooling components to handle sensible loads. Chilled beams and radiant floor heating will be used to manage sensible loads. Chilled beams have become increasingly popular over the years, and coupled with a radiant floor heating system, can effectively hand the sensible loads within the building.

The proposed DOAS, chilled beam, and radiant floor heating could be extended to include the laboratory spaces of the building as well if the driving factor of airflow can be determined. If laboratory required ventilation or cooling required drives the amount of air required in a laboratory, a chilled beam system could be beneficial. If the fume hoods drive the airflow, as is the case in spaces containing many fume hoods, chilled beams may not result in the desired savings. Careful investigation of what spaces will be most practical for chilled beam application will be crucial in the DOAS, chilled beam, and radiant floor heating redesign. Labs21, a *program that promotes the energy conscious and sustainable design of laboratories within the United States, has produced media promoting the use of chilled beams in laboratories that can be used to guide further investigation.*

Since DOAS only delivers the air required for ventilation or latent loads, the amount of air that needs to be distributed decreases. Smaller AHUs, less fan energy, and smaller ductwork in the plenum space are all possible benefits. The 4th floor of the Millennium Science Complex which is packed with structural and mechanical components in the existing design could be more easily coordinated with smaller equipment and smaller ducts.

The DOAS, chilled beam, and radiant floor heating systems require coordination with other design disciplines. Chilled beams will need to be integrated with the lighting design of the space. Chilled beams can range from four to eight feet and will need to fight for space within the acoustic ceiling. The opportunity exists to utilize integrated chilled beams that contain lighting fixtures as well. A radiant floor system must integrate with the architectural finish of the floor and the structural system of the floor. There are multiple ways to install radiant floor heating. The best solution will consider impact on structural design and heat transfer criteria.

Chilled beams have been cited by Labs21 to have lower intial costs than VAV systems when components and material are considered, now that installation of chilled beams is becoming increasingly common. Coupled with the proven energy usage reduction, the DOAS + Chilled Beam + Radiant Floor Heating redesign seems to be an ideal choice for providing thermal comfort in office and less-dense laboratory spaces. The image below illustrates the potential advantage of chilled beams: delivering less air, varying the temperature of the delivered air based on room conditions, elimination of reheat energy, and potentially decreasing the floor to floor height.

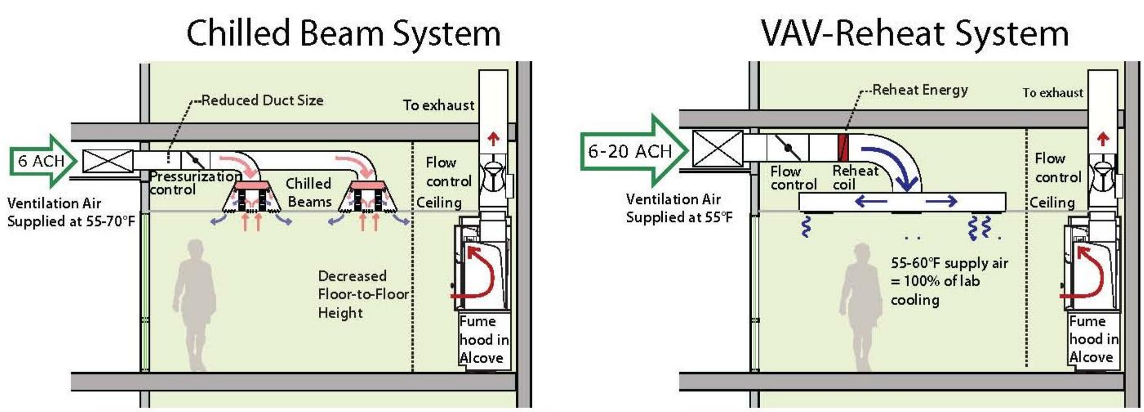


Figure 34: Chilled Beam vs. VAV-Reheat systems in laboratories. From Labs21: Chilled Beams in Laboratories

Labs 21 Environmental Performance Criteria

The Millennium Science Complex has been designed to achieve LEED Gold certifcation under LEED NC v2.2. Labs for the 21st Century (Labs 21) created a rating system called Environmental Performance Criteria (EPC). EPC is aimed at ensuring energy efficient and sustainable design in laboratories, which are typically energy intensive. The current EPC is modeled after LEED NC v2.2 and proposes additional credits. Labs 21 does not certify buildings that achieve these credits as it is meant to only extend LEED principles to laboratory design. Using Labs 21 while redesigning the mechanical system will ensure that energy saving measures and sustainable practices specific to laboratories are implemented. The breakdown of additional credits can be found in Appendix B.

Exploratory Energy Saving Strategies

The following recommendations can be applied to the improvement of the energy use of the building. Most of these options will be investigated further and will affect the proposed DOAS, chilled beam and radiant floor heating alternate system. These suggestions may include some risk or cost factors that Penn State may not wish to manage during the lifetime of Millennium Science Complex.

Fume Hood Face Velocity Control

The OSHA recommendation range for the face velocity of fume hoods is 60-150 feet per minute. Typically, most systems are designed at 100 feet per minute due to safety concerns and previous rules of thumb. The fume hoods are maintained at 100 feet per minute regardless of the opening of the sash. High performance or low-flow hoods instead specify face velocities as low as 60 feet per minute and result in energy savings. Since most of the cooling loads in the spaces are driven by the exhaust requirements, the amount of cooling in the space has the potential to be reduced as well. Fume hood face velocity of 60 feet per minute has been proven to be sufficient in containing chemical vapors and ensure fume hood operator safety. As with other recommendations, it is important to prove to Penn State that the occupants of the Millennium Science Complex will be safe when operating fume hoods and that energy savings are realistic.

Fan Wall AHUs

A FanWall air handling unit consists of an array of smaller fans moving air through a system. The FanWall AHU has been proven to reduce AHU energy usage, vibration, and reduce footprint of equipment. In a conversation with the engineer, it was mentioned that Penn State was unwilling to risk using FanWall AHU because of their inexperience with the equipment and the potential for extra maintenance needed for each fan, despite reliability claims from HUNTAIR, the manufacturer of FanWall.

If the footprint of the AHU can be reduced with a FanWall AHU the potential exists for simpler coordination and straighter runs of ducts in the 4th floor mechanical rooms. The FanWall AHU could be included in the DOAS system redesign.

Snow Melt System under Canteliver Opening

A low cost and smaller scale suggestion would be to expand the existing snow melt system to include areas of the slab underneath the canteliver opening. A snow melt system would cost more initially but would save on man power required to evacuate the space of snow and maintain the safety of passerbys regardless of maintenance schedules.

Ductless Fume Hoods

Ductless fume hoods detach fumehoods from a dedicated exhaust system and instead rely on pressurization within the fume hood and high quality filters to contain and remove contaminants from the space. Ductless fume hoods can potentially save energy by eliminating the need for a dedicated exhaust system. Also, the loads in the laboratory spaces may then be driven by cooling loads, not the exhaust requirements of the fume hoods. Overall, ductless fume hoods could result in less conditioned air needed to be delivered to the space, smaller equipment, and less operating cost. However, owner concerns, operator error, and the upkeep and disposal of filters could prevent the application of ductless fume hoods within Millennium Science Complex.

Further research needs to be done to determine if the chemicals specified by ductless fume hoods coincide with the chemicals that will be used in applications within Millennium Science Complex. If it is determined that there are some similiarities, ductless fume hoods could become a focus of investigation. A ductless fume hood would still need an emergency purge exhaust system in case of failure. However, the size of the AHU needed to supply the reduced cooling air to the lab space could reduce, as well as operating costs associated with the exhaust fans that were used to constantly remove air from ducted fume hoods.

The National Insitutes of Health and many leading research facilities do not recommend using ductless fume hoods. Varying the chemicals that are used within ductless fume hoods could result in filter failure. Also, the filters need to be monitored to ensure the operator can safely work. Ductless fume hoods are most practical when a less toxic chemical will consistently be used and most likely would not be endorsed by Penn State in this project.

Table 3: Millennium Science Complex Research Fume Hoods

Size	Basement	1st	2nd	3rd	Total/Size
4’	-	-	2	-	2
5’	-	3	7	5	15
6’	10	9	4	4	27
8’	-	1	-	-	1
Total/Floor	10	13	13	9	45 Total

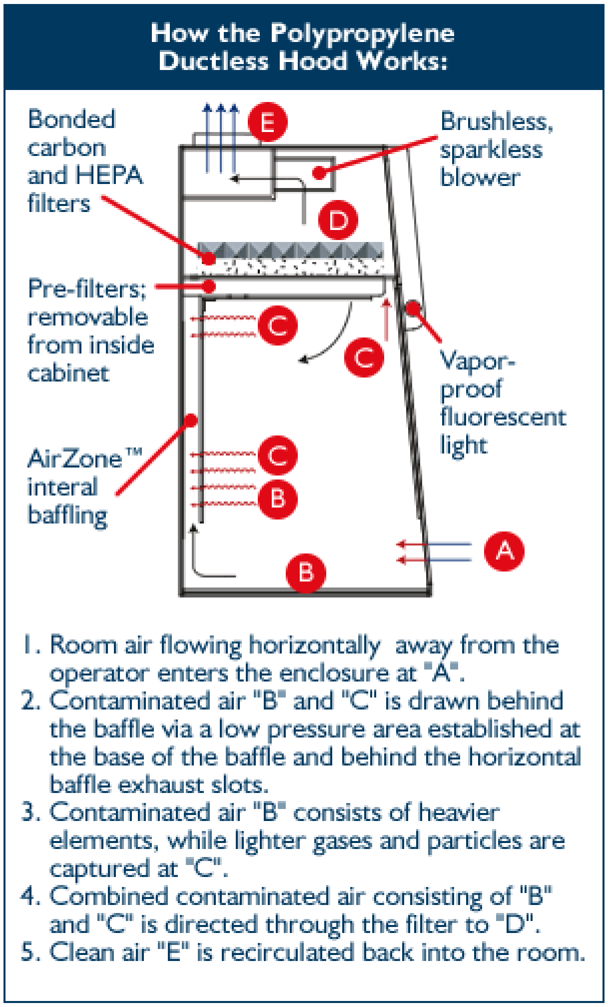


Figure 35: Ductless fume hood diagram and image from aircleansystems.com

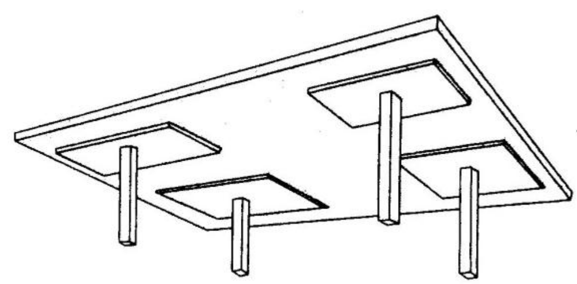
REDUCE COSTS AND APPLY SAVINGS TO IMPROVE OTHER SYSTEMS

Structural Redesign Impact

Structural Alternative Research

Three different alternate floor systems were explored initially. A skip joist floor system, flat plate and flat slab system were designed considering the worst case loads in our building. A girder slab system was also researched in addition to the previously mentioned systems, however no hand calculations were performed for this option. Since the current structural cost is around $90 psf, a goal of this initial investigation was to explore alternate options which might lower the cost of the structural system while maintaining the layout and constructability as well as consider its effects on the mechanical, lighting and electrical systems. The results of the hand calculations and research brought about several revelations as to the possible alternate structural systems and how well each could integrate with the other disciplines.

Flat Slab System



A flat slab system was considered due to the way it fit into the building's layout. The Millennium Science Complex uses square bays across the entire building with only a few locations where columns do not coincide with the grid lines. Using drop panels would alleviate the need for excessive reinforcement around the columns to resist punching shear and counteract torsional effects and it would increase the overall stiffness of the frame. Installing Mechanical and Electrical equipment in the ceiling plenum would not require workarounds for beams as a flat slab does not offer obstacles due to its flat design. The system meets all the design requirements as it would decrease the floor-to-floor height, satisfy strength requirements, and it was thought that using concrete could decrease the cost of materials and cut down on the existing structural cost. However, there are issues regarding formwork cost and the amount of concrete required relative to the other alternate floor systems. Due to the unusually large height of each floor (~20') for this floor system along with the drop panels, shoring costs would be higher than normal. A mechanical system expansion could also prove costly, requiring reinforcing around holes in the slab especially when compared with the existing system, where reinforcing is inherent in the composite deck ribs. Even though drop panels would indeed help with shear, they are more often used in longer spans and may even be unnecessary in this application. The flat slab system would be beneficial to the mechanical layout, but it loses efficiency in these shorter spans and would not be economical for the Millennium Science Complex.

Flat Plate System

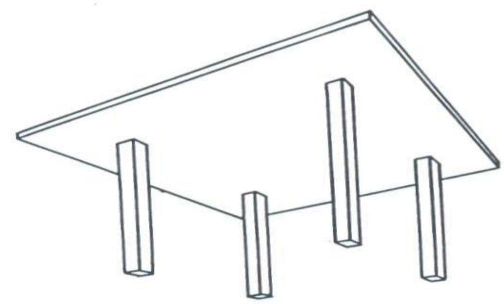


Figure 36: Flat Plate

A flat plate system allows for a large amount of architectural freedom of spaces and is easy to integrate into a building's aesthetics. It was examined in the hopes that it might decrease floor-to-floor heights and allow for a more flexible layout. Formwork would be simple to construct, cutting costs in both materials and labor (relative to other concrete options). This system is fairly fast to construct due to the simplicity of its formwork, and although it does not match up to the construction time of steel, it outperforms the other floor systems that were considered. Unlike the flat slab system, where drop panels actually made the system overdesigned, the flat plate fits very well into the existing spans, with 22' sitting between the suggested values. On the other hand, the absence of drop panels make this system more vulnerable to punching shear; although this can be resolved with stud rails or some other form of shear reinforcement. And unlike the existing steel system, the slab is not easily cut through without some excess reinforcement, which will raise the cost of a future mechanical expansion if Penn State chooses to do so. This system also sees the same problems with formwork as well, with floor-to-floor heights exceeding the norm, raising costs in shoring. Inherently, this system is not as resilient against lateral forces as the other concrete systems and additional lateral support may need to be provided. Although the flat plate design for the Millennium Science Complex might use more concrete than a traditional beam, slab, girder design, it allows more room for the mechanical and electrical systems, and less planning by the MEP engineers.

Pan Joist System

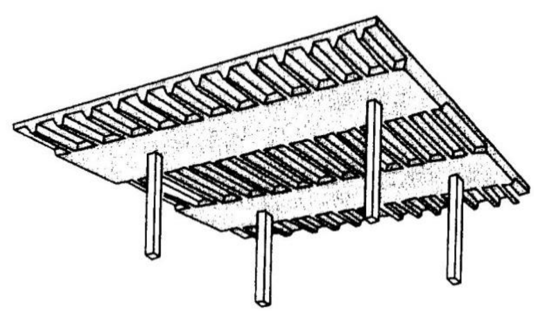


Figure 37: Pan Joists

Although the system itself may be out of date, the construction process continues to be simple and its benefits are evident. A skip joist system, though more efficient in materials, was not an appropriate option for the 22-foot square bays. It could be said that a one-way system would be more suited in a layout where rectangular bays are used, however this system provides a sufficient amount of strength and uses less concrete than the other two concrete options. It also allows for freedom of mechanical expansion as the system is prepared for holes in the slab with joists that direct the load away from the slab. Inherently, pan joists are resistant to vibrations, which is a big advantage given that the majority of the building is devoted to laboratories that require extra dampening. Concerning the lateral system, a one-way pan joist system is more rigid than a flat plate or flat slab, shrinking the amount of lateral force resisting elements required. The final design of the system could be less than half the depth of the current steel configuration, allowing more space for the MEP equipment. Due to the closely arrayed joists though, there is potentially a good amount of wasted space in the voids where mechanical equipment may not be able to fit. Also the formwork contributes to over half the entire cost of the system adding to the additional price of shoring due to the large floor heights. It may turn out to be *costlier than the other systems, but a pan joist arrangement will allow for ample strength, a minimal amount of materials, and it would be the most flexible to mechanical changes.*

Slab Girder System

Used primarily for residential applications, this system was considered as an alternative steel option. Concrete planks are used to span between two D-Beam girders, which are essentially W-shapes cut in half with a long steel flange welded to the edge of the web. It is rated for spans of up to 28 feet with decks in 8 inch and 10 inch variations. The best advantage to this system is its fast assembly time, with no shoring required during construction. Unfortunately the system is rated for residential loads and would be on brink of its capacity in a laboratory environment. Its efficiency is realized in rectangular bays with spans that coincide with divisible plank widths, and the Millennium Science Complex will not provide the optimization that could be met in a residential tower. Given that the existing steel structure is far more effective, this option was disregarded in favor of an alternate concrete design.

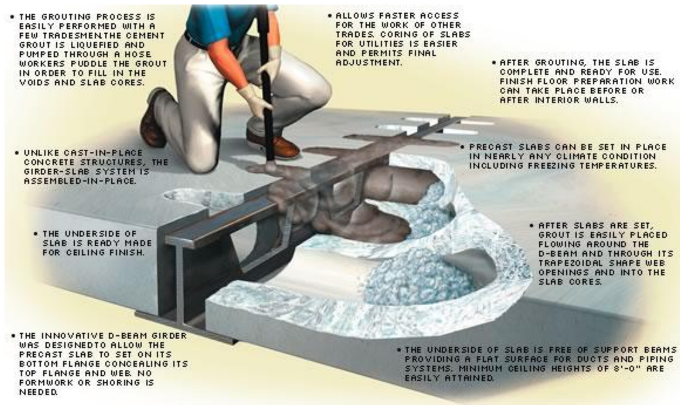


Figure 38: Slab Girder Illustration

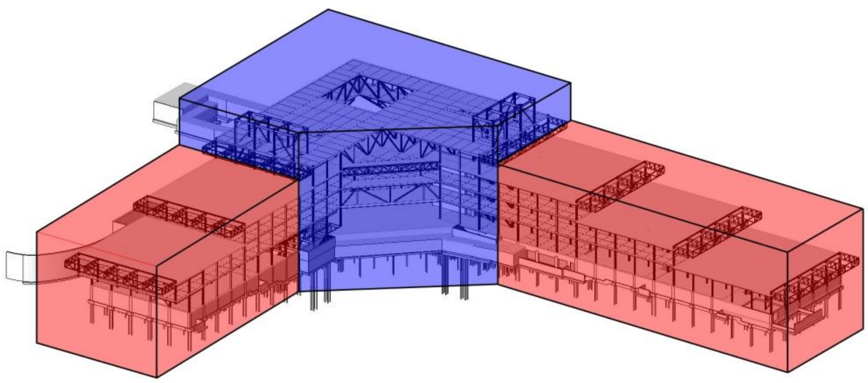
Research Conclusions

The existing steel structure was chosen due to its fit within the layout of the Millennium Science Complex. It is an ideal system to use in terms of structural efficiency; however it is also very costly. Among the four systems considered to replace the existing gravity system, only two were seriously considered. The flat slab and pan joist systems meet the design requirements as they would increase ceiling plenum space, they would potentially decrease the cost of materials, and they would be better suited for dampening vibrations. Unfortunately, State College lies in an area where steel buildings remain prominent. It would be fairly unusual and therefore more expensive, in terms of labor, to erect a concrete building in an area where new projects are disproportionately steel.

One solution to this paradox would be ignoring the paradox, focusing instead on material cost. If more than half the building were concrete, a balance might be met between savings and labor expenditures.

The Hybrid

After multiple design considerations a preliminary idea was formulated. Steel itself is expensive. Cutting costs of materials could lower the overall cost of the structure and could allow the savings to be applied to other systems. If steel was replaced with concrete, material savings could be seen. Maintaining any sense of the existing architecture limits the amount of steel that can be replaced. The cantilever, as it exists now, relies heavily on both the compressive and tensional capacities of steel. Using concrete to replace the existing trusses would be very difficult due to analytical complications and constructability issues. Essentially, the steel needs to remain as is if the cantilever aesthetic and the internal layout are to remain unaffected. Past a certain point in the building, the gravity system becomes nearly uninfluenced by the overturning moment of the cantilever. At this point, a concrete system can begin to lower the cost of material. This hybrid concept would divide the building into three sections: the two concrete gravity frames in the wings, and the cantilever superstructure.



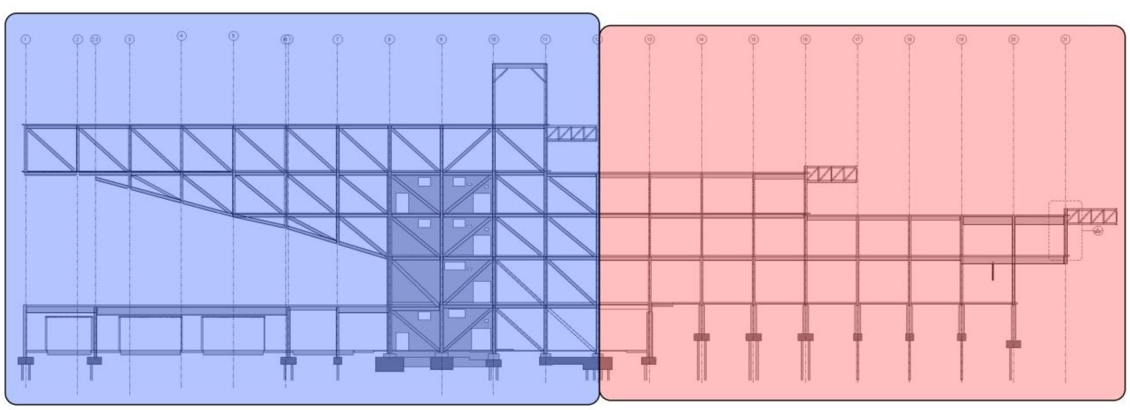


Figure 39: Division of the Steel and Concrete Systems.

As the above diagram illustrates, the existing steel wings would be replaced by a pan joist floor system as seen in red. At column lines M and 12, the gravity system and cantilever, in blue, can be divided as they are independent of each other. At this point, the transition from steel to concrete can be made.

Choosing a pan joist system for the concrete floor system in each wing would increase available MEP space in the ceiling plenum because of its shallower depth and could simplify the structural layout with a very repetitive and fairly consistent design. Inherent dampening against vibrations and lateral load resistance are other added benefits.

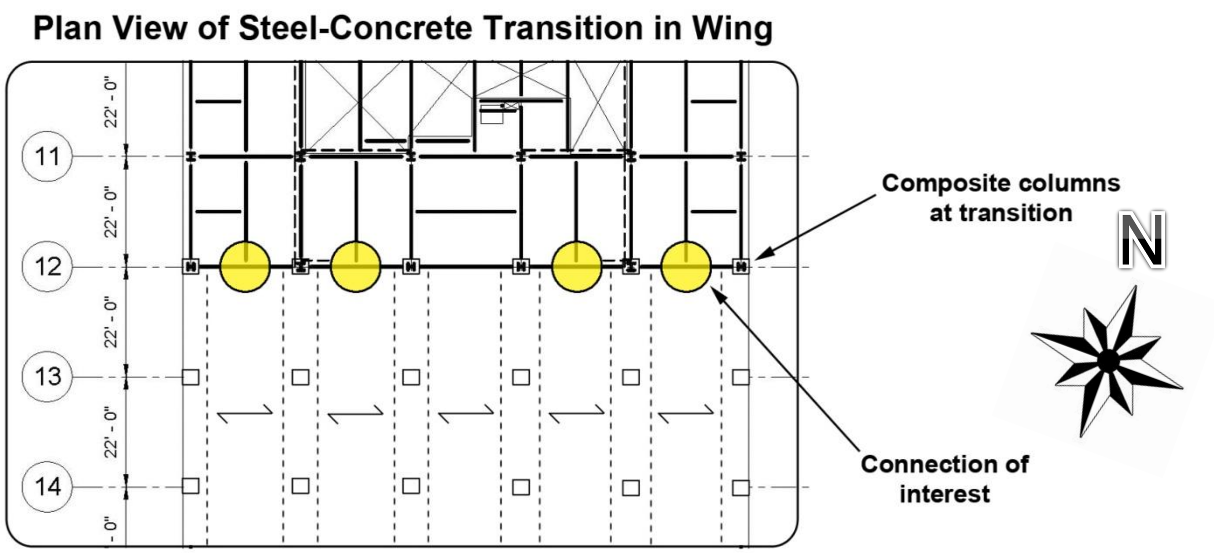


Figure 40: Transition at grid line 12

Transitioning from concrete to steel would prove difficult due to connection issues. As the two systems meet at grid line 12, beams do not line up and a typical connection does not seem to be available. A seamless conversion may be too costly and time consuming to both design and replicate in the field.

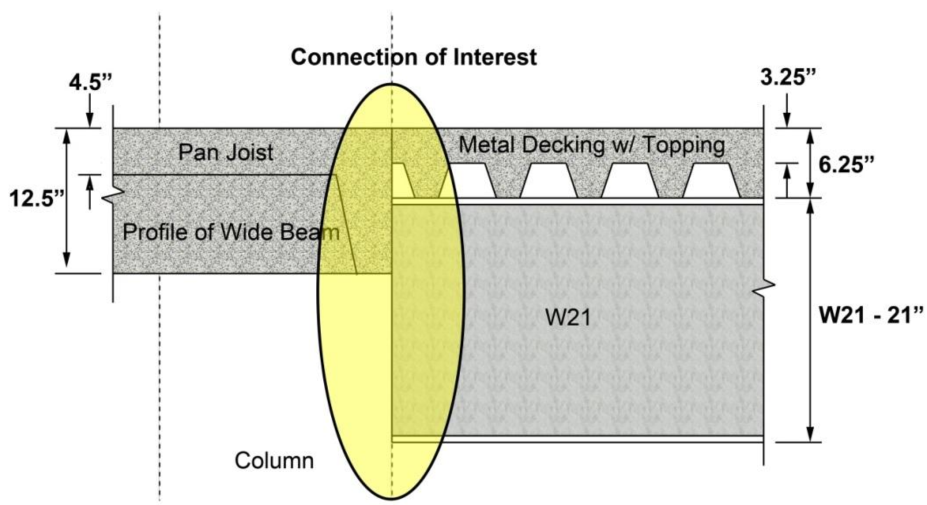


Figure 41: The problem connection

There are several issues brought on by construction. Along with the unapparent connection scheme, steel would presumably be constructed first leaving formwork to be squeezed in between joists and around steel columns. The process may take more time than can be afforded and inadvertently raise costs.

Reasoning behind such a design becomes less apparent as more critiquing is done and begs the question: do the pros of a concrete gravity system outweigh the cons? If the entire building were made from concrete, then a justification could be made in favor of concrete. However, the building being both steel and concrete, the justification fails and a hybrid proposal does not seem economical in comparison with the existing structure. Though this design idea seems to fail on more levels than succeed, it still remains an option (although an unlikely one) and encourages better solutions.

The Column Concept

Reviewing the various concrete schemes and the construction process, it becomes readily apparent that steel is the most ideal material. For its availability in central Pennsylvania, and its reoccurrence in new construction, steel wins over concrete in the battle of structural material of choice. Price still remains the problem in the Millennium Science Complex. If the floor system is as efficient and economical as possible, then the problem must lie in the cantilever. Using massive amounts of steel to support its own weight, this 150 foot cantilever is fairly self-indulgent and entirely unnecessary from a purely practical perspective. It could be said that the cantilever is a focal point of the building, but placing the focal point in the corner of two buildings is nonsensical. Most of the structural cost lies within the steel of the cantilever, and it would be very easy to cut the cost by a fair amount with a simple column or four. Raphael Vinoly's design concept was to make the building appear as if it were floating. Integrating a column at the edge of the cantilever into the theme would be a challenge, but possible and wholly justifiable.

Using a completely vertical column in this setting would not suit the overall architecture. Slanting the column slightly makes things more organic. The incline will also create tension in the chords of the truss reducing their size out of the absence of buckling. Since a naked structural column does not fit into the architecture of the rest of the building, alternate materials could be used to shape and encase it.

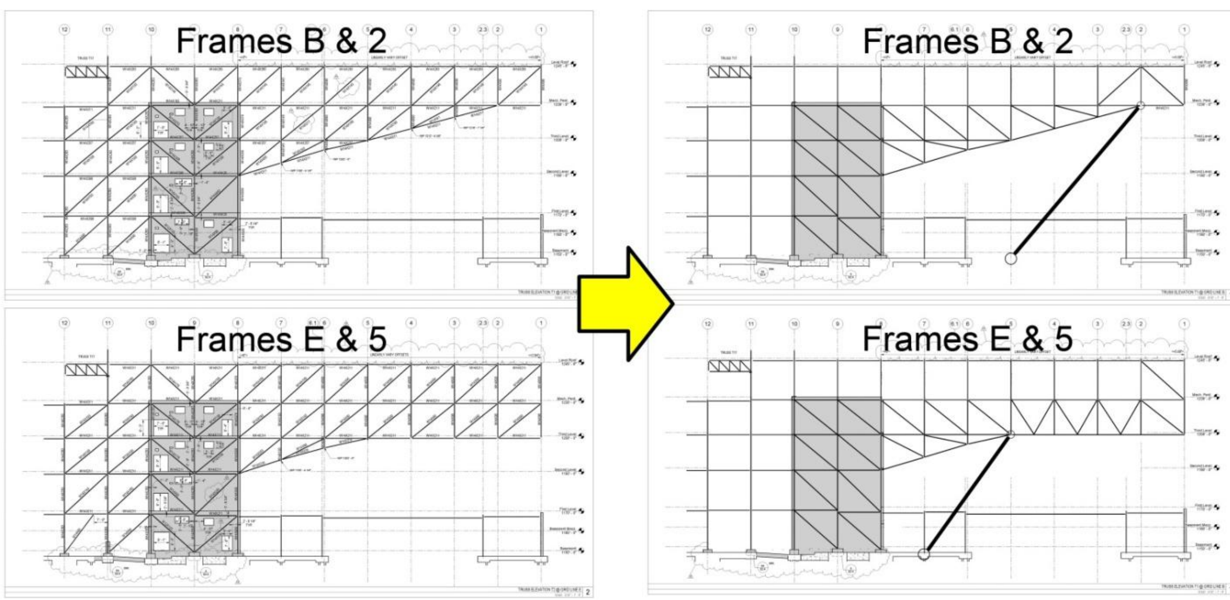


Figure 42: Columns would be placed at each truss frame, eliminating the need for many of the braces in the current configuration

The figure above delineates an initial concept to brace the cantilever directly via a column in each truss. This method would eliminate several bays of steel used to resist the overturning moment of the existing cantilever. It would also shrink the sizes of the braces as they are currently oversized due to buckling from compression forces. Introducing the columns would reverse the braces inside the trusses turning them into tension members. Since the fourth floor braces are no longer essential to the truss, the mechanical penthouse would be free of those obstacles allowing more freedom of design to the mechanical engineer. However, given such a drastic restructure of the cantilever, an entirely new analysis will be required for a complete design which will require time and resources.

Plan View of Basement

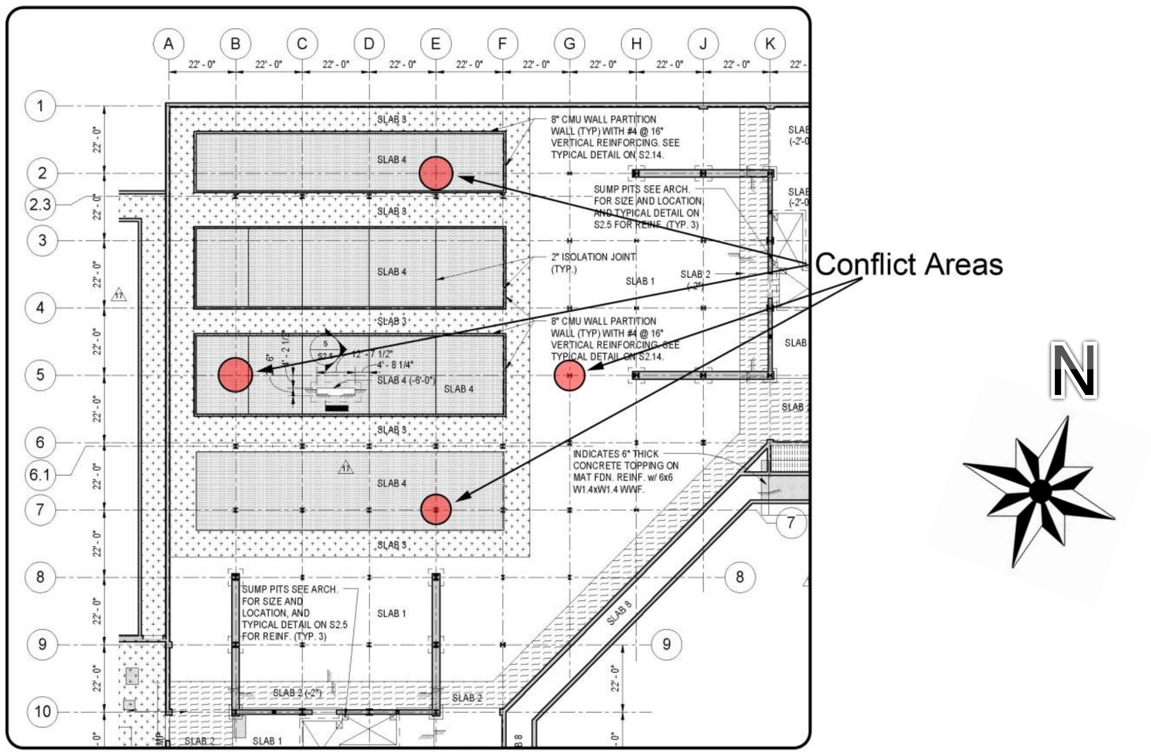


Figure 43: Locations where cantilever bracing will meet the basement floor and the pile caps: Isolation slabs, beams and existing column conflicts resolved through minor offsets

In the figure above, the red dots represent the base of the cantilever braces and areas of conflict with the existing elements. The current configuration allows 3, fairly large isolation labs to be located directly beneath the overhang. Bracing the cantilever would cause the columns to interfere with the isolation labs since they sit at the base of the columns which would essentially ruin the vibrational sensitivity. The labs would need to be moved or shrunk in size to allow room for extra pile caps and foundational additions to accommodate the immense forces which will be induced by the columns. The columns also interfere with various existing beams and columns, requiring them to be slightly offset. These alterations are fairly minor and would not cause a large increase in the structural cost. The columns themselves present the biggest issue. Due to the height they must reach as well as the angle at which they sit, the columns need to be massive. A custom shape may need to be considered for the columns as well as extra bracing to prevent buckling. The cost may spike with the construction of cantilever braces, but considering the shear amount of steel saved and the freeing up of mechanical space, the benefits could far outweigh the negatives.

MEANS OF ANALYSIS

Mechanical

Energy Model: Trane TRACE

- I. *DOAS + Chilled Beam + Radiant Floor Heating for office*
- II. *PCM Façade*
- III. *Fan Wall AHU*
- IV. *Fume Hood Redesign*

Life Cycle Cost Analysis (including material, installation, operating costs): Excel

- I. *DOAS + Chilled Beam + Radiant Floor Heating for office*
- II. *PCM Façade*
- III. *Fan Wall AHU*
- IV. *Fume Hood Redesign*
- V. *Snow Melt System*

Coordination Model: Revit MEP & Structure, Navisworks

- I. *Downsized ductwork and HVAC equipment*
- II. *Lost usable space analysis*
- III. *Material quantity*
- IV. *Fume Hood Redesign*
- V. *FanWall AHUs*

Construction Management

For the review of the redesign of the precast panels, the following will be utilized:

- I. *Revit Architecture*
  - a. *To be used for modeling of the redesigned façade.*
- II. *Industry Professionals*
  - a. *To be consulted on the maximum size panel that should be used, and if the redesign options are plausible.*
- III. *Precast Panel Manufacturer*
  - a. *To be used for panel design consultation and constructability input.*
- IV. *AE Faculty*
  - a. *To be used for structural consultants on the capabilities of LW concrete and the possibilities of our design options.*
- V. *Whiting-Turner Project Team*
  - a. *To be used for construction logistics and schedule implications of precast design changes.*
- VI. *RAM Structural*
  - a. *To be used to analyze the effect of lightening the precast panels*

Lighting/Electrical

Daylighting Shading Study: AGI32

- I. *Existing daylighting shadow study*
- II. *Phase Change Material shadow study*
- III. *Light shelf addition shadow study*

Daylight Illuminance Delivery: AGI32/Daysim

- I. *Existing illuminance from daylight*
- II. *Illuminance once phase change material is added*
- III. *Illuminance distribution with light shelves*

Energy Savings from Daylight Harvesting: Daysim

- I. *Existing energy usage for select rooms*
- II. *Energy usage with phase change addition (electric lighting only)*
- III. *Energy usage with light shelf addition*
- IV. *Energy usage with new shade orientation*

Structural

Analytical model: Existing conditions

- I. *Model existing conditions*
  - a. *SAP model for special systems*
  - b. *ETABS model for typical gravity frames*
  - c. *Merge the models*
- II. *Analyze existing conditions*
  - a. *Create load cases based on initial wind, seismic, and gravity load analysis*
  - b. *Run models*

Analytical Model: Design Concept

- I. *Model frame*
  - a. *Referencing existing conditions, and preliminary calculations, start sizing members*
  - b. *Create adjusted load cases for self-weight*
- II. *Analyze Alternate Systems model*
  - a. *Run analysis*
  - b. *Resize members as necessary*

Coordination Model: Structural Revit Model

- I. *Complete Revit Structural Model referencing Analysis Model*
- II. *Import to Navisworks for coordination with MEP*

MEASURES OF SUCCESS

Mechanical

Energy Model: Trane TRACE

I. *Annual and monthly operating costs*
II. *Maintenance costs*
III. *Envelope loads*

Life Cycle Cost Analysis (including material, installation, operating costs): Excel

I. *Initial system cost vs. Payback period*

Coordination Model: Revit MEP & Structure, Navisworks

I. *Collision-free*
II. *Efficient use of plenum space*

Labs 21 vs. LEED NC v2.2

I. *New credits attained vs. added costs*

Construction Management

Measures of Success

I. *Façade Redesign*
   a. *Is the system an improvement in schedule over the existing system?*
   b. *Are the changes to the system cost effective?*
   c. *Is the façade more energy/daylighting efficient?*
   d. *Is the new design of the architectural precast panels architectural pleasing?*
   e. *Does the façade have a lighter gravity load that can reduce structural loads?*

Lighting/Electrical

Daylighting Shading Study: AGI32

I. *Maintained or increased useful illuminance with diminished direct gains*

Daylight Illuminance Delivery: AGI32/Daysim

I. *Uniformity from alternative delivery systems within design criteria for the space*

Energy Savings from Daylight Harvesting: Daysim

I. *Lower annual energy usage for electric lighting*
II. *Reasonable payback period*

Structural

Analytical Model: Existing Conditions

I. *Replication of existing member sizes*

Analytical Model: Design Concepts

I. *Successful analysis of model returning no errors*
II. *Reasonable numbers returned from analysis*
III. *Smaller member sizes required*

Coordination Model

I. *Successful import of Revit structure*
II. *Zero conflicts with MEP System*

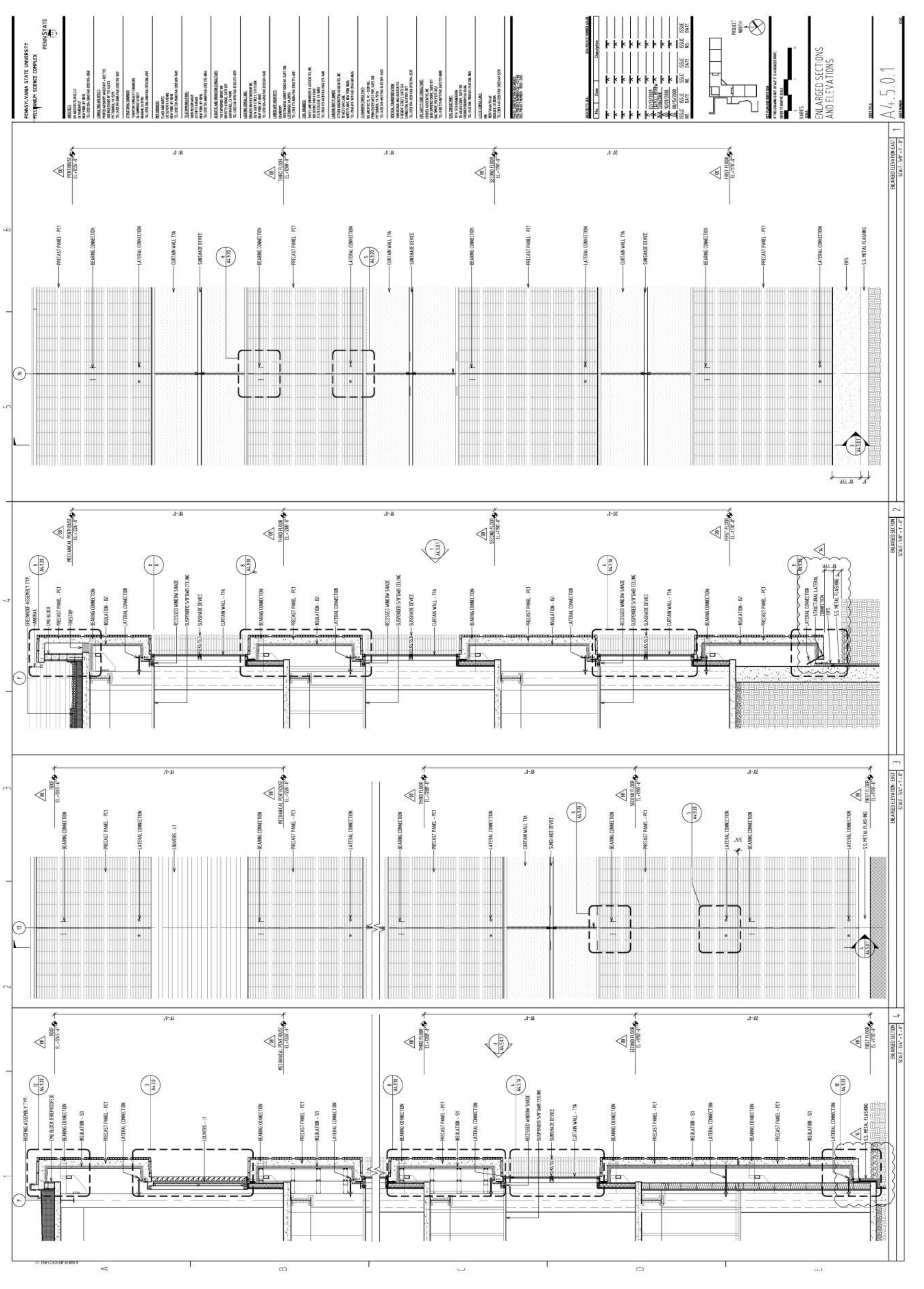
ALTERNATE SYSTEMS DESIGN REVIEW CONCLUSION

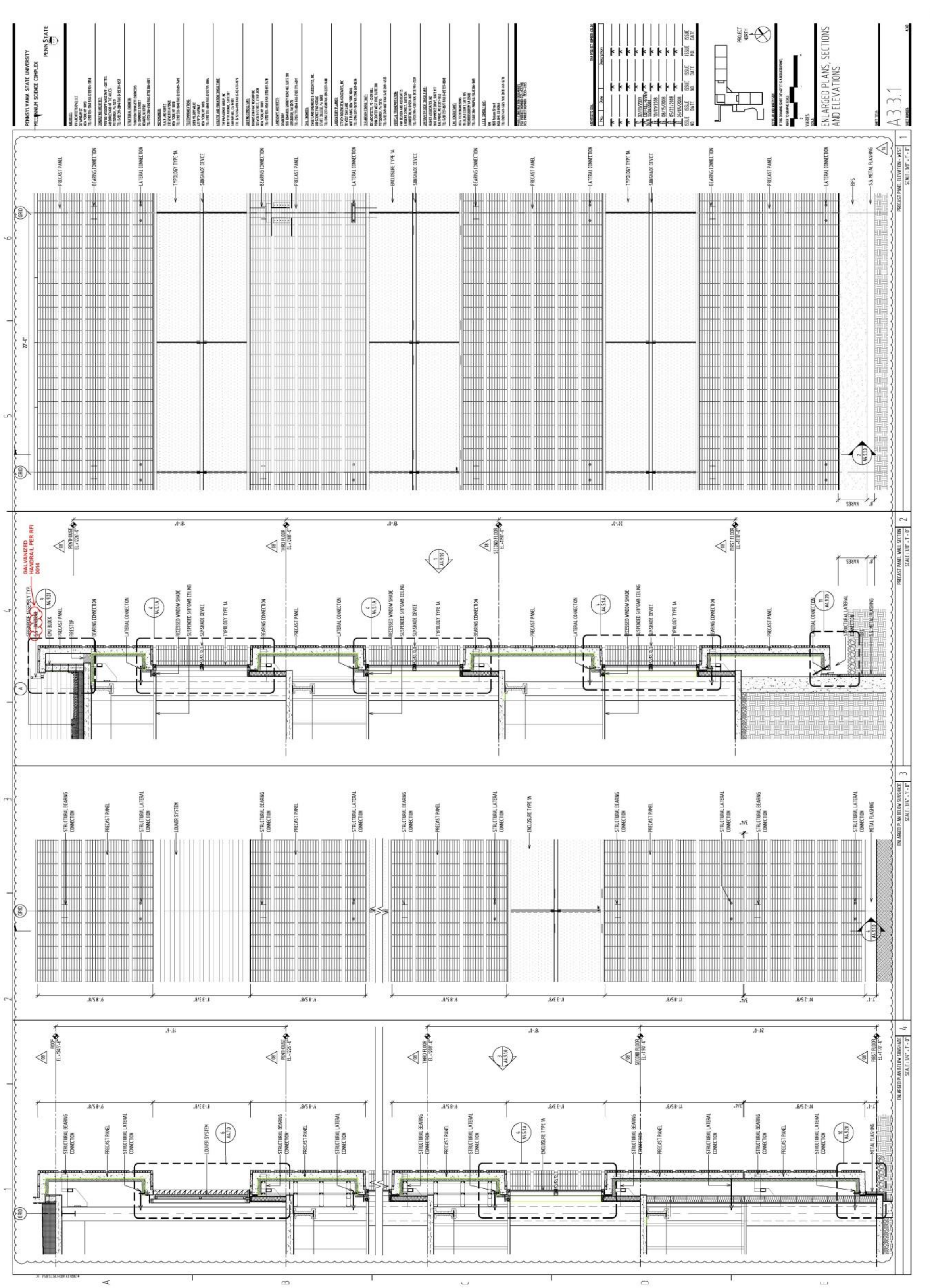
The challenge for the thesis project on Millennium Science Complex is to redesign an efficient façade, improve energy savings of the building and apply other cost saving strategies to offset initial costs of alternatives. All of these goals will be investigated and evaluated, while keeping in mind that the design of the building must be of the highest quality as The Pennsylvania State University is looking for a signature, state of the art research facility.

KGB Maser has worked together to develop different proposals in order to achieve each one of these goals. These proposals include lightening the precast panels of the façade, utilizing and developing different structural design systems, using energy efficient mechanical systems, and incorporating daylighting designs into the façade.

KGB Maser will have to work as an integrated team, with every proposal having an effect of each member of the team. Each team member will utilize BIM on the focus proposal to facilitate the sharing of information across the team. A central model will be used to coordinate different redesigns for each proposal. The objective is to incorporate and integrate each team member's efforts into a team proposal that provides the best result for the owner. It is important to lay out the process, work as an open, integrated team, to utilize BIM to facilitate each team member's analysis, and to integrate each team member's ideas together to a team proposal.

Appendix A: List of Figures and Tables




PENNSYLVANIA STATE UNIVERSITY
MILLENNIUM SCIENCE COMPLEX
ENLARGED PLANS, SECTIONS AND ELEVATIONS
A3.3.1

Appendix B: Environment Performance Criteria

Sustainable Sites		16 Points
Prereq 1	**Construction Activity Pollution Prevention**	Required
Credit 1	**Site Selection**	1
Credit 2	**Development Density & Community Connectivity**	1
Credit 3	**Brownfield Redevelopment**	1
Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	1
Credit 4.4	**Alternative Transportation**, Parking Capacity	1
Credit 5.1	**Site Development,** Protect of Restore Habitat	1
Credit 5.2	**Site Development,** Maximize Open Space	1
Credit 6.1	**Stormwater Design,** Quantity Control	1
Credit 6.2	**Stormwater Design,** Quality Control	1
Credit 7.1	**Heat Island Effect,** Non-Roof	1
Credit 7.2	**Heat Island Effect,** Roof	1
Credit 8	**Light Pollution Reduction**	1
Credit 9.1	**Safety and Risk Management, Air Effluent**	1
Credit 9.2	**Safety and Risk Management, Water Effluent**	1

Water Efficiency		7 Points
Prereq 1	**Laboratory Equipment Water Use**	Required
Credit 1.1	**Water Efficient Landscaping, Reduce by 50%**	1
Credit 1.2	**Water Efficient Landscaping, No Potable Use or No Irrigation**	1
Credit 2	**Innovative Wastewater Technologies**	1
Credit 3.1	**Water Use Reduction, 20% Reduction**	1
Credit 3.2	**Water Use Reduction, 30% Reduction**	1
Credit 4.1	**Process Water Efficiency, Document Baseline**	1
Credit 4.2	**Process Water Efficiency, 20% Reduction**	1

Energy & Atmosphere		25 Points
Prereq 1	**Fundamental Building Systems Commissioning**	Required
Prereq 2	**Minimum Energy Performance**	Required
Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
Prereq 4	**Assess Minimum Ventilation Requirements**	Required
Credit 1	**Optimize Energy Performance**	1 to 10
Credit 2	**Renewable Energy**	1 to 3
Credit 3	**Enhanced Commissioning**	1
Credit 4	**Enhanced Refrigerant Management**	1
Credit 5	**Measurement & Verification**	1
Credit 6	**Green Power**	1
Credit 7	**Energy Supply Efficiency**	1 to 5
Credit 8	**Improve Laboratory Equipment Efficiency**	1
Credit 9.1	**Right-size Laboratory Equipment Load: Measure Comparable Lab**	1
Credit 9.2	**Right-size Laboratory Equipment Load: Metering Provision**	1

Materials & Resources		14 Points
Prereq 1	**Storage & Collection of Recyclables**	Required
Prereq 2	**Hazardous Material Handling**	Required
Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1
Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1
Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
Credit 3.1	**Materials Reuse**, 5%	1
Credit 3.2	**Materials Reuse**,10%	1
Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1
Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1
Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally	1
Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regionally	1
Credit 6	**Rapidly Renewable Materials**	1
Credit 7	**Certified Wood**	1
Credit 8	**Chemical Resource Management**	1

Indoor Environmental Quality		18 Points
Prereq 1	**Minimum IAQ Performance**	Required
Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
Prereq 3	**Laboratory Ventilation**	Required
Prereq 4	**Exterior Door Notification System**	Required
Credit 1	**Outdoor Air Delivery Monitoring**	1
Credit 2	**Increased Ventilation**	1
Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
Credit 5	**Indoor Chemical & Pollutant Source Control**	1
Credit 6.1	**Controllability of Systems**, Lighting	1
Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
Credit 7.1	**Thermal Comfort**, Design	1
Credit 7.2	**Thermal Comfort**, Verification	1
Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1
Credit 9.1	**Indoor Environmental Safety, Airflow Modeling**	1
Credit 9.2	**Indoor Environmental Safety, Fumehood Commissioning**	1
Credit 9.3	**Indoor Environmental Safety, Alarm Systems**	1

Innovation & Design Process		5 Points
Credit 1.1	**Innovation in Design**: Specific Title	1
Credit 1.2	**Innovation in Design**: Specific Title	1
Credit 1.3	**Innovation in Design**: Specific Title	1
Credit 1.4	**Innovation in Design**: Specific Title	1
Credit 2	**LEED™ Accredited Professional**	1

Project Totals	85 Points
Certified TBD points **Silver** TBD points **Gold** TBD points **Platinum** TBD points	

SECTION 03451

ARCHITECTURAL PRECAST CONCRETE

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Architectural precast concrete wall panels; and enclosure panel units with embedded solid brick, half brick, sills and other precast elements, indicated.

B. Supports, anchors, reinforcements, welded wire steel fabric, ties and attachments required for reinforcement of precast concrete units.

C. Structural steel inserts, lifting hooks, anchor units, plates, dowels, etc., cast into precast concrete members required for handling and for the connections of precast members, and all loose structural steel anchor units, angles, plates, etc., required to connect precast concrete units to the structural framework of the building, and to make connections between precast concrete units.

D. Angles, plates, bearing pads, shims, bolting, welding, grouting, dry-packing, and all other materials and accessories necessary for the setting, accurate placement and connection of the precast concrete units to cast-in-place concrete, architectural structural fabrications steel and steel fabrications.

E. Brick facing embeds, inserts, anchors, housings, trim or devices supplied by other trades for the installation of Work attached to the precast concrete.

F. Intermediate and perimeter joint seals.

1.02 RELATED REQUIREMENTS

A. Section 03200 - Concrete Reinforcement.

B. Section 03300 - Cast-in-Place Concrete: Admixtures.

C. Section 04810 - Unit Masonry Assemblies

D. Section 05500 - Metal Fabrications

E. Section 07212 - Board and Batt Insulation: Integral Insulation.

F. Section 07620 - Sheet Metal Flashing and Trim: Reglets recessed in units.

G. Section 07900 - Joint Sealers: Perimeter joints with sealant and backing.

1.03 REFERENCE STANDARDS

A. ACI 301 - Specifications for Structural Concrete for Buildings; American Concrete Institute International; 2005.

B. ACI 318 - Building Code Requirements for Structural Concrete and Commentary; American Concrete Institute International; 2005.

C. ASTM A 36/A 36M - Standard Specification for Carbon Structural Steel; 2005.

D. ASTM A 153/A 153M - Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware; 2005.

E. ASTM A 185/A 185M - Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete; 2006.

F. ASTM A 307 - Standard Specification for Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength; 2004.

G. ASTM A 325 - Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength; 2006.

H. ASTM A 325M - Standard Specification for Structural Bolts, Steel, Heat Treated 830 MPa Tensile Strength (Metric); 2005.

I. ASTM A 497/A 497M - Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete; 2006.

J. ASTM A 563 - Standard Specification for Carbon and Alloy Steel Nuts; 2004a.

K. ASTM A 563M - Standard Specification for Carbon and Alloy Steel Nuts [Metric]; 2006.

L. ASTM A 615/A 615M - Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement; 2007.

M. ASTM A 775/A 775M - Standard Specification for Epoxy-Coated Steel Reinforcing Bars; 2006.

N. ASTM C 33 - Standard Specification for Concrete Aggregates; 2003.

O. ASTM C 150 - Standard Specification for Portland Cement; 2005.

P. ASTM C 260 - Standard Specification for Air-Entraining Admixtures for Concrete; 2006.

Q. ASTM C 979 - Standard Specification for Pigments for Integrally Colored Concrete; 2005.

R. ASTM D 3963/D 3963M - Standard Specification for Fabrication and Jobsite Handling of Epoxy Coated Reinforcing Steel Bars; 2001.

S. AWS D1.1/D1.1M - Structural Welding Code - Steel; American Welding Society; 2006.

T. AWS D1.4/D1.4M - Structural Welding Code - Reinforcing Steel; American Welding Society; 2005.

U. PCI MNL-117 - Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products; Precast/Prestressed Concrete Institute; 2005.

V. PCI MNL-120 - PCI Design Handbook - Precast and Prestressed Concrete; Precast/Prestressed Concrete Institute; Sixth Edition, 2004.

W. PCI MNL-122 - Architectural Precast Concrete; Precast/Prestressed Concrete Institute; 2007, Third Edition.

X. PCI MNL-123 - Design and Typical Details of Connections for Precast and Prestressed Concrete; Precast/Prestressed Concrete Institute; 1988, Second Edition.

Y. PCI MNL-135 - Tolerance Manual for Precast and Prestressed Concrete Construction; Precast/Prestressed Concrete Institute; 2000.

1.04 DESIGN REQUIREMENTS

A. Structural Performance: Provide precast architectural concrete units and connections capable of withstanding design loads within limits and under conditions indicated.
   1. The design of all precast concrete shall be the responsibility of the Contractor and shall be performed under the supervision of a Professional Engineer licensed in the Commonwealth of Pennsylvania who has experience in precast concrete design. This engineer shall be referred to as the Contractor's Engineer throughout this specification.

B. The Contractor's Engineer shall be responsible for the implementation of his design by reviewing the fabrication process to assure conformance with his design. The Contractor's Engineer at the end of construction shall issue a written statement signed and sealed with his Pennsylvania professional seal certifying to this conformance with his design. This certification is in addition to any quality assurance program for special inspection established by the Owner's inspection agency.
   1. Any field modifications to precast unit connections are not permitted unless approved in writing by Contractor's Engineer.

C. Design, fabricate and install architectural precast concrete to withstand normal loads from wind, gravity, movement of building structure, and thermally induced movement, as well as resist deterioration under conditions of normal use including exposure to weather without failure.

D. Design units to withstand design loads as calculated in accordance with state and local code, and other authorities having jurisdiction and erection forces, but in no case less than the loadings shown on the Drawings. Calculate structural properties of units in accordance with ACI 318.

E. Design units to consider the effects of gravity loads, wind loads, seismic loads, differential moisture absorption of components, thermal loads, metal framed curtainwall load, wall louvers and other effects such as building movement, shrinkage and creep. Where applicable, the effects of lateral earth and hydrostatic pressures shall be included in the design. Load combinations shall be considered. the system shall be designed to support its own dead weight in combination with all other specified pressures and loads.

F. Design units to withstand static loads and anticipated dynamic loading, including positive and negative wind loads and thermal movement loads.

G. Design and size components to withstand seismic loads and sway displacement as calculated in accordance with state and local code.

H. Design precast structural frame to work within the parameters set forth by the structural design criteria, upon which the foundation design has been based, as defined by the structural design documents and by the architectural drawings. Any proposed changes to the foundation system, and/or architectural drawings, if accepted by the Architect, Engineer and Owner, shall be implemented with the precast subcontractor and Contractor bearing all costs of such changes including the redesign costs of the Architect and Engineer.

I. Design units to accommodate construction tolerances, deflection of building structural members, and clearances of intended openings.

J. Design component connections to accommodate building movement and thermal movement. Provide adjustment to accommodate misalignment of structure without unit distortion or damage. Provide movable joints and anchor connections to accomodates the full range of manufacturing tolerance, field tolerance, thermal movement, beam sag, and foundation settlement specified herein or as indicated in the construction documents. Design joints to accommodate the greatest total combination of effects so as to prevent internal stress, deterioration or failure of weather seals or precast.

K. Provisions for Structural Movement: Accomodates structural movements of the type and magnitude described below:
1. Vertical interstory live load deflection at midspan of perimeter spandrel beams: 3/8 inch
2. Horizontal interstory differential movement (a.k.a. "drift") due to:
   a. Wind H/360 where H=floor to floor height
   b. Earthquake H/130 where H-floor to floor height
3. Vertical superimposed dead load deflection at reentrant and cantilevered corners and above transferred columns: 3/8 inch
4. Vertical live load deflection at reentrant and cantilevered corners and above transferred columns: 3/8 inch.
5. Design, fabricate and install the exterior wall to accommodate column shortening (due to loading). Anticipated column shortening in this installation will not exceed 0.10 inch per floor.

L. Wind Loads: Precast units shall consist of materials, accessories and installation that complies with the state and local building code and other governing regulations having jurisdiction for wind loading at the Project location, minimum MPH wind load shall be no less that specified code and to match the most stringent requirements either specified in this section or per code. Requirements shall be reviewed by the Manufacturer and the Owner.
1. Deflection of precast elements normal to the plane of the wall under full design wind pressure shall be limited to L/240 or 3/4 inch, whichever is less.

2. Deflection of cantilevered elements at full design wind pressure at full design wind pressure (e.g. parapets) shall not exceed 1% of the cantilever length or 3/4 inch, whichever is less.
3. The entire precast panel system shall be designed to withstand 1.5 times the full design positive and negative wind pressure without component failure or damage other than a maximum permanent deformation in panel members.
4. Deflection of any member under 1.5 times design wind load shall not result in any sealant failure.
5. Supplemental precast anchors (to prevent progressive failure of the precast) shall be provided at no less than every fifth floor
6. At corners and other changes in plane, both surfaces shall be assumed to experience the most severe combinations of negative and positive pressures simultaneously.

M. Design, detail and fabricate connections of architectural precast units to the building's structural frame so that allowance is made for not only fabrication and erection tolerances, but also structural deflections from loads and other causes.

N. Prevent galvanic and other forms of corrosion by insulating metals and other materials from direct contact with non-compatible materials. Provide minimum coverage per requirements to prevent corrosion of reinforcement steel, but not less that 1-1/2 inches.

O. Base the thermal component of joint movement on a minimum material temperature increase of 100 degrees F and decrease of 100 degrees F relative to time of installation. Design for these assumed temperature changes regardless of surface areas exposed to exterior and interior. Assume the entire cross section has uniform temperature. For thermal design other that joint movement, the design winter surface temperature shall be -10 degrees F. The design summer surface temperature shall be at least 160 degrees F. System components shall b e capable of withstanding without failure, design winter temperature to design summer temperature with simultaneous specified loads.

P. Freeze-Thaw Resistance: Panels shall show resistance to a minimum of 300 cycles of freezing and thawing, based upon testing of one test sample panels (3'-0" long x 3'-0" high), in accordance with ASTM C666, without an effects that will affect the stability of the panel or the brick veneer.

Q. All exposed structural anchor system shall be factory primed and painted properly to prevent corrosion.
1. Any damage to the paint shall be repaired immediately in accordance to the requirements as slated in Section 09900.

R. Fabrication of Panels shall include keys or methods to prevent concrete and brick from cracking and/or delaminating. Fabricate panels without sharp edges.

S. For curing and bonding purpose, use low-initial absorption brick type, less than 15%, and low shrinkage concrete. The initial brick absorption must be higher than 5% to bond to concrete.

T. Design modifications may be made only when it has been approved. Maintain general design concept shown without increasing or decreasing sizes of members or altering profiles and alignment shown.

1.05 SUBMITTALS

A. General Conditions of Contract

B. See Section 01300 - Administrative Requirements, for submittal procedures.

C. Section 01330 - Submittals

D. Product Data: Manufacturer's information on accessory products, including pigments, admixtures, inserts, plates, etc. Submit fabricator's specifications, data and instructions for manufactured materials and products. Include mix designs, certifications and laboratory test reports as required.
   1. Include water absorption test report for units with exterior exposure..

E. Shop Drawings: Indicate layout, unit locations, configuration, unit identification marks, reinforcement, connection details, support items, location of lifting devices, dimensions, openings, and relationship to adjacent materials. Provide erection drawings.
   1. Include details of mix designs.
   2. Include structural design calculations, for information purposes only, bearing the seal of a structural engineer qualified in the design of the architectural precast concrete assemblies and licensed in the Commonwealth of Pennsylvania.
      a. Indicate the section moduli of wind-load-bearing members
      b. Include calculations of stresses and deflections for performance under design loading.
   3. Include erection procedure for precast units, sequence of erection, and erection tolerances.
   4. Show layout, concrete strengths and finishes, face brick layout, dimensions and identification of each precast unit corresponding to sequence and procedure of installation.
   5. Indicate welded connections by AWS standard symbols. Detail inserts, connections, and joints, including accessories and construction at openings in precast units.
   6. Show caulked joints, including expansion joints ("soft type").
   7. Show reinforcing details, including grade, type and reinforcing bars, bending and placement and welded wire fabric. Show prestressing tendons. Include all special reinforcement required and openings through concrete structures.
   8. Indicate protective finishes and ASTM identification for metal items including connectors.
   9. Show joints, bearings, connection devices, length and types of welds, all related embedded items and grouting and dry-packing. Show temporary loading on building structure. Show reaction loads from the precast on the building. Show reaction loads from the precast on the building.
   10. Show jointing clearances and clearances between the units
   11. Show full size typical details of joints between the units, showing methods of sealant and insulation, coordinated with the sealant subcontractor.
   12. Show typical details of indicated reveals, face brick insets, and related decorative items and their relationship to precast units, provide elevation of scoring/jointing of each panel type and each pattern indicated.
   13. Show full size typical details of adjacent items and their relationship to precast units.
   14. Indicate locations and details of brick joints and joint treatment.
   15. Indicate all special precautions to be taken by other trades affecting the work of the Section.
   16. In addition to the above requirements, show the following:
      a. Dimensions, size and location of openings.
      b. Quantities, location of stressing force of prestressing tendons
      c. Anticipated cambers at time of erection
      d. Strength of concrete at prestressing and at erection.
      e. Elongation for prestressing and at erection.
      f. Show calculation of forces to be carried by floor or roof diaphragm after installation of concrete topping by others.
   17. Prepare shop drawings to meet or exceed "Manual of Standard Practice for Detailing Reinforced Concrete Structures" (ACI-315), except where in conflict with local building regulations. Scale of details: Adequate as determined by the Architect to fully and clearly illustrate work.
   18. Submit complete design calculations for all precast members and connections. Indicate all design loads, including live loads, wind loads, and dead loads and including all stresses during shipment and erection and due to loads from construction

procedures. Design calculations shall have the seal of the Precast Concrete Contractor's Professional Engineer, licensed to practice in the Commonwealth of Pennsylvania. Shop drawings and calculations shall be submitted and approved prior to start of fabrication. Design calculations shall be based upon requirements of "Design Requirements" specified herein. Each change of component configuration and design shall have its own set of calculations.

19. Shop drawings shall explicitly show tolerances on major dimensions, i.e. length, width, thickness and diagonals of each typical unit. A note summarizing the other above mentioned tolerances shall also appear.

F. Control Samples: Submit sets of samples of each type of precast concrete unit. Sets shall consist of three 12" x 12" panels, for each different mix, color and finish directed by the Architect. Control samples shall depict the proposed range of quality, mix design, color and texture/finish. Color, texture and finish to match Architect's approved samples. Submit samples of anchorages and accessories as requested by Architect.

G. Samples:
1. Prior to preparing sample/mock-up panels, review the accepted Control Samples that have been approved by the Architect. The basis of all samples shall be the formula and finishes of the Control Samples. Items not matching the Control Samples will be rejected.
2. Submit two (2) large scale sample/mock-up panels' measuring 8'-0" long by size, shape, arrangement and configurations indicated on the Drawings (Profile "A"). Sample/Mock-up panels shall be of each different accepted Control Sample; and erected on-site. Samples shall show the full range of proposed finishes for each item; and identically match the approved Control Samples. Show quality, color, and texture of surface finish proposed for all exposed precast concrete work with the brick inset, using the proposed concrete mix and cast against the same form material to be actually used in the construction, finish as specified. Full scale samples/mock-ups must be accepted by Architect prior to preparing full size production (benchmark) mock-ups or starting fabrication.
3. Samples for each full and half-brick unit required, including special shapes, dimensions, and to demonstrate the following:
   a. Flashed color variation: to match Architect's samples
   b. Embossing: to match Architect's samples
   c. Pattern: to match Architect's samples
   d. Basic color: to match Architect's samples
   e. Edge Conditions: to match Architect' samples
   f. Texture: to match Architect's samples
4. Repair Approval: Submit approved 12 inch by 12 inch sample panels of each type and finish, damage panels with documentation of type and damage provided, provide repairs to damaged panels for approval.
5. After approval of sample/mock-up and prior to production fabrication of precast concrete units, provide one full size production mock-up of size, shape and configuration shown; at fabricator's plant for Architect's review. Notify Architect when full-size sample/mock-ups are ready for inspection. Do not start production fabrication of precast concrete units until the full-size sample/production mock-up has received Architect's written acceptance. Form materials are subject to rejection if forms used do not product finish specified; or does not match the approved Control Samples. Approved sample/production mock-up may be incorporated in the work, provided it is still in acceptable condition.
6. Approval of samples will be for color, texture, appearance and general conditions only. Compliance with all other requirements of the Contract Documents is the exclusive responsibility of the Contractor.

H. Names of Manufacturer and/or Supplier: Submit the manufacturer's and/or supplier's name for the following items with the first submittal:
1. Cement, each type
2. Aggregate, each type
3. Reinforcing bars and prestressing tendons

4. Welded steel wire fabric
5. Concrete
6. Face Brick
7. Mortar
8. Welding Electrodes
9. Studs
10. Inserts, anchors, cast-in trim
11. Masticord pads
12. Sealants

I. Casting Formula: Submit the manufacturer's/fabricator's detailed casting formula, including all ingredients, additives, components, colors, and the percentages and volumes of each material required for each different approved casting composition, texture and color.

J. LEED Documentation:
   1. Indicate whether each product contains post-consumer or post-industrial recycled materials, or both.
   2. Indicate location of manufacture, highlighting those materials manufactured within a 500-mile radius. For those materials manufactured within a 500-mile radius, indicate location of extraction, harvest or recovery.

K. Record Documents for LEED:
   1. Show use on LEED Calculator Spreadsheet as prescribed in the LEED Program Requirements.
   2. Show Contractor's official stamp indicating specific products used in the Work.

L. Certificates: Submit the following:
   1. Mill certificates for all cement, identifying by lot material, of each grind and shipment.
   2. Mill certificates for all reinforcing bars and welded steel wire fabric.
   3. Mill certificates for all structural steel plates, shapes and members.
   4. Notarized certificates of compliance of anchors, bolts, sheer studs, welding electrodes, concrete inserts, masticord pads, shop paint, field paint and non-shrink grout.
   5. Certification of welders for welding reinforcement, shop and field connections in accordance with AWS qualification tests and any required recertification.
   6. Certification that precast concrete panels, required to have fire resistive rating where so indicated on drawings, are equivalent to UL listed or PCI "rational design" fire-rated precast concrete panels.

M. Contractor's Independent or PCI Certified In-House Testing Laboratory: Submit the following:
   1. Name of Contractor's Independent Testing Laboratory, proposed by Contractor, for making concrete ingredients tests and design mixes, or PCI certification of Subcontractors in-house testing laboratory.
   2. Contractor's Independent Testing Laboratory or PCI certified in-house laboratory report of concrete ingredients test and concrete design mixes, with all back-up data, test, curves,etc.

N. Fabricator qualifications.

O. Maintenance Data: Indicate surface cleaning instructions.

1.06 QUALITY ASSURANCE

A. Perform the work of this section in accordance with PCI MNL-117, PCI MNL-120, PCI MNL-122, PCI MNL-123, PCI MNL-135, and ACI 318. Perform welding in accordance with AWS D1.1., D1.4.

B. Fabricator Qualifications:
   1. Firm having at least 5 years of documented experience in production of precast concrete of the type required.
   2. Plant certified under Architectural Precast Association Plant Certification Program for production of architectural precast concrete.

C. Design Engineer Qualifications: Design precast concrete units under direct supervision of a Professional Structural Engineer experienced in design of precast concrete and licensed in the State in which the Project is located.

D. Installer Qualifications: A firm which has specialized in installation of the design and extent of that indicated for this project for not less that 5 years, and which is acceptable to the precast concrete fabricator.

E. The Fabricator shall provide a full-time supervisor to advise the Contractor throughout the delivery and erection process. The above supervisor shall report to the Contractor and the Owner's Representative any problems that might adversely affect the final installation.

F. Brick Fabricator Qualifications: Firms which have a minimum of 5 years successful experience in the fabrication of brick units, similar units required for this project, will be acceptable. Fabricator must have sufficient production capacity to produce, transport, and deliver required units without causing delay in the work.

G. Welder Qualifications: all field welding shall be performed by AWS certified welders only.

H. Testing Agency Qualifications: An independent testing agency qualified according to ASTM E 329 to conduct the testing indicated, as documented according to ASTM E548.

I. Single Source Responsibility for Precast Concrete: Obtain precast concrete units with brick inset panel and mortar ingredients through one source from a single manufacturer.

J. Field Constructed Mock-up: Prior to installation of precast concrete units. Erect sample panels for each of the following units to represent completed installation.
   1. Build mock-up to include all related materials, including anchors and adjacent materials as required to indicate a complete installation.
   2. Mock-up shall be approved by the Architect prior to the commencement of the work.

1.07 MOCK-UP

A. General: Prior to the start of the work, provide full size mock-ups of each type, shape and finish of specified assemblies at fabricator's plant for review. The full size mock up shall include all accessories and hardware with specified finishes to be used in the finished work. Provide mock-ups of scope and locations indicated by the Architect. Obtain Architect's written approval of mock-up's material quality and workmanship before start of work. Retain accepted mock-up's as a standard for judging Work of this Section.
   1. Approved full-size sample may be incorporated into the Work, provided it is still in acceptable condition.

1.08 PRE-FABRICATION CONFERENCE

A. At least one month prior to commencement of fabrication work, the precast contractor shall schedule with the Architect, a pre-fabrication meeting at the fabrication plant. The Contractor shall require responsible representatives of every party who is concerned with fabrication of the precast work to attend the conference, including but not limited to the following: precast installer and installers of associated work, Architect, Owner, and manufacturer's representatives, to discuss mock-ups, fabrication, schedules. procedures, and related work.

1.09 PRE-INSTALLATION CONFERENCE

A. At least one month prior to commencement of the work, the precast contractor shall schedule with the Architect, a pre-installation meeting at the project site. The Contractor shall require responsible representatives of every party who is concerned with the precast work to attend the conference, including but not limited to the following: precast installer and installers of associated work, Architect, Owner, and manufacturer's representatives, to discuss mock-ups, fabrication, schedules. procedures, and related work.

1.10 DELIVERY, STORAGE, AND HANDLING

A. Handling: Lift and support precast units only from support points. Lift with wide belt slings; do not use wire rope or ropes that might cause staining. Move precast concrete units, if required, using dollies with wood supports.

B. Blocking and Lateral Support During Transport and Storage: Use materials that are clean, non-staining, and non-harmful to exposed surfaces. Provide temporary lateral support to prevent bowing and warping.

C. Protect units to prevent staining, chipping, or spalling of concrete.

D. Mark units with date of production in location that will be concealed after installation.

E. Store precast concrete units on wood skids or pallets with non-staining, waterproof covers. Arrange to distribute weight evenly and to prevent damage to units. Ventilate under covers to prevent condensation.

F. The Owner reserves the right to inspect delivered units. Owner's inspection does not alleviate the Contractor from responsibility for patent and latent damages and compliance with the Contract Documents.
   1. Panels that are found to be damaged by the Owner's inspector shall be repaired in accordance with the specified requirements, and if repairs can not be made, damaged panels shall be removed from project site and replaced without delay.

1.11 TESTS & INSPECTIONS

A. Proportioning and Test for Proportioning: Tests for concrete mix designs shall be by Independent Testing Laboratory or PCI certified in-house laboratory engaged and paid for by the Contractor and approved by the Owner.

B. Plant and Field Test and Inspection (by Owner's Testing Laboratory)
   1. Testing Laboratory: Plant and field tests and inspection will be conducted by Owner's Testing Laboratory and/or field inspector engaged and paid for by the Owner, and under separate contract with the Owner.
   2. Cooperation: The Contractor shall cooperate with the Owner's Testing Laboratory regarding all arrangements for plant and field tests and inspections to be made by the Owner's Testing Laboratory. The Contractor shall notify the Owner, the Architect, and the Owner's Testing Laboratory in writing, one week in advance of fabrication of precast concrete units and one week in advance of installation of precast concrete units.
   3. Plant Tests and Inspections by Owner's Testing Laboratory may include, but not be limited to:
      a. Sample and test actual concrete ingredients.
      b. Review and check Contractor's proposed design mixes
      c. Inspection of plant and equipment for measuring, mixing, and delivering concrete
      d. Inspection of batching and mixing operations
      e. Checking delivery tickets of plant mixed concrete.
      f. Inspection of concrete mix. Checking cement analyses and aggregate analyses.
      g. Inspection of formwork
      h. Inspection of reinforcement and embedded items. Checking mill test reports for steel.
      i. Inspection of welding of steel reinforcement, dowels and inserts.
      j. Checking amount of water added to the concrete mix.
      k. Making samples and tests for air-content in concrete.
      l. Making slump tests.
      m. Making cylinders for laboratory testing of compressive strength.
      n. Taking temperatures of as-mixed concrete, of as-deposited concrete and of concrete during curing period.
      o. Taking air temperatures during placing and curing of concrete.
      p. Checking concrete pouring and curing procedures.
      q. Checking size of completed units
      r. with finish requirements

s. Compliance with fabrication tolerances
4. Delivery Inspections by Owner's Testing Laboratory:
a. Inspection of all delivered panel units for damage during transport prior to removal from shipping trailers
5. Field Tests and Inspections by Owner's Testing Laboratory: May include, but are not limited to:
a. Contractor shall cooperate with Owner's Testing Laboratory/inspection service, including providing access to scaffolds where necessary.
b. Erection methods
c. Connections in accordance with approved shop drawings
d. Welding of connections
e. Compliance with erection tolerance
f. Compliance of all members with sizes, types and finishes
g. Checking of leveling and grouting
h. Inspection of bearing pads
i. Field tests for concrete strength, if required
j. Checking the cleaning of joint edges prior to erection of units and width of joints between erected units.

1.12 REJECTIONS

A. Defective Work:
1. Precast units which do not conform to the specified requirements, including dimensional tolerances, strength, color and finishes, shall be replaced with precast concrete units that meet the requirements of this Section. The Contractor shall also be responsible for the cost of corrections to any other work affected by or resulting from corrections to the precast concrete work.
2. Defective precast concrete units and materials may be rejected at any time during the construction, whether in place or not. Promptly remove and replace rejected precast concrete units and materials at no additional cost to the Owner.

B. Dimensional Tolerances:
1. Units having any dimension smaller or greater than permitted tolerance, and outside the tolerance limits specified herein, will be considered deficient and shall be rejected if the appearance or function of the unit is adversely affected, or if the larger dimensions interfere with other construction. repair, remove and replace rejected units as required to meet the construction conditions.

C. Strength Deficiencies:
1. When there is evidence that the strength of a precast concrete unit does not meet specification requirements, the Owner's Testing Laboratory, upon direction from the Owner, shall take cores drilled from hardened concrete or perform non-destructive strength tests to determine compressive strength.
2. Determination of compressive strength by drilled cores, shall comply with ASTM C42 and as follows:
a. Take at least three (3) representative cores from precast units of suspect strength, from locations directed by Owner.
b. Test cores in a saturated-surface-dry condition per ACI 318 if the concrete will be wet during the use of the completed structure.
c. Test cores in an air-dry condition per ACI 318 if the concrete will be dry at all times during the use of the completed structure.
d. Strength of concrete for each series of cores will be considered satisfactory if their average compressive strength is at least 85% of the 28-day design compressive strength.
e. Test results will be made in writing on the same day that the tests are made, with copies to the Owner, the Architect and the Contractor. Include in test reports the project identification name and number, date, name of precast concrete manufacturer, name of concrete testing service, identification number, number, and type of member or members represented by core tests, nominal maximum size aggregate, design compressive strength, compression breaking strength, and type of break (corrected for length-diameter ratio), direction of applied load to core

with respect to horizontal plane of concrete as placed, and moistened condition of core at time of testing.

3. Patching: Where core test results are satisfactory and precast units are acceptable for use in the work, fill core holes solid with patching mortar, and finish to match adjacent concrete surfaces.
4. When core test results are satisfactory, the cost of the test and cost of the patching the core holes, calculated on a time and material basis, shall be borne by the Owner.

D. Finishes: Precast concrete units, whose finish in the opinion of the Architect or Owner, has any of the following finish defects visible from a viewing distance of ten (10) feet will be considered defective and will be rejected. Repair, if permitted by the Owner, or remove and replace rejected units as required to meet the requirements of this Section.
1. Does not match previously approved samples as to uniformity of color or texture.
2. Has chipped, ragged, irregular or broken corners or edges
3. Joints, false joints, drips or notches are not properly located or aligned.
4. Air pits and voids evident on the exposed surfaces
5. Adjacent flat and return surfaces with a difference in exposure in excess of the approved mock-up
6. Has damaged surfaces, or other surface defects beyond permitted brick standards.
7. Casting lines evident from different placements
8. Visible form joints or irregular surfaces
9. Rust staining on exterior panel surfaces
10. Blocking or acid stains evident on panel surfaces more that thirty (30) days after observation.
11. Foreign material embedded in the facing mix
12. Cracks visible after wetting
13. Visible repairs
14. Reinforcement shadow lines.

PART 2 PRODUCTS

2.01 MATERIALS

A. Products with recycled content are preferred, as defined in LEED Version 2.0 Reference Guide dated June 2000.

B. Select products that are manufactured/assembled within a 500-mile radius of the project site.

2.02 MANUFACTURERS

A. Architectural Precast Concrete:
1. Available fabricators: Subject to compliance with requirements, fabricators offering products that may be incorporated into the Work include, but are not limited to, one of the following or an approved equal:
2. Artex Systems.
3. Benton Prefabriques Du Lac.
4. Global Precast.
5. High Concrete Structures
6. Saranac
7. Arban & Carosi
8. Shockey

B. Substitutions: See Section 01600 - Product Requirements.

2.03 REINFORCEMENT

A. Reinforcing Steel: ASTM A 615/A 615M Grade 60 (420), or A706 Grade 60
1. Epoxy coated in accordance with ASTM A 775/A 775M.

B. Steel Welded Wire Reinforcement: ASTM A 185/A 185M, plain type.
1. Flat Sheets.
2. Where indicated, or as recommended by the manufacturer, provide flat sheet-type deformed-steel welded wire fabric reinforcing complying with ASTM A 497.

C. Weldable Deformed Steel: ASTM A706

D. Supports for Reinforcement: Provide supports for reinforcement including bolsters, chairs, spacers and other devices for spacing, supporting and fastening reinforcing.
   1. Where legs of supports are in contact with forms, provide supports with legs which are plastic protected (CRSI, Class 1), or stainless steel protected (CRSI, Class 2)

2.04 CONCRETE MATERIALS

A. Cement: ASTM C 150, Type I - Normal portland type. Use one brand, type and source of cement throughout the project. Standard "grey" Portland cement may be used for non-exposed back-up concrete.

B. Coarse Aggregates for Facing Mixes: ASTM C 33; clean, hard, durable, carefully selected and graded crushed stone or gravel; free of material causing staining or reacting with cement. Match sample.

C. Fine Aggregate for Facing Mixes: ASTM C33; sand of same material as coarse aggregate, unless otherwise acceptable to Architect.

D. Surface Finish Aggregate: Conforming to sample in office of Architect.

E. Color Additives: Pure, concentrated mineral pigments specifically intended for mixing into concrete and complying with ASTM C 979.
   1. Color(s): To match Architect's sample(s) when incorporated into specified mix design(s).
   2. Pigments: Non-fading, resistant to lime and other alkalies.

F. Water: Clean and not detrimental to concrete.

G. Air Entrainment Admixture: ASTM C 260.

H. Water-Reducing Retarding, Accelerating Admixtures: ASTM C494, Type as selected by fabricator and containing not more that 0.1% chloride ions.

I. Curing Compound:
   1. The compound shall be in accordance with ACI 533 and compatible with "Hydrozo Enviroseal 40" sealing compound or approved equal. some of the compatible curing compounds are "Sonosil" by Sonoborn or "Ucosil" by the Euclid Chemical Company or approved equal.
   2. All cast-in-place concrete, e.g. for "wash" must be cured by a wet cure using continuous fog spray or immersion in water. Do not use curing compounds on surfaces to be wet cured.
   3. Sealing Compound: the compound shall be "Hydrozo Enviroseal 40" sealing compound or approved equivelent, and shall be applied in accordance with the manufacturer's requirements.

J. Acid-Wash Finish: Exposed precast concrete shall have an acid-wash finish at the joints and reveals.

2.05 FORMWORK

A. Where forms and, where required, form facing materials of metal. plastic, wood, concrete, or other materials accepted, that is non-reactive with concrete and will produce required finish surfaces.

B. Accurately construct forms, mortar-tight, and of sufficient strength to withstand pressures due to concrete placing operations, temperature changes and, when prestressed, pretensioning and detensioning operations. Maintain formwork to provide completed precast concrete units of shapes, lines and dimensions indicated, within specified fabrication tolerance.
   1. Provide custom formwork units of curved shapes, lines and dimensions indicated. form curves of continuous profiles, faceting will not be acceptable.

C. Unless forms for plant-manufactured prestressed units are stripped prior to detensioning, design forms so that stresses are not induced in precast units due to deformation of material under prestress or to movement during detensioning.

D. Material: Glass fiber reinforced polyester or silicone.

2.06 BRICK UNITS AND ACCESSORIES

A. **Solid Full &** Half-Brick Units: ASTM C216, Grade SW, Type FBX, 2 inches thick or less, exclusive of full brick for "reveal" and as follows:
   1. Face Size: Norman: 2-1/4" high by 11-5/8" long, sized specifically for casting into concrete.
      a. size and fabrication tolerances of brick units shall be held tighter that those allowed by the referenced standard and shall conform to dimensional requirements for brick units as specified, and for the overall precast assembly. Panels with dimensions, mortar joints, and other aggregate measures affected by brick unit fabrication irregularities and deviations form specified sizes will not be acceptable. **Only brick with a length of 11-17/32" to 11-23/32" are acceptable.**
      b. Calibrate bricks for standard stack bond.
   2. Unit Compressive Strength: Provide units with a minimum average net-area compressive strength of 3000 psi, unless otherwise indicated.
   3. Special Shapes: Include formed corners, edge corners, end edge corners and sizes to conform to precast concrete panel dimensions.
   4. Initial rate of Absorption: Less that 30g/30 sq. in. (30g/194sq. cm.) per minute when tested per ASTM C67
   5. brick that has been tested according to ASTM C67 and is rated "not "
   6. Color and texture:
      a. Harding Blend Brick, to match Architect's sample.
      b. Flashed color variations: to match Architect's samples
      c. Embossing: Patterns and types to match Architect's samples.
   7. Brick Surface Texture: To match Architect's sample
   8. Referenced standard is to be used as the basis of quality with all criteria included except thickness is as specified in this section and as shown on the Drawings.
   9. Bond patterns: Stack-bond pattern, unless otherwise indicated.
   10. Products: Subject to compliance with requirements, provide the following:
      a. Harding Blend Norman Brick, as manufactured by GlenGery, to match Architect's sample.
   11. **Waxing of Brick Surface: Waxing of the brick surface or use of a retarder shall be necessary to prevent the staining of the brick.**

B. Setting Mortar: Portland Cement, ASTM C150, Type I, and clean, natural sand, ASTM C144. Mix at ratio of 1 part cement to 4 parts sand, by volume, with minimum water required for placement.

2.07 SUPPORT DEVICES

A. Connecting and Support Devices: ASTM A 36/A 36M steel; hot-dip galvanized in accordance with ASTM A153/A 153M.

B. Steel Plates: Structural Quality, hot-rolled carbon steel, ASTM A283, Grade C

C. Steel Shapes: ASTM A36

D. Bolts, Nuts, and Washers: ASTM 307 heavy hex bolts, Type A, hot-dip galvanized, with matching ASTM A 563 (A 563M) nuts and matching washers.

E. Electrodes for Welding: Comply with AWS Code

F. Finish of Steel Units: hot dipped galvanized after fabrication, ASTM A153

G. Head Shear Connectors: As manufactured by Nelson Stud Welding, KSM Products , or approved equal.

H. Elastomeric Shim Pads: Mastercord or AASHTO grade neoprene pads, molded to size or cut from a molded sheet. 90 Shore A Durometer for pads supporting panels on elastomeric flashing. Size as to bearing capacity of flashing material. Submit size and material for approval.

I. Shims: hot dipped galvanized steel (2 oz. coating) plastic, "Korolath" or approved equal.

J. Flashing Reglet: 28 gage (0.014") stainless steel, Type 302/304; type profile and conditions as shown on drawings.

K. Slide Bearing Plates: Bearing pads, not subject to movement beyond that of flexure of the member shall be AASHTO grade 100% chloroprene (neoprene) Mastercord, or approved equal, meeting the requirements of AASHTO standard specifications for Highway bridges.

L. All slotted inserts, plates, threaded insert bolts and nuts shall be stainless steel unless otherwise indicated.

M. Primer: Zinc rich type.

2.08 INSULATION

A. Integral Insulation: Rigid glass fiber reinforced polyisocyanurite insulation, specified in Section 07212.

2.09 MIX

A. Prepare design mixes for each type of concrete required.

B. Design mixes may be prepared by independent testing facility or by qualified precast manufacturing personnel, at precast manufacturer's option.
1. Design Mixes: The Contractor's testing laboratory shall recommend the design mixes to be used for the project for the type and strength of concrete that will produce concrete of specified strengths and finishes. Design mixes shall indicate water-cement ratio, water content, admixture content, cement content, aggregated gradiations, slump, air content and strength. Design mixes and related tests shall be in accordance with the procedures referred to in the Referenced Standards,
2. Trial Mixes: For the type and strength of normal weight concrete, make four (4) trial mixes, using varying cement ratios.
3. Strength of Trail Mixes: Make trial mixes so that when cured and tested under laboratory conditions, the compressive strength will exceed the required strength by 25%. For each trial mix, make six (6) 6" x 12" cylinders to determining compressive strength. Test three (3) cylinders at 7 days and test three (3) cylinders at 28 days. The 7 days test shall equal at least 65% of the 28-day strength required for the trial mixes. From these tests, prepare charts plotting a curve showing the relationship between water-cement ratio and compressive strength, one (1) chart for seven day strength, and a second chart for twenty-eight day strength.

C. Proportion mixes by either laboratory trial batch or field experience methods, using materials to be employed on the project for each type of concrete required, complying with ACI 318.
1. Responsibility: The Contractor shall be responsible for making and paying for all concrete design mixes and tests to determine the suitability of ingredients and the proportion of specified ingredients for the concrete type and strength, of the specified air entrainment, that will be fully workable for all placing conditions and that will produce finishes matching approved samples. the Contractor shall engage and pay for a Testing Laboratory acceptable to the Owner, for making the design mixes and tests for this purpose.
2. Ingredients Test: Prior to making design mixes, the Contractor's Testing Laboratory shall conduct the following tests on samples from material batches to be incorporated in the work in accordance with the procedures referred to in the Reference Standards to assure conformance with the specifications.
   a. Cement: Specific gravity of cement
   b. Aggregates: Sieve analysis, specific gravity, soundness, percentage of voids, absorption, and moisture content of fine and coarse aggregate. Dry-rodded weight of coarse aggregate. Fineness modulus of fine aggregate.

D. Design Mix: Standard weight concrete consisting of specified Portland cement, aggregates, admixtures, and water to product the following:

1. Concrete: Minimum 5000 psi (34 MPa), 28 day strength, air entrained to 4-6 percent in accordance with ACI 301. Water absorption not to exceed 5% to 6% by weight, except 3% to 4% for sloping surfaces (sills) for improved weathering staining resistance.

E. Back-up Concrete: Standard-weight concrete with compressive strength of 5000 psi at 28 days.

F. Adjustment to Concrete Mixes: Mix design adjustments may be requested when characteristics of materials, job conditions, weather, test results, or other circumstances warrant. Laboratory test data for revised mix designs and strength results must be approved before use in the work.

G. Admixtures: Use air-entraining admixture in strict compliance with manufacturer's directions. Admixtures to increase cement dispersion, or provide increased workability for low-slump concrete, may be used subject to approval.

1. Use amounts as recommended by admixture manufacturer for climatic conditions prevailing at time of placing. Adjust quantities of admixtures as required to maintain quality control.

H. Calcium chloride shall not be used.

2.10 BRICK FACINGS

A. Place form liner templates accurately to provide grid for brick facings. Grid shall provide a depth of 1 inch from brick face after casting. Provide so;lid backing and supports to maintain stability of liners while placing bricks and during concreting.

B. Securely place brick units face down into form liner pockets

C. Completely fill joint cavities between brick units with sand-cement mortar, and place precast concrete backing. Mix while sand-cement mortar is still fluid enough to ensure bond.

D. Clean faces and joints of brick facing.

E. **Hot wash entire precast panel to remove wax or retarder on brick surfaces.**

2.11 FABRICATION

A. Fabricate in conformance with PCI MNL-117 and PCI MNL-135.

B. Fabricate and handle epoxy-coated reinforcing bars in accordance with ASTM D 3963/D 3963M.

C. Maintain plant records and quality control program during production of precast units. Make records available upon request.

D. Use rigid molds, constructed to maintain precast unit uniform in shape, size, and finish.

E. Maintain consistent quality during manufacture.

F. Fabricate connecting devices, plates, angles, items fit to steel framing members, inserts, bolts, and accessories. Fabricate to permit initial placement and final attachment.

G. Embed reinforcing steel, anchors, inserts plates, angles, and other cast-in items.

H. Cast rigid insulation into units. Cut drainage channels in exterior face of insulation to route moisture to exterior. Position weep drains to suit. Maintain drainage channels clear.

I. Place recessed flashing reglets continuous and straight.

J. Locate hoisting devices to permit removal after erection.

K. Cure units to develop concrete quality, and to minimize appearance blemishes such as non-uniformity, staining, or surface cracking.

L. Minor patching in plant is acceptable, providing structural adequacy and appearance of units is not impaired.

2.12 FINISH - PRECAST UNITS

A. Finish Type A: Ensure exposed-to-view finish surfaces of precast units are uniform in color and appearance.

B. Finish Type B: Acid wash exposed to view joints and reveals of precast concrete units to provide a uniform texture and appearance.

2.13 FINISH - SUPPORT DEVICES

A. Clean surfaces of rust, scale, grease, and foreign matter.

2.14 FABRICATION TOLERANCES

A. **Conform to PCI MNL-117 and PCI MNL-135**.

2.15 SOURCE QUALITY CONTROL AND TESTS

A. Provide testing of concrete mix.

PART 3 EXECUTION

3.01 EXAMINATION

A. Verify that building structure, anchors, devices, and openings are ready to receive work of this section.

3.02 PREPARATION

A. Provide for erection procedures and induced loads during erection. Maintain temporary bracing in place until final support is provided.

3.03 ERECTION

A. Erect units without damage to shape or finish. Replace or repair damaged panels.

B. Erect units level and plumb within allowable tolerances.

C. Align and maintain uniform horizontal and vertical joints as erection progresses.

D. When units require adjustment beyond design or tolerance criteria, discontinue affected work; advise Architect.

E. Weld units in place. Perform welding in accordance with AWS D1.1.

F. Touch-up field welds and scratched or damaged primed painted surfaces.

G. Set vertical units dry, without grout, attaining joint dimension with lead or plastic spacers. Pack grout to base of unit.

H. Exposed Joint Dimension: 1/2 inch (12 mm).

I. Seal perimeter and intermediate joints in accordance with Section 07900.

3.04 ERECTION TOLERANCES

A. Erect members level and plumb within allowable tolerances. Conform to PCI MNL-135, except as specifically amended below.
   1. Plan Location from Building Grid Datum: Plus or minus 3/8 in (9.5 mm).
   2. Top Elevation from Nominal Top Elevation: Plus or minus 3/8 inch (9.5 mm).

3. Maximum Plumb Variation Over Height of Structure or 100 ft (30 m) (whichever is less): Plus or minus 1/2 inch (12.5 mm).
4. Exposed Joint Dimension: Plus or minus 3/16 inch (4.5 mm).
5. Maximum Jog in Alignment of Matching Faces or Edges: Plus or minus 3/16 inch (4.5 mm).
6. Differential Bowing or Camber as Erected Between Similar Adjacent Members: Plus or minus 3/16 inch (4.5 mm).

3.05 ADJUSTING

A. Adjust units so that joint dimensions are within tolerances.

3.06 PROTECTION OF FINISHED WORK

A. Provide non-combustible shields during welding operations.

END OF SECTION

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