Alternative Systems Design Review

Millennium Science Complex

University Park, PA

Advisors:
Dr. Andres Lepage
Dr. Richard Mistrick
Dr. John Messner
Dr. Jelena Srebric

Building Stimulus
Jon Brangan
Paul Kuehnel
Mike Lucas
Sara Pace

10.27.2010

Table of Contents

Executive Summary

The IPD/BIM Thesis project involves a year-long two course sequence where four group members, one from each option, explore the existing conditions and possible redesigns of the Millennium Science Complex. The use of building information modeling (BIM) will help to facilitate this collaborative effort. Moving forward, consideration is needed to determine what the purposed redesigns discuss previously mean in terms of BIM. Currently the computer program of focus for 3D collaboration is Revit Suite 2011. The upgrade to Revit 2011 yields unforeseen challenges in terms of importing/exporting between other analysis suites, specifically ETABS a structural analysis program.

The Millenium Science Complex is a four story, 275,600 square foot, LEED Gold Certified laboratory and office facility for the Life and Material Sciences on The Pennsylvania State University, University Park campus. Located on the eastern end of campus, the Millennium Science Complex is the focus of the Integrated Project Delivery / Building Information Modeling (IPD / BIM Thesis). The building will house research facilities for the Material Science and Life Science departments. This report provides a review of possible system design alternatives to be incorporated into the redesign of the Millennium Science Complex in order to achieve more efficiency in every discipline's design, with respect to reduced time, reduced cost, reduced energy use, and reduced use of resources.

The third floor of the Millenium Science Complex, at approximately 45,000 square feet, was selected as the focus of the building for this analysis. This floor provides a unique opportunity to study both life and material science laboratories, while incorporating common offices and conference rooms. It allows for complex interactions between all disciplines to be within the scope of detailed analysis. Although the third floor was the main focus for the report, the whole building was considered on a holistic level.

When reviewing current systems and determining candidates for alternatives, it became apparent that the current enclosure places a heavy burden on the structure. On a project that boasts such a great cantilever, relieving the complex structural system of any unnecessary dead load can only benefit the facility. From a construction standpoint, several alternatives were researched as possible replacements for the current application of precast concrete panels. After focusing on implementing lightweight precast panels, metal wall panels, and glass curtain wall, it was determined that replacing current precast panels with lightweight carbon fiber reinforced precast panels would ultimately reduce the precast panel dead loads by up to 50% and minimally complicate current site coordination. However, while lightweight precast panels are a beneficial option, it is certainly recommended to expand the use of metal panels where possible to reduce additional dead loads.

The main focus on redesigning the structural floor system of the Millennium Science Building involved an investigation into switching structural materials from steel to concrete. Three concrete floor systems were schematically designed for comparison with the existing structural system namely flat plate, flat slab, and one-way joist floor systems. Due to the ease of construction, formwork, and thin structure depth a flat plate floor system was recommended as the most efficient floor system. Using a flat plate floor system resulted in a structure depth of 8 inches, which is a third of the depth of the current floor system. Ultimately this reduces the floor-to-floor heights resulting in a cost savings of MEP systems and façade materials.

With respect to the mechanical systems, three possible alternatives were considered in order to improve the building's energy , use of resources, and cost. The building enclosure, energy sources, and air distribution systems were analyzed as possible systems to redesign based on the impacts to the mechanical system. Due to its ability to coordinate well with the other disciplines, especially lighting, a double skin façade proved to be the most viable

option to reduce the energy use and heat gain, since approximately 46% of the cooling loads are from solar heat gain, allowing equipment sizes to be reduced. Chilled beams also are a viable system alternative to reduce energy use in load heavy spaces and in turn reduce floor to floor height due to a decrease in duct sizes. Finally, alternative energy sources were researched to determine their application to reduce consumption of fossil fuels.

Electrical lighting systems were reviewed with a heavy focus on daylight integration in the building. The Millennium Science Complex was designed to dim fluorescent lighting fixtures by way of daylight and occupancy sensors. Current exterior daylight integration features are a louvered overhang at the midpoint of the glazing, the overhang created from the setback of the glazing from the front of the precast façade, and a fritted glass on the upper half of the glazing. An overview of the exterior façade was studied in a daylight analysis program to determine the effectiveness of the current daylight integration features of the exterior enclosure. Two hourly simulations were run for each face of the enclosure, once for 9:00AM – 5:00PM on December 21st, and once from 5:30AM – 7:30PM on July 21. Each of these simulations will show the most extreme solar angles Millennium Science facades will encounter. Once reviewed, several alternatives to the existing daylight integration features were studied. Primary focuses on improving the existing design were energy savings, functionality, maintaining the architectural theme, reducing solar heat gain, and reducing glare.

Construction Management Design Alternatives

Current Enclosure

Advantages	Disadvantages
Variety of exterior finishes Simple and quick installation Typically low costs On-site mock up Standardized sizes Customizable panels	System adds significant amount of weight to structure Supports no load Additional equipment and coordination needed (crane)

Table 1: Current Enclosure Comparison

The primary means of enclosure of the current system is precast concrete panels. The panels are 6" thick with 2" of brick veneer on the exterior. Using precast panels provides a tremendous amount of benefits. The designer is given limitless freedom in the aesthetics of the panels while the ability to customize each individual panel allows this form of enclosure to be applied to even the most unique structures. While customizable, it is cost-efficient to standardize panels where able to do so. Doing so reduces production time and installation time due to familiarity, all which results in cost savings. Panels are relatively simple to install and extremely quick to install, shortening a significant portion of the schedule. However, due to the current systems inability to carry load, the steel substructure must be erected prior to the panel installation.

The current system has one serious downside: the addition of a significant amount of weight to the structure. As shown in the calculations, the typical panel, a 22' x 12' panel, weighs up to 1.088 kips/LF. This load, across a perimeter of over 1,800', requires a much more complicated structure, especially around a weight-sensitive cantilever.

	Length (ft)	Width (ft)	Thickness (ft)	Concrete (lbs/ft^3)	Weight of Member (lbs)
Face	22	12	0.5	145	19,140
Legs (x2)	22	1.5	0.5	145	4,785
Total	-	-	-	-	23,925

Table 2: Individual Panel Weight Calculation

<u>Weight of Panels Per Linear Foot of Perimeter Per Floor</u>

23,925 lbs / 22 LF = 1.088 Kips/LF

Precast Concrete Panels with Carbon Fiber Reinforcing

Advantages	Disadvantages
Variety of exterior finishes	More expensive
Simple and quick installation	Supports no load
Significantly reduced weight	Additional equipment and coordination
Standardized sizes	needed (crane)
Customizable sections	
Improved thermal performance	

Table 3: Precast Concrete Panels with Carbon Fiber Reinforcing Comparison

The current system implemented on the Millennium Science Complex takes advantage of all the benefits that precast panels have to offer. However, on a facility that hoists a massive cantilever such as the one on the Millennium Science Complex, a great structural feat in itself, weight of enclosure is a great concern. Precast concrete panels with carbon-fiber reinforcing reduce the weight of each panel by up to 50%. This is done by using thinner panels. Carbon-fiber reinforcement allows the panels to be reduced from 6" of concrete to nearly 2", drastically reducing weight. While using thinner panels, the alternative panels can still achieve equivalent R – values for effective insulation due to carbon-fiber's low thermal conductivity. Using substantially less concrete reduces weight and price, yet the costly values of carbon-fiber reinforcement, about twice as much as traditional steel, can balance out the savings and typically can cost more than conventional precast panels. The real value is seen in the structural system. With the entire precast system's weight reduced by 50%, the structural steel is put under considerably less strain. This allows the potential for smaller steel members, fewer members, and reduced ceiling plenums. Reduction in ceiling plenums can lower building heights, which can cut significant costs. On-site coordination and schedule essentially remains the same as the current system. Precast carbon fiber panels can be provided by High Concrete Group, the supplier of Millennium Science Complex's current precast panels. Compared to other alternatives, precast panels require the presence of crawler cranes. Panels are installed onto already completed bays as to not interfere with concurrent steel erection.

Architectural Metal Panels

Advantages	Disadvantages
Variety of metallic finishes	Limited exterior finish styles
Simple and quick installation	Sub frame and scaffolding needed
Significantly reduced weight	Undesirable to Owner
Standardized sizes	Scissor lifts required
Customizable sections	

Table 4: Architectural Metal Panels Comparison

Architectural metal panels are an option that has been utilized on the Millennium Science Complex project, yet not extensively. Currently, panels can be seen inside the light-well of the cantilever and create a complimentary style to the facility. The use of metal panels could be expanded throughout the enclosure, providing many benefits including cost reduction and weight reduction. According to estimates, the metal panels currently being used cost $35.00/ft^2, nearly half as much as the cost of precast panel, $65.00 / ft^2. With a more widely used metal panel system, stress and strain on the structural system would be minimized drastically.

Figure 1: Office building with metal panel enclosure

However, while metal panels show significant benefits, they fail to provide the owner and architect with very important aesthetic details. Metal paneling is used on multiple buildings found on Penn State's University Park campus; however, the brick currently being used on the Millennium Science Complex is clearly part of a campus-wide theme by the campus architect. With several buildings on campus using the exact shade and style of this brick, it is highly unlikely that the owner would be apt to its non-usage. However, it is possible, and certainly recommended that metal panels be used more frequently, specifically on the cantilever, but at the Owner's discretion.

Glass Curtain Wall

Advantages	Disadvantages
Variety of glazing finishes	Undesirable to Owner
Simple and quick installation	Sub frame and scaffolding needed
Lightest dead load on structure	Thermal insulation issues
Standardized sizes	Lower life span
Customizable sections	

Table 5: Glass Curtain Wall Comparison

Among other alternatives, a more expanded use of a glass curtain wall could potentially solve the weight and cost issues of the Millennium Science Complex. Like architectural metal paneling, a glass curtain wall has negligible dead load on the steel structure and at $45.00 / ft^2 cost much less than the precast concrete panels. But similarly to the metal panels it will not satisfy the needs of the owner and architect of the facility. Again, numerous buildings on campus, such as the HUB – Robeson Student Center and the Smeal College of Business Building, utilize glass curtain walls extensively; however, a more expanded use of a glass curtain wall over what is already used is considered highly undesirable for the owner. Glass curtain walls tend to have a shorter life span than most alternatives, from 10-15 years. However, glass curtain walls are susceptible to breaches, cracking, and shattering due to drastic temperature changes, seismic forces, flexibility in substructure, and various other potential hazards. Installation of glass curtain walls requires close attention focused on sealants between glazing and sub frame. Post-installation tests must be performed to ensure proper water proofing and complete seal. Additional glazing would also require further daylighting design and load calculation regarding mechanical systems. Glass curtain walls should only be considered if felt architecturally necessary.

.

Figure 2: Hollow Steel sub frame used as lateral support for glass curtain wall

Overall Evaluation

After reviewing the existing enclosure of the Millennium Science Complex, it has been determined that an improved design focusing on a lightweight solution would present a myriad of opportunities to redesign the structure, mechanical systems, as well as the coordination of the construction process. Currently, 6" precast panels are predominantly used on the project, delivering a dead load of approximately 1.088 kips/LF per floor. An alternate solution resulting in significant weight reduction could potentially reduce the size of steel members, minimizing building height as well as ceiling plenums. Alternate systems under consideration include the application of lightweight precast concrete panels with carbon fiber reinforcement, architectural metal wall panels, as well as a more extensive glass curtain wall system.

While researching potential enclosures, it was considered important to avoid improvements that would drastically affect on-site coordination, schedule, and induce significant cost increases. According to schedules provided by Whiting-Turner, installation of panels began more than 3 months after steel erection began to coincide the complete enclosure with the completion of concrete work; however, precast panel installation is able to begin right after steel is erected if necessary. During analysis of potential alternatives, it became abundantly apparent that the use of precast panels provided key benefits that were simply too invaluable to the owner's vision and the project's overall success to ignore completely. Precast concrete panels expedite the overall enclosure of the facility and require significantly less installation time than comparable enclosure options. More importantly, precast panels give the designers a great amount of creativity and flexibility. Precast panels can be customized to fit unique curves and very precise angles. The designers took full advantage of this capability especially around the large cantilever reducing any on-site fabrication from other enclosure options. Also, the architect is given nearly limitless possibilities of exterior finishes. The panels on the current system utilize the Penn State brick scheme which has become the common theme amongst newly constructed buildings on campus to blend with the older brick facilities. This specific aspect of precast panels, and their extensive use throughout the project, is a clear indication of how important the brick exterior was to Penn State and Viñoly Architects. While precast panels are the only option considered that can provide the brick exterior, there are lightweight precast panel options that could have been considered for the Millennium Science Complex. Precast concrete panels utilizing carbon fiber reinforcement can reduce panel weight up to 50% according to AltusGroup, the panel manufacturer. Reduction of weight is due to carbon fibers weight compared to the conventional steel re-bar reinforcement but more specifically due to the reduction in concrete in each panel. Panel concrete thickness would drop from 6" to potentially 2"-4". These weight losses drastically reduce dead loads throughout the building. High Concrete Group, the suppliers of the current precast panels, list carbon fiber precast panels in their catalog meaning coordination, production, and delivery of these panels would go seemingly unchanged from the current system, which saw very minor conflicts.

Precast panels using carbon fiber reinforcement provide the owner and architect with the ability to efficiently achieve their vision for the Millennium Science Complex; however, alternative enclosure systems researched provide benefits that precast panels simply cannot achieve. While the brick façade of the Millennium Science Complex meshes well with surrounding facilities, it is strongly recommended to utilize the lightweight characteristics of metal wall panels and/or glass curtain walls. Both of these options are currently being used on the Millennium Science Complex and a more extensive use of both of these materials could relieve the structure of significantly more dead load than either precast panel option could realistically achieve. A more widespread use of metal panels and/or glazing would alter the trade coordination on-site minimally. While additional trades would be needed for installation, less-cumbersome equipment would be needed on-site. Crawler cranes needed for precast panel installation would be removed earlier as scissor lifts are currently the only piece of equipment being used for metal wall panel installation. Metal panels are currently installed via scissor lift on the interior light well of the cantilever. An expanded panel application on, or near, the cantilever would drastically reduce weight on the system, as well as, simplify activities in the North-West corner of the site, as crawler cranes for precast panel installation would not need to be present, only the already present metal panel contractor and necessary equipment.

As the application of alternative enclosure systems is being explored, it is our initial recommendation to seriously consider the total replacement of the currently implemented 6" precast concrete panels with reduced concrete precast panels with carbon fiber reinforcement. It is also recommended to consider a much more extensive application of architectural metal wall panels, predominantly around the cantilever, to relieve the structural system of a significant amount of dead load.

Structural Floor System Design Alternatives

Existing Floor System

Description

Thornton Tomasetti, the original structural designers of The Millennium Science Complex, chose a slab on metal deck as the primary floor system. The typical bay size is 22 ft square with 3 in. metal deck and 3 ¼ in. lightweight concrete topping supported by W21x44 beams spaced at 11 ft, framing into W24x76 girders. The load is then further transferred to the foundation by way of W14x68 columns.

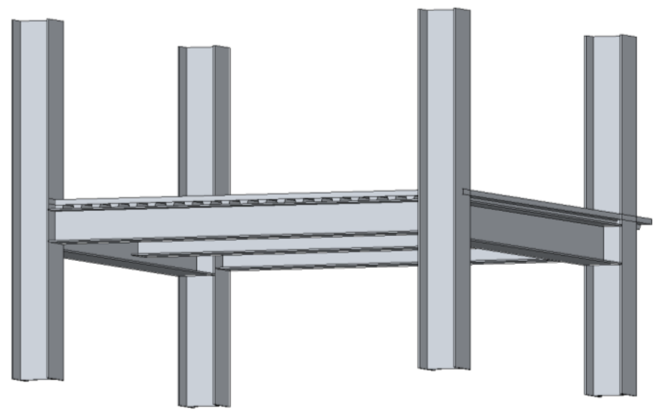

Figure 3: Existing Floor System: Concrete on metal deck with steel framing

This assembly was verified using the AISC Steel Construction Manual and the United Steel Deck design guide. This included checking the deck for unshored strength, composite beams and girders for strength and serviceability requirements, and columns for strength capacity.

Advantages

The advantages of this system are ease of construction, load carrying capacity, and weight. At the span length of 11 ft. it is not necessary to shore the metal deck during construction. This translates to a reduction in cost because there is no need for formwork and the additional labor required in placing formwork and shoring. Also, the speed of the steel erection process allows for flexibility in overlapping scheduling of steel erection and placement of deck and concrete. Furthermore, the composite interaction of the steel beams/girders and the concrete topping translates to an addition of strength which allows for members to be sized shallower than non-composite beam counterparts.

Disadvantages

The main disadvantage of this floor system is the depth of structure needed to support the required loads. It was mentioned previously that due to the composite interaction of this floor system shallower members could be used, however the structure for this typical bay is still greater than 30 in. thick. This 2 ½ plus ft. of structure is space that could be used for MEP plenum space and in many locations of this building it was necessary to cut horizontal openings into the structure for electrical conduits, plumbing, or mechanical ducts. This translates to an increase in cost in both materials and labor.

Feasibility

As testament to the feasibility of this structural design the building is currently under construction with the structural system complete. When taking into account ease of construction, weight, and load carrying capacity, composite metal deck with steel framing is a very efficient structure for this building.

Flat Plate Floor System

Description

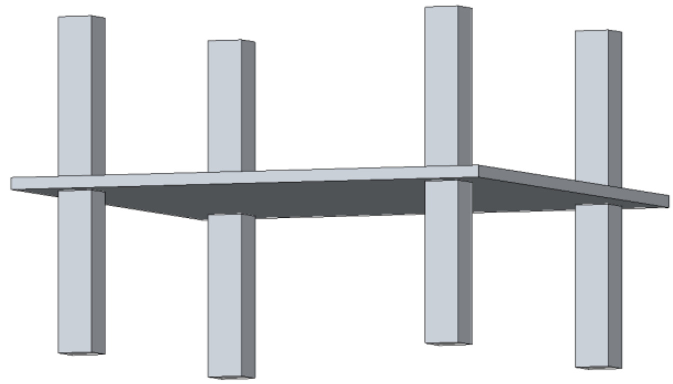

Figure 4: Flat Plate Floor System

A flat plate floor system is composed of a concrete slab with mild reinforcement in two directions; this is supported by integral reinforced concrete columns. This was evaluated for a typical interior bay of 22 ft. square. To begin design it was important to select a design method; based on ACI 13.6 the direct design method was chosen. Secondly, a slab thickness of 8in was determined to be of adequate thickness to control deflections as per ACI 9.5.3. Progressing through the schematic calculations for 2-way slab design it became apparent that this thickness would not be adequate for punching shear, in response the slab was thickened to 10 in. For further optimization of this design it would be beneficial to calculate the thickness of the slab using stud rails to resist punching shear instead of increasing the slab depth.

Advantages

The advantages of the flat plate system are thin structure, simple formwork, and flat soffits. The integral interaction of 2-way slab allows for wider distribution of moment capacity and therefore a large effective width for carrying moment. This results in the ability to use a thin structure to support the required loads. The typical 22 ft. square bay sizes of the MSC stands out as a prime candidate for flat plate construction, the simplicity of a flat concrete slab with repetitive bays lends itself well to construction efficiency. Flat soffits are of particular advantage to construction of an apartment building or hotel where ceiling finishes will be applied directly to the underside of the slab. This allows for a reduction in story height and ease of construction. Due to the nature of the building being a research facility there is an extensive amount of MEP systems. Thus, a large amount of plenum space is necessary making ceiling finishing not of particular advantage. However, the flat soffit also means there is are no complexities when hanging or installing MEP fixtures due to uniformity of the supporting structure.

Disadvantages

The main disadvantages of the flat plate system are deflection control, punching shear at columns, and future core drilling. The relatively thin slab of the structure makes it susceptible to excessive deflections and floor vibrations, in a laboratory facility such as the MSC this could be an issue. The uniformity of the flat plate system may lend itself to an ease of construction, however, it is not very efficient at resisting shear forces at critical locations, namely columns. If the slab is found to be inadequate to resist punching shear, certain measures can be introduced to strengthen these locations. These include increasing the depth of the slab over the entire panel, increasing the column size, adding a shear capital, or adding shear reinforcement. Furthermore, in a research facility experiments and equipment is often changing to meet the needs of the current industry. This often results in retrofits to the structure involving core drilling of the slab. In a 2-way system this can be problematic because it significantly lowers strength capacity of the floor system.

Feasibility

Given the typical uniform bay sizes of the MSC a flat plate floor system is a viable option as an alternative to the existing floor system. Openings in the slab can be mitigated with steel framing where necessary if required for future renovations. With the addition of stud rails the flat plate system is the thinnest of the 3 systems analyzed and least complicated to construct. This makes it a very cost effective and efficient structural system.

Flat Slab Floor System

Description

The flat slab floor system is much like that of the flat plate system, incorporating a 2-way concrete slab but with the addition of drop panels at column locations. This provides extra resistance to punching shear without increasing the slab thickness where it is unnecessary. Like above, calculations were performed using the direct design method based on provisions of ACI 13.6. Based on ACI 9.5.3 a slab thickness of 8 in. and drop panel thickness of 2 ¼ in. as per ACI 13.2.5 were chosen to adequately support the required loading.

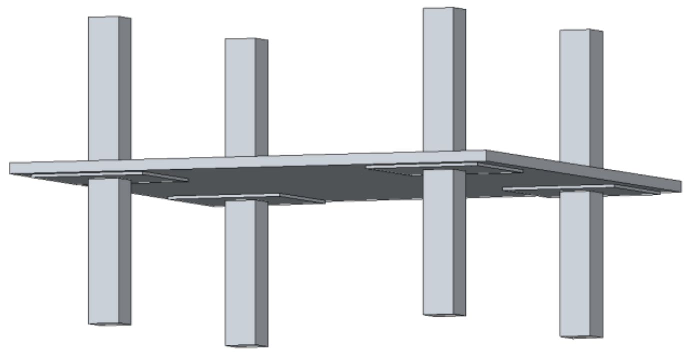

Figure 5: Flat Slab Floor System

Advantages

The flat slab system shares many of the same advantages of the flat plate system including: thin structure, simple formwork, and relatively flat soffits. Like the flat plate system, the 2-way flat slab utilizes a large width of the slab to resist moments due to loading. With the introduction of drop panels at column locations the form work becomes slightly more complex than that of a flat plate but it is still a relatively simple procedure and the drop panels add to the shear strength of the slab. With the introduction of drop panels comes irregularity in the soffit. However, because this irregularity is limited to the location of the columns it is reasonable to say that it will not poorly affect the MEP plenum space. On another note, by introducing drop panels a thinner slab is able to be used therefore plenum space is gained where necessary.

Disadvantages

The disadvantages of the flat slab system are deflection control and future core drilling. Like the flat plate system, the thin slab is susceptible to excessive deflections and floor vibrations which could prove to be a viable reason not to use a flat slab system. As with other two way systems the strength is significantly lowered when cutting openings through the slab.

Feasibility

As with the flat plate system, the flat slab system works well with the uniform bay sizes of the MSC. However, the added cost in formwork and additional concrete due to the drop panels where stud rails would be just as adequate, the flat slab systems seems to pose no added benefits over other proposed system designs. Therefore, the flat slab system will not be pursued further.

One-way Joist Floor System

Description

A one-way joist floor system is a floor slab supported by a series of joists (tapered toward the base) spanning towards girders which frame into columns. The joists are formed using pans 30 in. wide and 8 in. deep, these dimensions depend on deflection and strength requirements. Due to a requirement for 2-hour fire rating, a slab thickness of the 4 ½ in. was used.

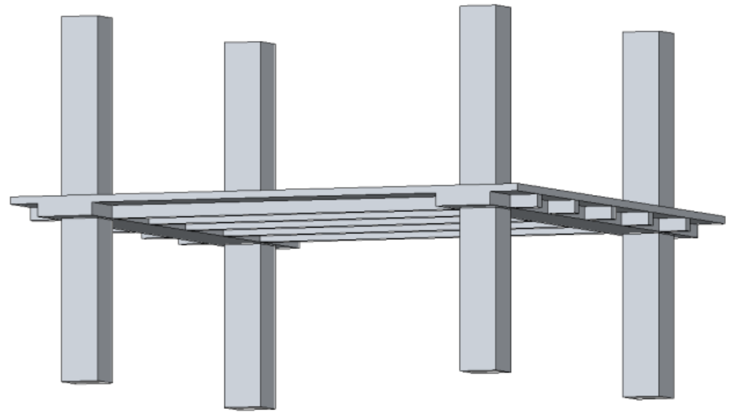

Figure 6: One-way Joist Floor System

Advantages

The advantages of the 1-way pan joist floor system are larger column spacing, inherent vibration resistance, reduced dead load, and easier future renovations. Pan joists are typically used in buildings where bay sizes may be unequal because they allow the joists to span the long direction framing into the girder spanning in the short direction. A pan joist system offers a reduced dead load when comparing it to a slab of equal depth because of the voids between joists. When considering future renovations, the pan joist system is very adaptable. Moment will be redistributed to other joists around the openings in the pan joist system.

Disadvantages

The main disadvantages of a pan joist floor system are complexity/availability of formwork and structure depth compared to other concrete floor systems. To construct a pan joist floor system often pans must be rented which adds to the construction cost because whether or not you are using a pan joist system deck formwork is required. Aside from renting and availability of the formwork, the pans must be constantly removed and reinstalled limiting the amount of concrete to be poured to the number of pans available at one time. Also, the depth of a pan joist system is often greater than the depth of other concrete systems which in turn adds to an increase in façade, plumbing, electrical, and various other costs.

Feasibility

A 1-way joist floor system is often used with rectangular bay sizes with the joists spanning in the long direction and girders in the short direction. Given the 22 ft. square bay sizes the structural system uses the least concrete of the three systems analyzed however, in terms of depth it is the thickest structural system. To optimize the efficiency of this system it would be beneficial to perform analysis with expanded bay sizes. As speculation this would increase the thickness of the structure while possibly increasing the efficiency. Lastly, the main talking point when considering feasibility is the availability of pan formwork and costs associated with labor and renting pans. This efficiency of this system would have to be great enough that it offsets the cost associated with these additional obstacles.

Overall Evaluation

When considering concrete as a structural system the construction is often the influential factor because of labor and placement costs. It is estimated that 50% of the cost incurred during concrete construction comes from labor and materials involved with formwork, 30% in concrete material, placing and finishing, and 20% in material and placement of reinforcement. Having said this, it is necessary to design a concrete system that is highly repetitive and uniform so formwork can be reused. The typical square bays of the Millennium Science Complex lend themselves well to using a flat plate floor system. The ease of construction, simplicity of formwork, and thin depth needed to support the applicable loading are all advantages that make this floor system the most desirable.

Challenges with using a concrete structural system will present themselves in terms of integrating the structural system of the cantilever. One possible course of action will be to separate the building into three separate buildings; one for each wing and one for the cantilever. This would allow the structural system of the cantilever to remain concrete on metal decking with steel framing and wings to be full concrete construction. The challenges this type of construction presents is having two different trades on the jobsite at the same time and issues with constructability. Another possible solution would be to convert the entire structural system to concrete; this presents many challenges when considering the construction of the cantilever. Initial ideas for construction of using concrete for the cantilever include shear walls with prestressed concrete beams or a suspension type design using a concrete tower and steel cables to support a prestressed concrete cantilever slab. These challenges must be explored through further and analysis in future reports.

The advantages and disadvantages of converting to a concrete structure from steel will need to be analyzed all the way back to early preconstruction phases. Costs and schedule will need to be adjusted significantly. Rough estimates may have the price of cast-in-place concrete being less expensive than steel, however, after considering availability of labor, and fluctuating material costs with concrete and steel, it is difficult to gauge relative costs on Millennium Science Complex at this time. The effects on schedule can be estimated more accurately. In a process such as Millennium Science Complex, the use of concrete may slow down aspects of the schedule. Scheduled predecessors of certain concrete decks and columns, such as the enclosure of the facility and the construction of the subsequent decks will rely on the pouring and curing of said decks and columns. This process takes significantly longer than the erection of a steel frame. Construction of a concrete facility can begin earlier as lead times are minimal compared to steel, yet actual construction of the concrete structure could last longer. The use of concrete may allow aspects of the schedule to be accelerated compared to the use of steel, however, those aspects would need to be researched more thoroughly. One significant benefit of utilizing a concrete structure is the ability to minimize floor depths from 30" using steel to nearly 10" using concrete. This increase in usable ceiling plenum allows for reduction in building heights, which can cut significant costs, or allow more flexibility in mechanical design within the plenum.

Regarding procurement of a cast-in-place system, 12 yd^3 mixing trucks could transport materials from local concrete plants. Similar to steel delivery, appropriate delivery schedules and routes would need to be devised to avoid campus congestion. Concrete would need to be prepared and tested before it is poured and would need to be observed and put under stringent quality control. While steel was erected using two large crawler cranes, the need for such cumbersome equipment does not exist. However, multiple means of placing concrete would be necessary. The presence of wheel barrows, chutes, buckets, and concrete pumps may also be necessary, as well as the massive amounts of re-bar to be used. The large size of the Millennium Science Complex would most likely demand the pouring of concrete during cold months. Additional consideration would need to be put into counteracting the forces of cold temperatures. Closing in the exterior with tarpaulins or plastic sheets, or even the use of heaters may be required along with admixtures.

It is possible to avoid many of the previous obstacles through the structural design of the facility. Precast concrete could be utilized, solving many of the cold weather issues, and accelerating the schedule by disregarding the curing process of concrete. The final design of the structure weighs in heavily on the ways and means of procurement and construction of the concrete structure. The construction of a concrete cantilever would be extremely time demanding and require a great amount of man-power, but it could be conceivable to find financial gains, both in cash flow and total costs. The design of the cantilever, whether it is left as steel or converted to concrete, will change the construction phases of the project. Currently, steel was erected from the legs of the facility and moved towards the cantilever. However, the application of concrete might demand construction to move in reverse, from cantilever heading towards the legs. If the cantilever is isolated and built alone with steel individual from the concrete legs, the facility may not be efficiently supporting itself. Yet to support itself efficiently, proper steel to concrete connections would need to be designed and would require a significant amount of coordination between designers and trades on site. All of these obstacles would need to be considered in the total structural redesign.

When considering concrete structural systems, it is important to not only consider the loads necessary to be support, but also the major resulting implications of schedule, budget, procurement, and construction coordination. All of these aspects will need to be considered the proposal develops.

Mechanical System Design Alternatives

Building Enclosure

The building façade has proven to be a good candidate for redesign following the initial building conditions analysis completed in Mechanical Technical Report 1. Based on the analysis of the Millennium Science Complex's third floor, the heat gain from the building's façade, including walls, glazing, and infiltration, accounts for approximately 8.8% of the cooling loads for the laboratory spaces and 46% of the office space cooling loads. These are significant percentages, especially compared to the ratio of glazing to brick on the façade, where MSC has less glazing than many new buildings constructed today. These significant percentages therefore exhibit the need for optimization of the building envelope. The existing façade as modeled in Trane TRACE consists of glazing used extensively throughout the construction with a U-value of 0.293 BTY/hr-ft^2-^{o}F and a U-value of 0.04 BTU/hr-ft^2-^{o}F for the wall construction.

In order to enhance the performance of the building envelope, double skin facades were investigated. Although they are utilized primarily on fully glazed facades, which the Millennium Science Complex is both a brick and glass façade, some of the techniques used to enhance the energy performance may be able to be applied to MSC. Double skin facades consist of two layers of glass that are separated by an air corridor. The air corridor functions as insulation against temperature extremes, wind, and sound. In this space, sun-shading devices can be placed to help control daylighting, which allows for full integration with the lighting/electrical discipline. The main layer of glass is usually insulating and is part of the conventional structural wall, whereas the second layer of glass can be placed in front of the main layer. Glass skins in this construction type are capable of spanning the entire envelope, or a portion of the structure, which is the setup to be applied to MSC.

The unique feature of this system is the air cavity. It is connected to the outside air to enable natural ventilation and night time cooling for the building. Acting as a thermal buffer in the winter, heat loss can be reduced and enable passive thermal gain from solar radiation. However, the cavity does have a tendency to become overheated during times of large solar radiation. To prevent this, the air corridor needs to be well ventilated, which is dependent on the wind pressure conditions on the building's skin, stack effect, and discharge coefficient of openings. These vents are either left continuously open, as in passive systems, or are manually/automatically open and closed with active systems. Most likely the vents used for the Millennium Science Complex will be an active system.

The ventilation system for the air cavity can be served with the overhead ventilation system currently in use in the MSC to supply or exhaust the cavity. By forcing air into the cavity, the air will rise and remove heat upwards to be exhausted or re-circulated. This system can help keep conditions in the buffer zone nearly constant to reduce the influence of the outdoor air to the indoor environment. As an exhaust system, the façade cavity does not have the possibility of heat recovery, but it is able to provide enhanced insulation in the winter and reduces solar radiation heat gains during the summer. It also provides full occupant control of the windows for ventilation. Figure 7 shows the exhaust setup of the façade.

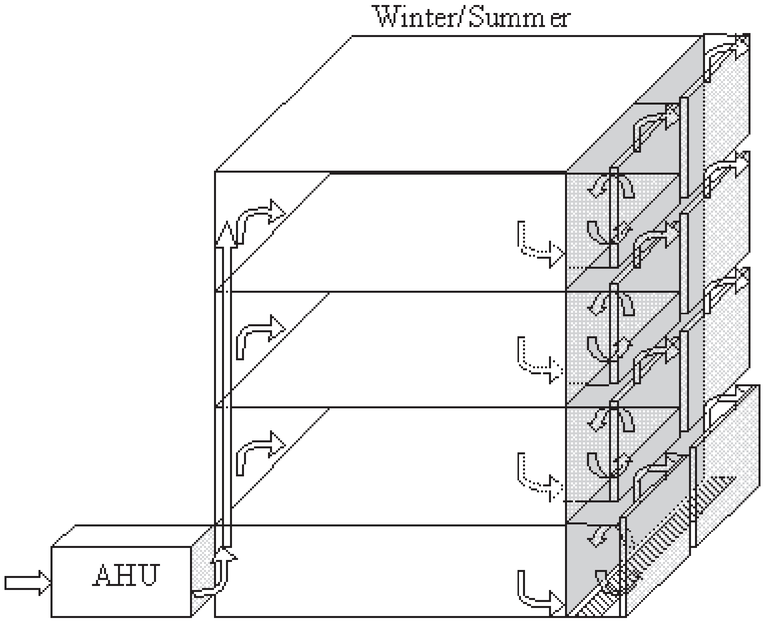

Figure 7: Double skin façade as exhaust, *image from Harris Poirazis: Double Skin Facades*

The Double Skin Façade can also serve as an individual supply of preheated air, as shown in Figure 8. Exhaust ventilation system helps improve the flow from the cavity to the room and exhaust duct. There are some disadvantages to this as extra conditioning of the air is needed in every room through radiators. It is also not applicable during the summer design conditions due to the high air temperature inside the cavity. However, occupants are able to have full control of the windows' openings.

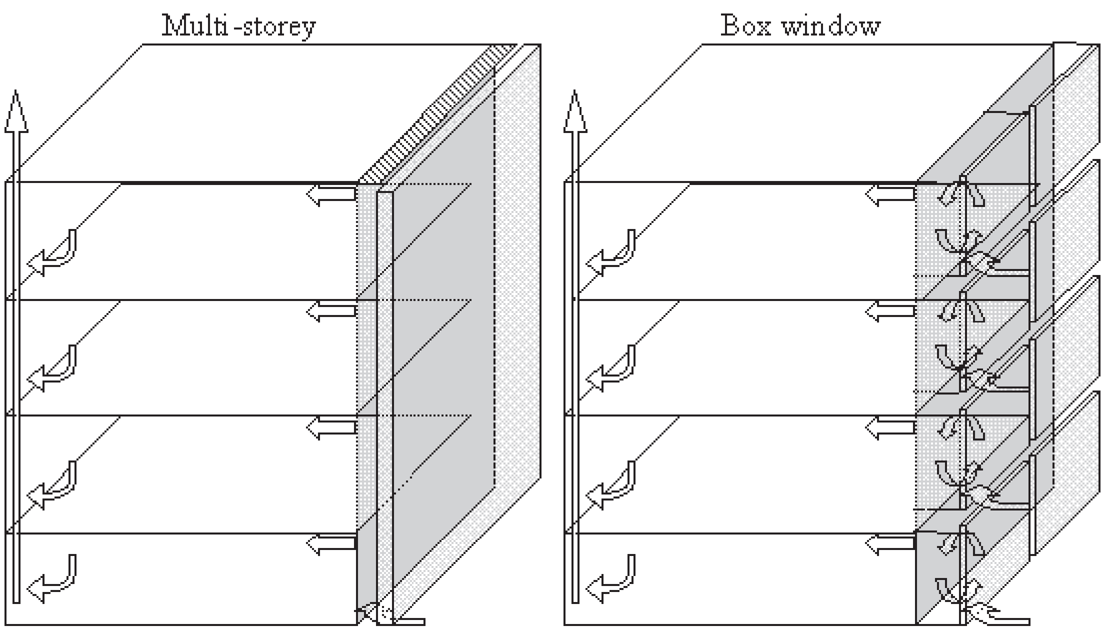

Figure 8: Double skin façade as individual supply of preheated air, *image from Harris Poirazis: Double Skin Facades*

The overall advantages of the double skin façade are:

- Increased Acoustic Insulation—reducing external noise pollution
- Increased Thermal Insulation—great for winter conditions to lower heat transfer rate
- Nighttime Ventilation—allows offices to be precooled every night during summer conditions
- Reduced Energy Use
  - Low thermal transmission (U-value)
  - Low solar heat gain coefficient
- Reduced Environmental Impacts
- Better protection of shading and lighting devices
- Reduced wind pressure effects
- Fire Escape—glazed space may be used as egress if wide enough

Disadvantages of double skin façade:

- Higher construction cost
- Reduced occupiable space—cavities vary from 20 cm to 2 meters
- Overheating—can arise if not properly ventilated
- Increased construction weight compared to typical curtain walls

Air Distribution Study

The existing air distribution is serviced by variable air volume boxes to all the spaces, both laboratories and offices. Ceiling mounted low velocity radial diffusers supply air to the spaces to maintain the room temperature setpoint. The return air is also removed through the ceiling plenum to the return air duct riser. CO_2 sensors are located in both the return air and outside air ducts on each floor to maintain the CO_2 concentration level of 470 ppm. All the lab spaces and vivariums are serviced by 100% outdoor air systems, and the non-lab spaces utilize outdoor air economizers to save energy, and are not 100% outdoor air.

In order to optimize the air distribution performance to the spaces for the Life Science and Material Science wings, active and passive chilled beams were analyzed to determine their appropriateness. The use of this relatively new technology for North America can help reduce the energy use needed to cool indoor air temperature for load based space design. However, due to the magnitude of the heating and cooling loads in the non-lab spaces, passive chilled beams do not appear to be a viable option. Chilled beams can help reduce the duct sizes throughout the building since there is a reduction of air flow needed and the overall size of the equipment. This decreases the overall floor to floor height of the structure. Currently, the MSC's duct work is oversized due to the large pressure drops associated with very long runs in the building. Static regain was used to design the current ducts in order to regain velocity for what was lost due to static pressure. This analysis describes the applicability of a chilled beam system to the Millennium Science complex and summarizes the advantages and disadvantages for the system.

Based on the EPA and DOE's, "Labs for the 21st Century," active chilled beams are permitted for use in laboratory spaces with a low density of fume hoods (maximum of two hoods per lab module), whereas the passive chilled beams are more suited for areas such as office and other load heavy spaces. There are two critical considerations to account for with chilled beam design: chilled water temperature and humidity ratio of the conditioned space.

Condensation of water on the coil can arise if standard chilled water at 45°F is used. Therefore, the chilled beam water must be actively maintained three or four degrees above the conditioned room's dew point.

Instead of using blown cold air supplied at 55°F to control the temperature of the spaces, pumped chilled water is used. Water has a volumetric heat capacity 3500 times that of air, which makes this medium a much more efficient design to remove heat. This allows the fan energy to be reduced approximately by a factor of seven as compared to the current VAV design. Active chilled beams rely on chilled water piping system to circulate water through integral cooling coils. Individual laboratory spaces are capable of being controlled to meet the fluctuating loads by adjusting the flow of chilled or hot water across the beams. The ventilation air supplied can range from 55-70°F, which reduces the reheat energy needed.

Chilled beams use an induction process to provide local recirculation of room air. Airflow from the air handling unit to the zone is introduced through small air jets to induce three to five times the amount of room airflow through the beam's coil. Figure 9shows a diagram of the air flow through the active chilled beam. A decrease in floor to floor height can be achieved with chilled beams due to the much shallower structure of the beams and ductwork as compared to the VAV boxes currently used in the building. This can provide significant savings for the construction of MSC's structure, as the current floor to floor height is approximately 19 ft., where nine feet is dedicated to mechanical and structural systems.

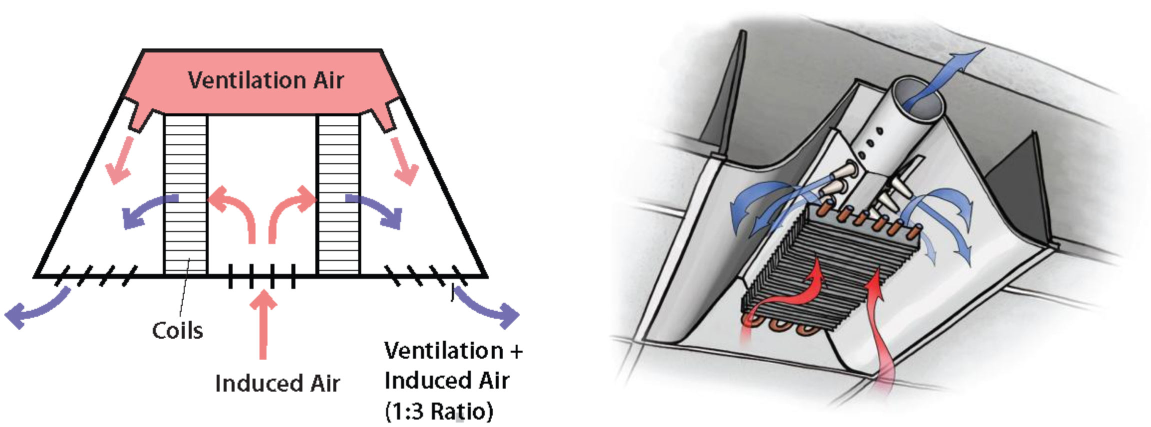

Figure 9: Active Chilled Beam Supplied with Air from AHU, *image from Labs 21 Chilled Beams*

After analyzing the spaces in the third floor of MSC, the equipment corridors and offices are optimal candidates for using chilled beams. These spaces are considered load heavy. The chilled beams are used to take care of the cooling load instead of traditional excess air change via VAV boxes, since these spaces are not driven by ventilation. Utilizing this technology can help save air handling unit sizes and ventilation loads due to the reduction in outdoor air required to handle the space loads. However, chilled beams will not save on cooling loads since chilled water is required to continuously remove the sensible load from the room. Dehumidification becomes an issue, since chilled beams only remove sensible load, so the central air handling system must still take care of the latent load. A run-around coil can be used to help with dehumidification. For placement in the laboratories, the fume hood proximity to the chilled beams needs to be considered so that the beam's supplied airflow does not interfere with the hood's. The application of chilled beams cuts down on required ventilation air for load based rooms, but not necessarily for the ventilation based spaces, which in turn reduces energy required.

Overall advantages of active chilled beam system:
Reduced floor to floor height—increased plenum space
Reduced duct sizes
Reduced fan energy
Reduced AHU sizes
Decoupled heating and cooling / ventilation
Higher chilled water and lower hot water temperatures

Overall disadvantages of active chilled beam system:
Condensation risk for standard chilled water
Moisture sensors required on chilled water supply lines
Additional piping
Increased initial costs
Minimal benefits for labs with high density of fume hoods or process exhaust
Increased water use
Increased pumping energy
Small increase in static pressure

Energy Sources Study

The existing mechanical systems utilize University Park's campus chilled water and steam from the central and boiler plant and electricity from the local utility. Steam is used for equipment throughout the building, such as laboratory sterilization and domestic hot water heat exchangers. It is also used for humidification, reheat and preheat coil at the AHUs, and perimeter heating elements in the areas where the glass height is greater than 11 feet high, such as office spaces, conference rooms, and laboratories. Chilled water is circulated throughout the building to the VAV boxes to service the cooling coils, and for the process cooling of equipment and supplemental loads in the building to serve cold rooms and environmental rooms.

Currently, the existing mechanical design utilizes enthalpy heat recovery wheels and integral exhaust fan to operate concurrently with the supply air for each air handling unit in order to utilize energy. Currently, Penn State purchases green power to offset emissions from the MSC and other buildings on campus. In order to decrease the emissions produced and fossil fuel consumption, renewable energy technologies were researched in this study to determine their applicability. They were assessed in terms of practicality, feasibility, and coordination with other disciplines in order to achieve the overall goals and scope of the design team.

According to Labs21®, the process heat load requirements of laboratories make them excellent candidates for on-site generation, as the energy needs of laboratories are often focused as process heat loads where the need is immediate and intense. For these situations, renewable resources such as solar can provide viable options through photovoltaic electricity generation systems and solar thermal collectors. Other renewable energy that can be utilized for MSC are wind energy systems, which are often intermittent. Natural gas fuel cells is a new technology capable of producing very clean and efficient forms of energy, despite using fossil fuels.

Solar-Thermal Systems

Solar-thermal systems heat water, or another fluid, by collecting solar radiation and the hot water is then used throughout the building. It relies on a renewable energy source to heat hot water instead of fossil fuels, therefore the primary energy use can be reduced in the building. To function properly, solar thermal collectors, such as evacuated tubes and flat plate collectors, often require additional heat exchangers and equipment, and more complex control systems. According to the National Renewable Energy Laboratory Resource Assessment Program, Concentrated Solar Power Resource Potential is 4-5 kWh/m^2/day for Pennsylvania. The system would be most likely placed on the roofs of the Millennium Science Complex, but the additional equipment may become a concern. Due to this added equipment and controls, the solar thermal collectors will not be cost effective since they only provide hot water to the building, which is currently supplied by Penn State's steam plant.

Photovoltaic

Photovoltaic panels collect solar radiation, just as solar-thermal systems, but to produce electricity. This technology is becoming more prevalent due to the federal energy credit incentives. The federal government currently offers at 30% investment tax credit for commercial solar electric systems. Efficiencies range from 12-26% for electricity production from solar radiation, depending on the type of panel. The performance of the PVs also varies according to the time of day and cloud coverage as it is dependent upon the amount of direct sunlight reaching the panel. Just as the solar thermal systems, primary energy use and emissions would be reduced for the building since solar energy is a renewable resource. This extra electricity supplied can be applied to some of the smaller lab and office equipment.

Wind Energy Systems

Electricity can be generated from small scale wind turbines and operate at approximately 20% efficiency. Most common turbines used for building applications are horizontal axis upwind machines with two or three blades. Power produced from the wind turbines is directly proportional to the size of the blades. Therefore, to make an impact in the building's electricity use, wind turbines of substantial sizes would be required. In order for wind turbine application to be economical, wind average wind speed needs to be at least 4.5 m/s. According to AWS Truewind, the average wind speed for State College, PA is approximately 5.0-6.0 m/s. Wind turbines usually produce intermittent energy that is not always reliable due to the weather. For the Millennium Science Complex, electricity produced from this renewable resource should be used for less critical equipment loads, not related to the critical lab spaces, unless short-term storage is used.

Natural Gas Powered Fuel Cells

Instead of generating electricity from traditional combustion processes, natural gas powered fuel cells use electrochemical reactions to produce electricity. By passing streams of fuel and oxidants over electrodes separated by an electrolyte, a chemical reaction occurs, generating electricity without the need for combustion or added heat. Through the production of electricity, only trace amounts of sulfur compounds and carbon dioxide are emitted, where the CO_2 is so concentrated that it can be easily captured without being emitted into the atmosphere. Since the fuel cells are compact in size and completely enclosed with no moving parts, they can be placed wherever electricity is needed for use as a dependable source that does not experience electricity surges. According to the National Energy Technology Laboratory, it is estimated that fuel cell generation facilities can operate at 70% efficiency in the 1-20 Megawatt range, which is much higher than traditional generation methods.

Overall Evaluation

The existing building enclosure was analyzed and approximately 46% of the office space cooling loads can be attributed to solar heat gain and infiltration. In order to remedy this excessive load on the building, a double skin façade was researched. This design can be coordinated well with the lighting/electrical discipline, as daylighting techniques can be integrated seamlessly into the design. Natural ventilation, increased thermal insulation, and thus reduced heat gain make this a viable choice for reducing the building's energy consumption. While there is a small increase in weight with this system as compared to a standard curtain walls, it will not negatively impact the current structure of the Millennium Science Complex. Application of the double skin façade will allow for a more complete envelope by integrating both lighting and mechanical performance into one structure.

Another system was analyzed to enhance the efficiency performance of the Millenium Science Comlex, chilled beams. They are a relatively new technology for North America, but are capable of reducing energy use in the building by relying on chilled/hot water to control the temperature setpoint of spaces instead of increasing ventilation for load heavy spaces. This system allows the mechanical equipment to reduce in size and also decrease the plenum space occupied by the mechanical systems due to the decrease in duct sizes.

Finally, alternative energy sources were analyzed for their application to the building in order to reduce the consumption of fossil fuels. Solar thermal collectors provide hot water to the building at minimal cost, however, since MSC is connected to Penn State's steam plant, this is not a reasonble option due to the increase in equipment needed to collect and supply the hot water. Photovoltaics and wind energy were also analyzed as sources of electricity. As with the solar thermal collectors, these systems increase the amount of equipment needed, but primary energy use and emissions are reduced. The last energy source analyzed is a relatively new technology, natural gas powered fuel cells. Although they use a fossil fuel, electricity is not produced through combustion, so the efficiency is 70% with only trace emissions produced. Their compact design allows them to be placed anywhere to provide an alternative to electricity provided by Allegheny Power utility plant.

Daylighting Overview & Alternatives

Daylighting Overview

An overall daylight study of each façade was done to determine which times of the year each façade will have direct sunlight. Studies were done of each façade at the summer and winter solstices. Each of the results will show the most extreme of sun angles the façade will encounter throughout the year.

The orientation of Millennium Science complex is 52° counter clockwise of plan, as shown in Figure 10. The orientation allows each wing to get ample amount of both direct and indirect sunlight throughout the day.

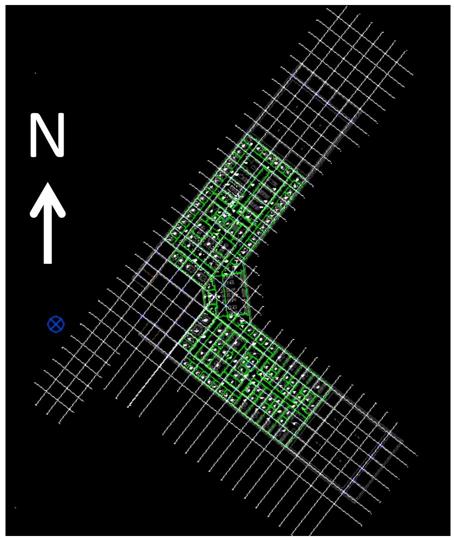

Figure 10: Building Orientation.

There is not a façade that faces due south, west or north. The connecting bridge between the two wings has a face that is almost due east. This east-facing area has a student study/café on the third floor and a pair of conference rooms on the second floor, which will primarily be used in the late morning and afternoon, avoiding direct sunlight during peak use. Each other façade is primarily dominated with student computer cubicles and offices, where direct glare can be most problematic.

Overall solar sun path of December 21st shows that the inside façade of the Material Science wing will receive low angle direct sunlight from roughly 8:30AM until noon. The south facing façade of the Life Science wing will receive low angle direct sunlight from roughly 10:00AM to 3:00PM. These two faces of the Millennium Science Complex will be primary concerns for both visual comfort and heat gain during winter months.

During summer months, the interior face of both Life Science and the Material Science wings will receive low angle sunlight in early mornings, and high angle sunlight during the late mornings. During evening hours, the north facing façade of the Material Science wing could receive direct low angle sunlight, but the Student Health Center will block direct sunlight due to its close proximity.

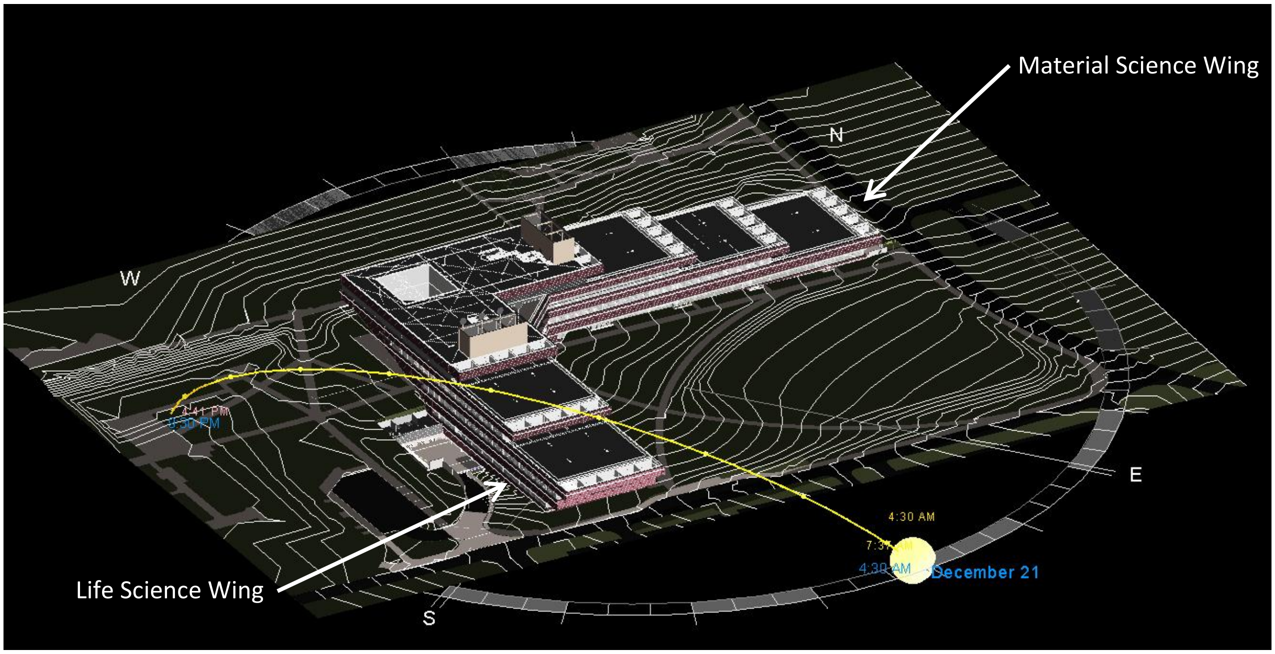

Figure 11: December 21st Sun path.

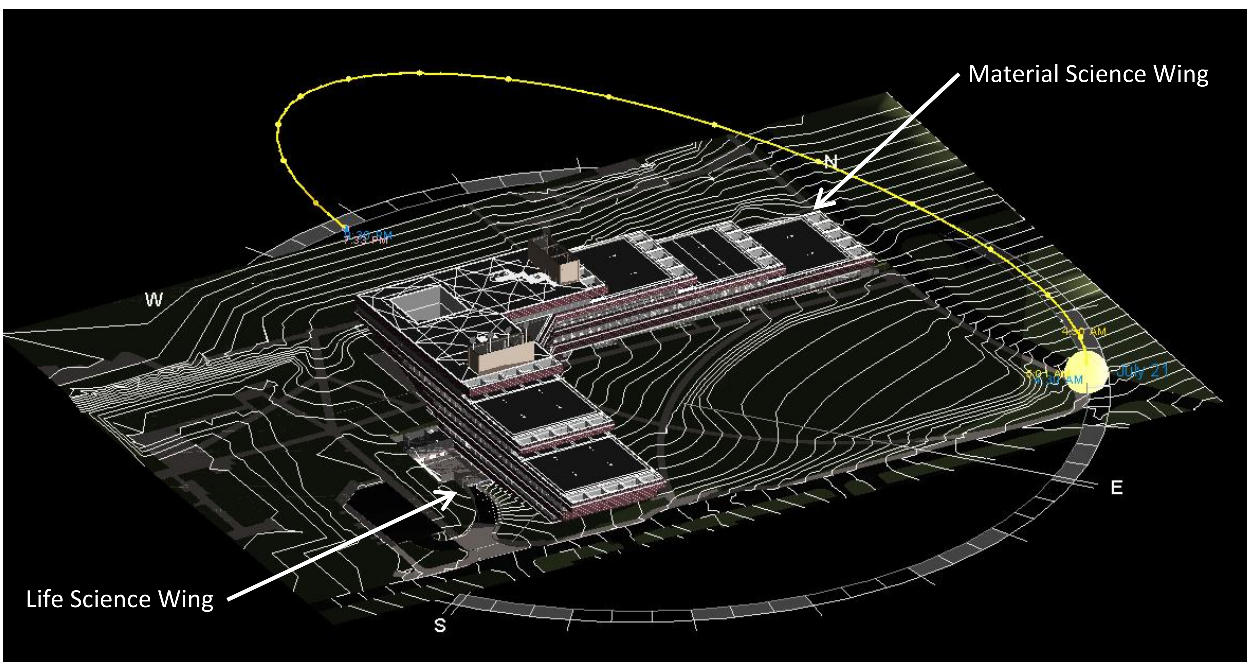

Figure 12: July 21st Sun path.

Current daylight design uses three techniques: an 18” louver placed at the midpoint of each exterior glazing, a 2’3” setback of the glazing off the face of the precast brick façade and a fritted glass on the upper half of the glazing. The louver and overhang are each shown in Figure 14, while the louver system is detailed in Figure 13. The louvers, overhangs and frit are homogenous across the entire building even though the daylighting demands on different facades are entirely different. This is presumed to be for architectural uniformity.

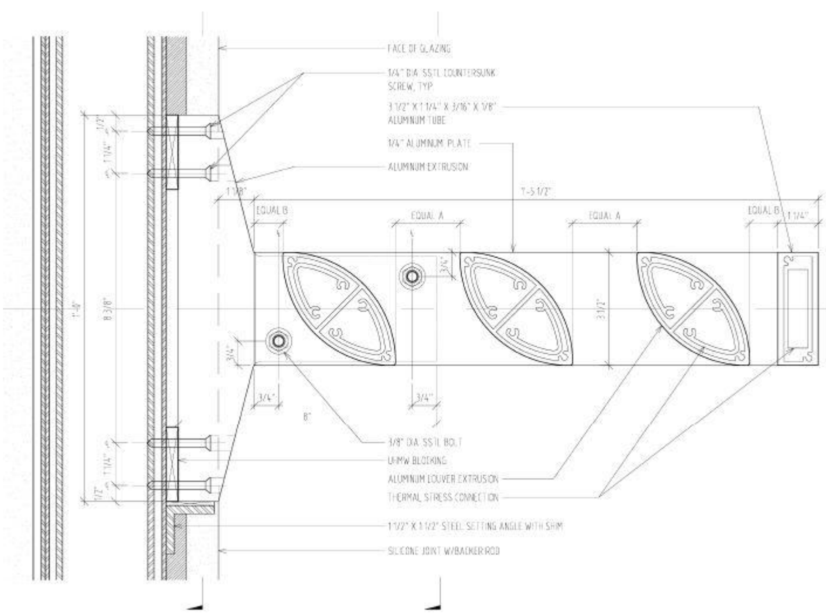

Figure 13: Exterior Louver Detail

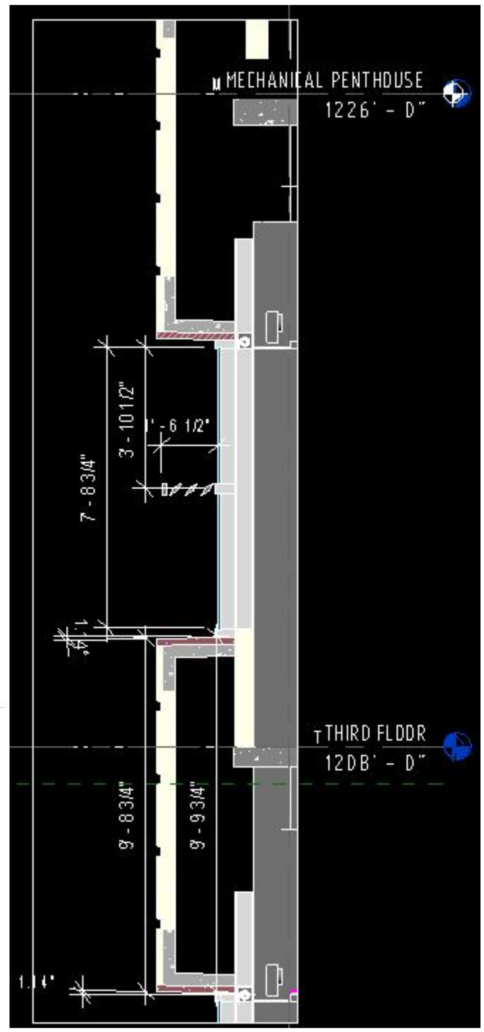

Figure 14: Typical Exterior Wall Section

The combination of the overhang and louvers will help keep high angle sunlight from directly entering a space, but do very little for low angle solar positions. Deep penetration of sunlight on the south-west facing façade is overpowering during winter months, particularly for computer based activities. Figure 15-Figure 20 below show the deepest sunlight penetration from low solar angles on this façade during December 21st while showing high solar angles on July 21st. These diagrammatic comparisons show both the pros and cons of the implemented daylighting techniques at the Millennium Science Complex.

December 21st *July 21st*

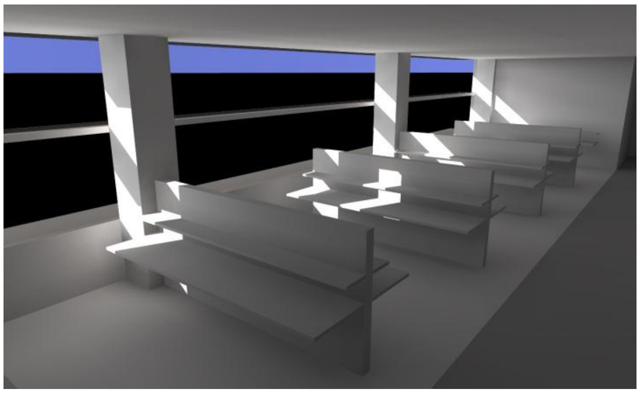

Figure 16: Southwest Facing Facade - Dec. 21 (10:00AM)

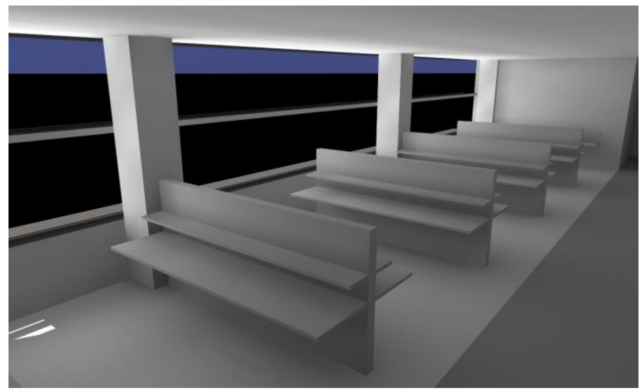

Figure 15: Southwest Facade - July 21 (11:30A)

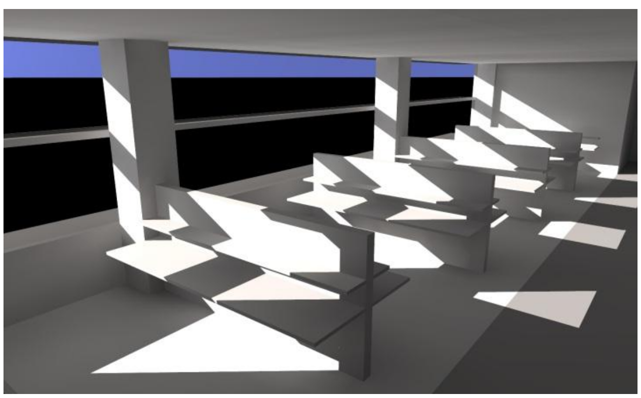

Figure 18: Southwest Facing Facade - Dec.21 (12:00PM)

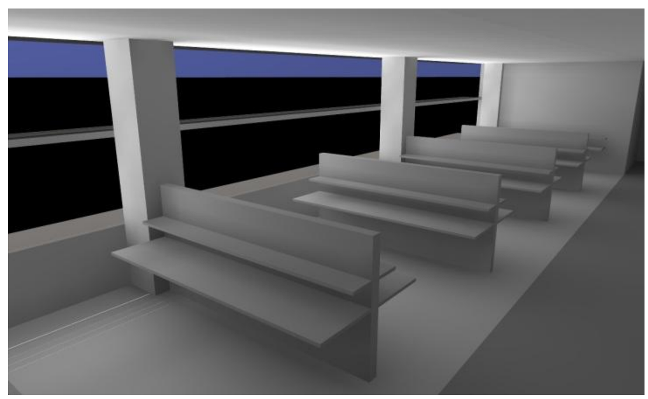

Figure 17: Southwest Facade - July 21 (1:30P)

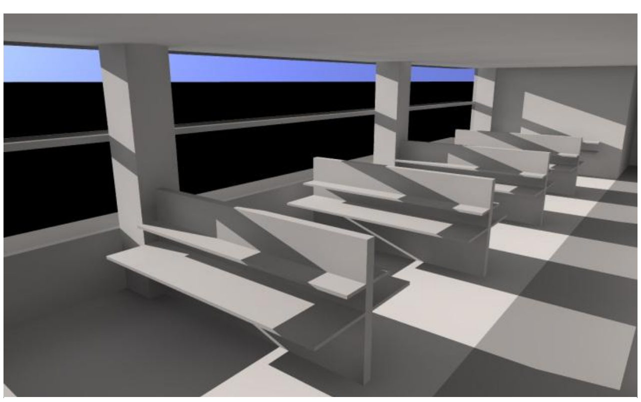

Figure 20: Southwest Facing Facade - Dec.21 (2:00PM)

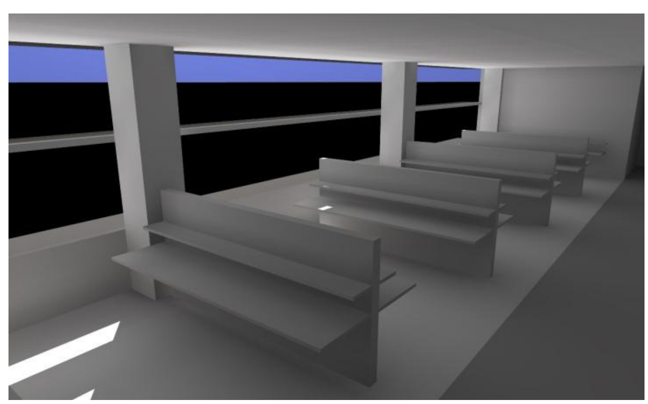

Figure 19: Southwest Facade - July 21 (3:30P)

Similar effects are shown on the southeast facing façade of the Material Science Wing. This façade will have deep sunlight penetrations during both early winter and summer mornings. The sun will stay lower in the sky during winter months creating a longer lasting direct glare than in summer months.

December 21st *July 21st*

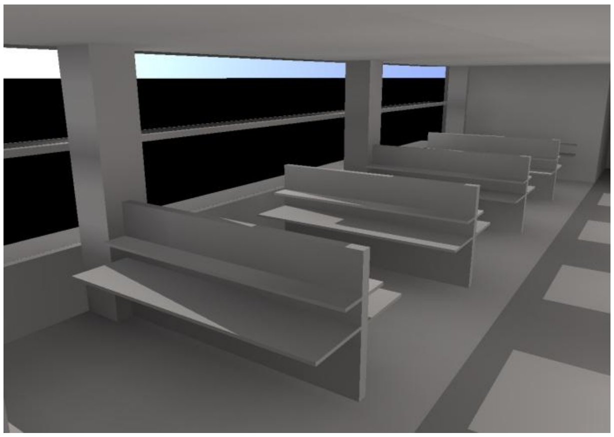

Figure 22: Southeast Facade - Dec. 21 (9:00AM)

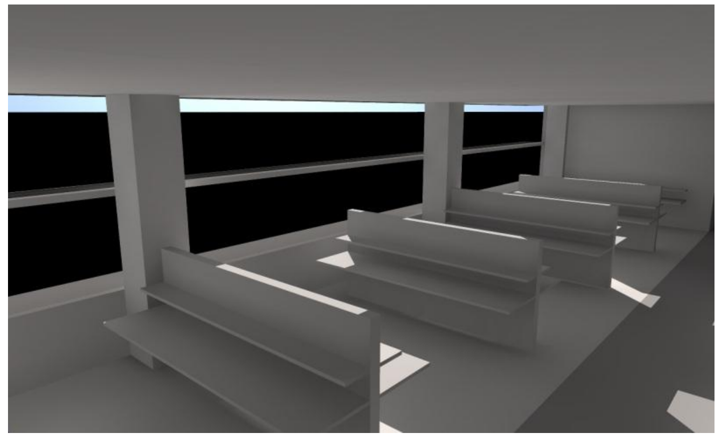

Figure 21: Southeast Facade - July. 21 (6:30AM)

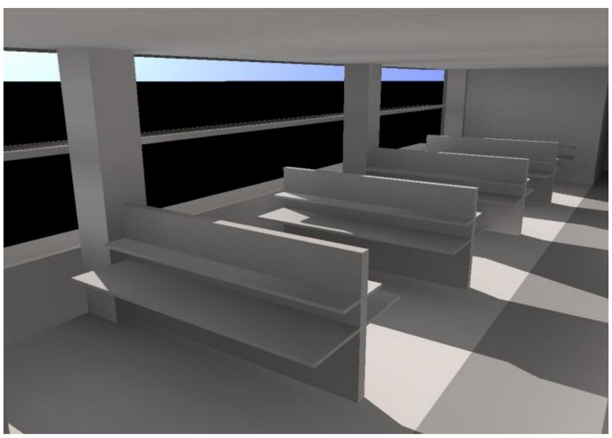

Figure 24: Southeast Facade - Dec. 21 (10:00AM)

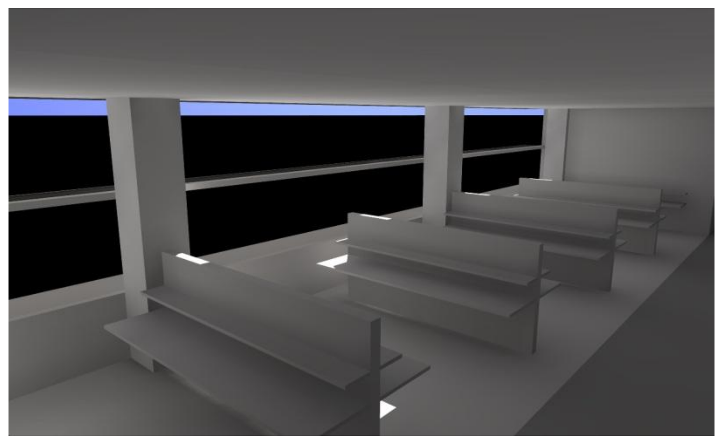

Figure 23: Southeast Facade - July. 21 (7:30AM)

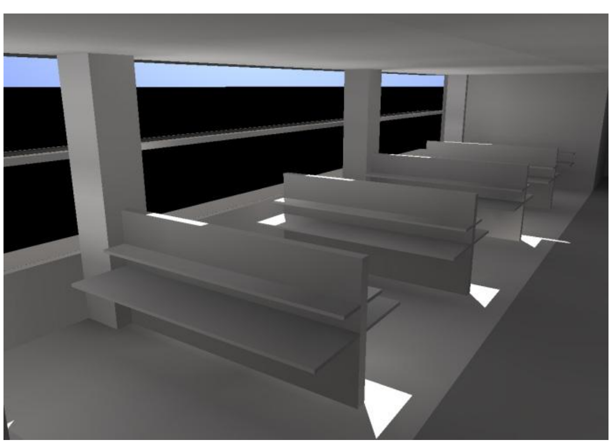

Figure 26: Southeast Facade - Dec. 21 (12:00PM)

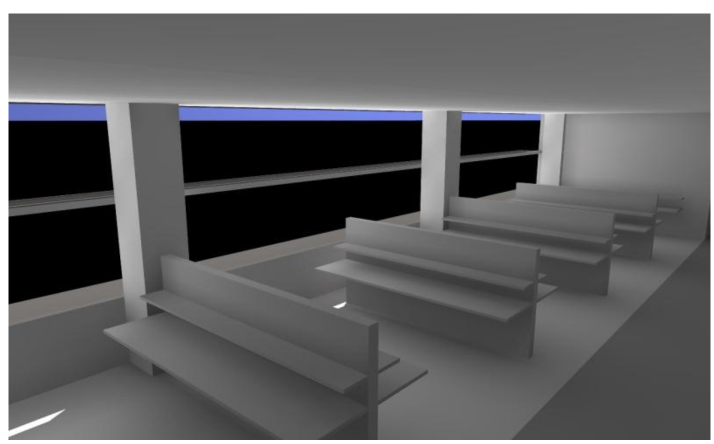

Figure 25: Southeast Facade - July. 21 (8:30AM)

Additional Exterior Louvers for Daylighting

Several primary goals were considered for the initial redesign of the daylighting system:

- Reducing Heat Gain
- Reducing Direct Glare
- Reducing Electric Light Loads
- Aesthetics
- Functionality
- Energy Savings

The daylighting system could greatly benefit from the addition of more solar shades. Adding several shading devices, whether they are louvers, similar to the current design, or a perforated metal panel, will create better overall angles for interim solar angles found between the extremes of winter and summer. In addition to horizontal louvers, the addition of a vertical element may be required to cut down wide solar angles from early morning and evening direct sun. Vertical shades can greatly change the overall look of the Millennium Science Complex, taking away from many of the continuous horizontal lines in the façade. Since maintaining the current architectural theme is a key element of design considerations, careful consideration of the vertical shading devices must be taken into account.

A comparison study of the original design and the addition of both vertical and horizontal shading devices is shown in Figure 7 - Figure 32. The initial redesign adds one-foot deep vertical mullions at 11 feet center to center and three horizontal shading devices, for a total of four. The continuous horizontal shading devices keep the theme of horizontal lines on Millennium Science Complex intact. The study shown was at the worst case scenario for low angle direct sunlight on the southwest facing Façade of the Life Science wing.

Though the initial redesign does not fully create a glare-free environment, it does help. Looking at the figures, the direct sunlight is cut roughly in half. A different configuration of horizontal louvers will more likely furnish better results. An additional option is to take care of the lower sun angles with adjustable louvers implemented on specific facades. Use of adjustable louvers would maximize functionality of the shading devices while maintaining a virtually uniform exterior façade.

December 21st - Original Design

December 21st - Initial Redesign

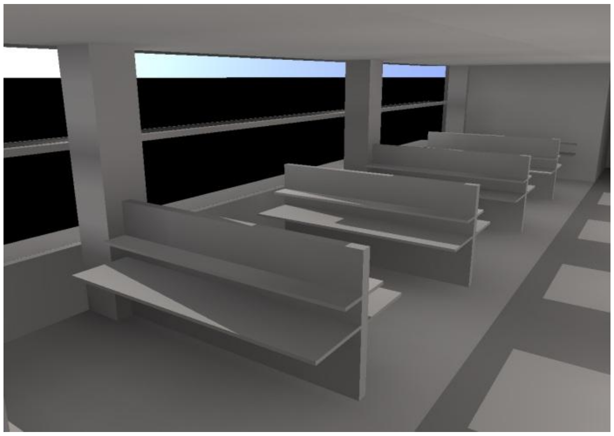

Figure 27: Southeast Façade – Dec. 21 (9:00AM)

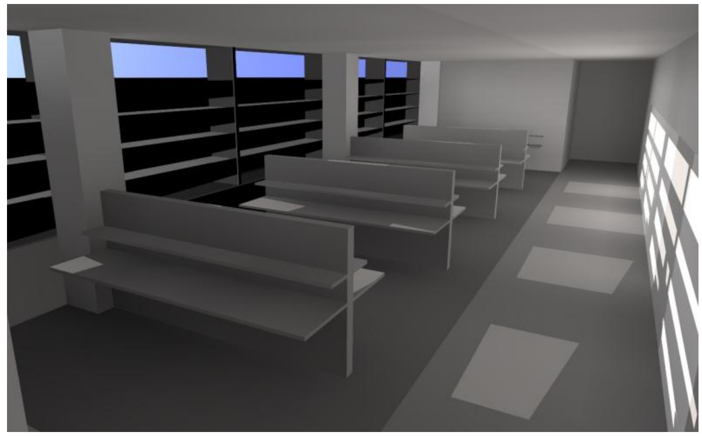

Figure 28: Southeast Façade Redesign – Dec. 21 (9:00AM)

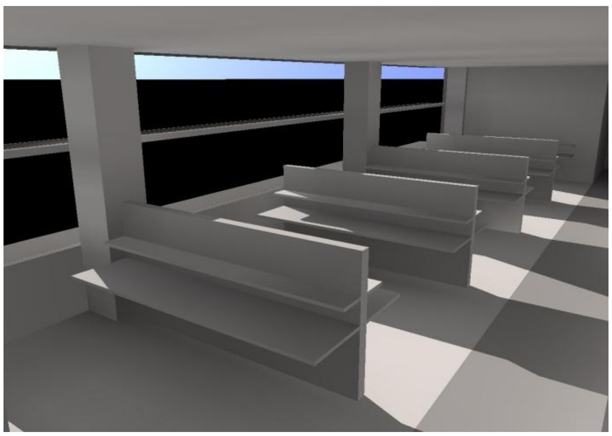

Figure 30: Southeast Façade – Dec. 21 (10:00AM)

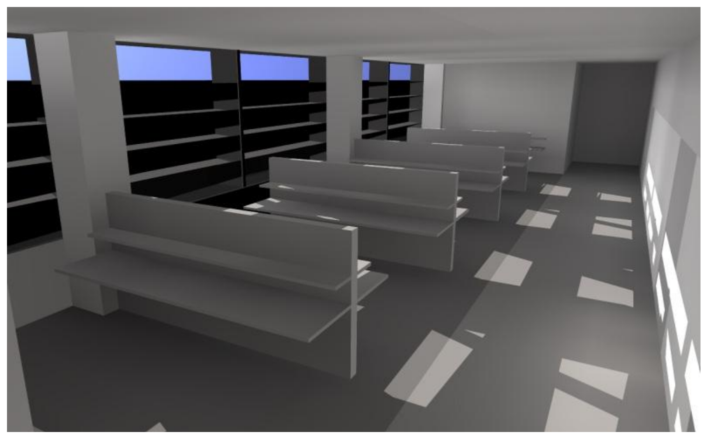

Figure 29: Southeast Façade Redesign – Dec. 21 (10:00AM)

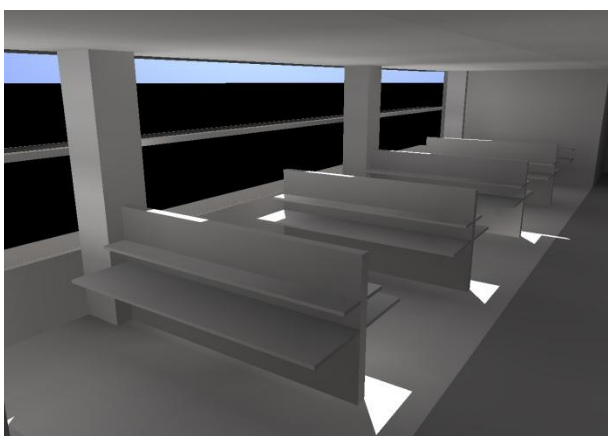

Figure 31: Southeast Façade – Dec. 21 (12:00PM)

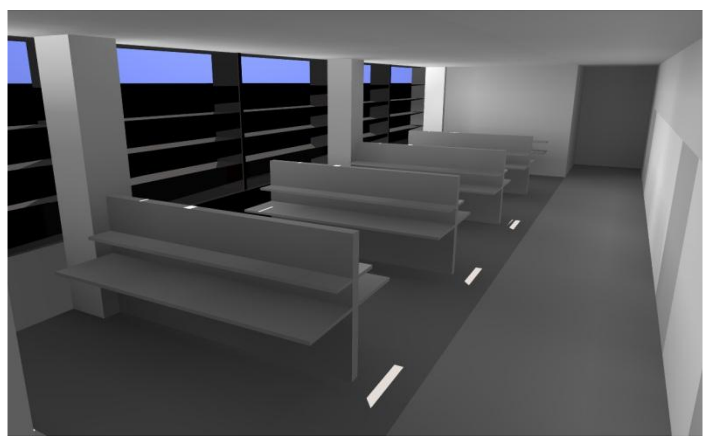

Figure 32: Southeast Façade Redesign– Dec. 21 (12:00PM)

Overall Evaluation

In conclusion of the study done on the existing daylighting systems, there are great deficiencies in limiting direct sunlight and solar gain of low solar angles with the equipment configured as it currently is. High solar angles are able to be filtered out on some facades more than others, but in general still allow more direct gain than is desirable. Internal shading systems will have to be used throughout the building, possibly creating an undesirable non-uniform image from the exterior of the building.

Direct solar heat gain can greatly stress the mechanical systems. If the daylighting is not properly addressed, the efficiency of the building enclosure will be greatly sacrificed. Providing a functional exterior shading system will limit the heat gain load into the exterior rooms.

Since the Millennium Science Complex already utilizes an addressable dimming ballast electrical lighting design with occupancy sensors and daylight sensors, a properly designed shading system would maximize the benefits these systems can provide.

It is uncertain at this point in time the exact information on the exterior glazing. All that its certain is that is fritted on the upper half, while not on the lower half. Future information will provide more accurate details on the transmittance and heat gain of these glazings. Once this information is provided, a study will be conducted to determine if there are more efficient systems available.

Coordinated/Integrated Design Alternative

To approach choosing an alternative system design it was decided that The Building Stimulus would focus on efficiency. In terms of building design, efficiency covers a wide array of topics such as, saving money, time, energy, and resources. The main challenge with this approach would prove to be collaboration among disciplines. As a group it was decided that each discipline would perform their own research highlighting a few possible alternative systems and present this data to the group. Each group member presented an efficient alternative system to the group and the impact these systems would have on the other disciplines can be found discussed below. The systems under review were method of building enclosure, daylighting redesign, structural floor system, and alternative air distribution.

The building enclosure offers a great opportunity for redesign and coordination between all the disciplines. Researching alternate enclosures such as metal panels and light weight precast panels introduced benefits to all disciplines involved, specifically regarding structure and coordination. The proposed solutions would alter coordination minimally, if at all, and would relieve the structure of a significant amount of dead load. While utilizing the proposed options may require cooperation from the architect with aesthetic alterations, the advantages of the proposed solutions are invaluable. A double skin façade is proposed to be integrated into the current structure to address daylighting and heat gain associated with solar radiation. Due to its unique air compartment, solar shading devices can be installed inside the façade, isolating the components from weather. Snow, rain and wind will not alter the intended design or integrity of daylighting equipment. In the event that automatic mechanically operated shading devices are incorporated into the daylighting integration system, this controlled environment will protect the mechanical components from freezing or water damage. Architecturally, the use of a double skin façade will allow for a completely uniform building enclosure. The exterior glazing of the facade will run flush with the precast panels, limiting the view of the solar shading devices. Diminishing the view of the solar shading devices from the exterior will allow for a more functional daylight integration design, by allowing the facades to be designed on a face-by-face basis. This approach allows the enclosure to be tailored to the outside conditions by controlling solar heat gain and encouraging natural ventilation. The double skin also increases the thermal insulation of the envelope which makes this a viable choice for reducing the building's energy consumption. The construction practices and structural system are not negatively affected by the addition of a double skin façade.

The typical 22 ft. square bays of the Millennium Science Complex translate well to using a flat plate floor system. The ease of construction, simplicity of formwork, and thin depth needed to support the applicable loading are all advantages that make this floor system the most desirable. The thin slab allows for shorter story heights which translate to significant cost savings when taking into consideration the ability to decrease vertical runs of MEP systems, cladding, partition walls, etc. As discussed previously switching from a steel to concrete structural system tremendously affects construction practices. The design will impact specific phases and direction of construction. While lead times would be minimalized, additional consideration would need to be put into the pouring and curing of concrete slabs during the cold winter months in State College, Pennsylvania. During design phase, construction methods need to be considered as major constructability issues arise when potentially designing a full concrete facility or deciding to build concrete legs and a steel cantilever system.

Overall, chilled beams appear to be a viable option for redesign in the Millennium Science Complex. While the initial costs for chilled beams are more than traditional diffusers, the operation costs generated from this system provides savings for the lifetime of the building that will offset the capital cost. As long as the system is designed properly, the reduced duct sizes will allow the AHU sizes and fan energy to decrease as well. This in turn allows room in the plenum space to increase, which gives more room for the electrical conduit, mechanical ducts and piping, and structural systems to fit more cohesively. Currently, the Millennium Science Complex has an average floor to floor height of 19 feet, where an average of nine feet is left for both structure and mechanical systems. However, the plenum space is very compact as each system fits snugly into the space. Additionally, the decrease in AHU sizes translates into a reduction in weight needed to be supported by the structure at the mechanical penthouse level. Many manufacturers of chilled beams offer units that can be integrated with luminaires. This would allow a consolidation of building systems and not negatively affect the construction time line because only one unit must be installed as with the current system using only a luminaire and no chilled beam. Applying chilled beams as a new system for many of the spaces enhances the coordination between the disciplines with respect to the shared plenum space.

Appendix A: Table of Figures

Works Cited

1. Holbert, David H, P.E. Concrete: Floor Framing Systems, lecture 10/4/2010.
2. Fanella, David A. "Concrete Floor Systems: *Guide to Estimating and Economizing*". 2nd Ed. Portland Cement Association, 2000.
3. Poirazis, Harris. "Double Skin Facades: A Literature Review." Department of Architecture and Built Environment, Division of Energy and Building Design. Lund University, Lund Institute of Technology, Lund 2006.
4. Natural Gas . org. "Natural Gas and Technology." http://www.naturalgas.org/environment/technology.asp
5. Labs for the 21st Century, Best Practice Guides. http://www.labs21century.gov/toolkit/bp_guide.htm
6. US Department of Energy. Energy Efficiency and Renewable Energy. http://www.eere.energy.gov/basics/renewable_energy/
7. Figure 1: Office building with metal panel enclosure http://www.metalarchitecture.com/Default.aspx?PublicationID=3&ArticleID=543&Title=Best+Smooth+Metal+Wall+Panels%3A+Cardiovascular+Innovation+Institute%3A+An+Expression+of+Cutting-Edge+Research
8. Figure 2: Hollow Steel sub frame used as lateral support for glass curtain wall http://www.wandglas.ro/en/