2012

SENIOR THESIS FINAL REPORT

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Construction Management
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Executive Summary

The purpose of this final report discusses four analyses conducted on the Biological Research Laboratory. The in depth analyses are designed to improve the construction processes of the project while delivering a better overall facility to the researching staff. Included within the report are also two breadths which redesign building systems to be more effective. Topics covered in the analyses include the design of modularization for interior spaces, Building Information Modeling incorporating virtual mockups, renewable energy systems and labor productivity.

Analysis 1: Modularization of the Laboratory Spaces

Modular units in recent years have been a viable solution for quality construction. Fabricating in an offsite location is less expensive compared to field assembly as well as has the scheduling benefit of reducing the overall duration. Quality is also assumed to be higher than if constructed in a factory, inexperienced subcontractors can perform unacceptable work which can delay the schedule. The analysis showed that it was possible to reduce the schedule by approximately 6 months by modularizing the interior spaces. A cost breakdown also showed a savings of $ 80,000.00 on all of the laboratory, procedure and animal holding rooms.

Analysis 2: BIM Implementation with Virtual Mockups

Virtual mockups allow users also to express their opinion on sample lab areas for space requirements and layouts without construction. Comparing virtual mockups to field mockups along with the users' opinion on which space can be more effective is a large piece of this analysis. A benefit of not using as many field mockups is the reduction of waste associated with the project, which can affect the LEED rating. Techniques learned in 597A will be applied, regarding modeling and the presentation of the virtual mockup. The creation of a virtual mock-up for this analysis allowed the user to catch a potential mistake on the plans and by not constructing the lab space in the field also potentially saves $ 110,000.00.

Analysis 3: Sustainability

Sustainable and energy efficient design is becoming mandatory by many owners and facility managers. The BRL Facility consumes high amounts of energy because of the redundant systems, allowing the building to achieve only LEED silver. Using techniques learned in AE 897G as well as other architectural engineering classes, the idea of solar panels will be implemented onto the facility. The study involves placing two set of panels onto the BRL facility while having a series of car canopies over the parking lot. Since the University is a non-profit organization, a power purchase agreement was set up in order to make the system viable. The total cost of the system was approximately $325,000.00 with a net present value of $5,500.00.

Analysis 4: Labor Resources Schedule Acceleration

The critical path of the project lies with the construction process, if one or more of these activities are not completed on time the project completion date would not be achieved. This analysis will examine the schedule of the project and break down different activities, imposing several changes to accelerate the project schedule. The introduction of a rolling 4 day 10 hour schedule on steel erection, placement of concrete on decking and the construction of the exterior walls created a schedule reduction of approximately 5 weeks. The cost saving were also broken down for the steel erection crew with a saving of approximately $ 34,000.00.

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My Family

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Project Description

The Biological Research Lab is an Animal Biological Safe Laboratory (ABSL-3) located on the Pennsylvania State University Campus. The laboratory's design of a modern barn captures the nature of the surrounding facilities. Making up the façade, the rusticated concrete masonry units, metal roof and unique windows fit with the agricultural part of campus while providing a high efficiency building envelope. The facility as seen in figure 1 is approximately 20, 330 square feet and has a scheduled cost of $23 million which is funded by the National Institutes of Health (NIH) along with Penn State.

Figure 1 - Courtesy of Payette Associates

The Animal Biological Safe Laboratory went through a lot of different designs due to the source of funding as well as taking into account the complex and one of a kind facility. Many BSL-3 facilities (Biological Safety Laboratory) across the country are modular built making it easier to construct the redundant mechanical systems required to carry out testing. The central design of the lab allows for a single corridor down the center of the building with a conference room utilizing the large window for natural daylight in figure 1. One benefit of design was to incorporate future expansion on the north side of the building.

The facility is comprised of three floors plus a basement; research will take place on the ground floor while Air Handling Units are located above, and the chilled water system and hydronic (boiler) system below in the basement. Other systems that are included in the mechanical penthouse are the effluent decontamination system, electrical and plumbing. Due to NIH standards the research laboratory was designed to meet construction and redundancy standards for ABSL-3 facilities. The U.S. Green Building Council, an organization that promotes sustainability in how buildings are designed and constructed, created a certification for green building entitled LEED. The new Bio-Research Lab is currently seeking the level of LEED Silver just above LEED Certified which is mandatory for all new construction on The Pennsylvania State University campus. The new facility will achieve this rating through concepts such as utilizing recycled materials and local materials to construct the new building.

Building Name	Biological Research Laboratory
Location	University Park, Pennsylvania
Occupant Type	Business (B); Research Facility
Gross Building Area	20,000 SF
Total Number of Stories	3 Stories: Including Basement and Mechanical Penthouse
Total Building Cost	Approx. $23,000,000
Project Delivery Method	Design-Bid-Build (CM at Risk)
Period of Construction	8/27/11- 1/31/13

Existing Conditions

The Biological Research Laboratory, on The Pennslyvania State University's main campus, is located in the agricultural area of campus north east of Beaver Stadium (below) in figure 2. The location was deteremined based on other similar facilities that are present in the general region. The contour on the site contains a gradient of 20 feet sloping down to the back of the proposed construction location. An environmental assessment also had to be performed on the site for the National Institute of Health (NIH) in order to receive grant money for the project. One of the stipulations for the environmental assessment was an archeology study of the disturbed area. The archeology was used to help determine the Biological Research Lab's effect on the environment.

Figure 2

The actual site itself has major utilities that need to be modified in order to place the Laboratory in its desired position. Animal fencing for cattle grazing needs to be removed around the site to make room for the approved blue wind screen fencing by the university. The building foot print lies directly on a cow pasture with an abundance of irrigation and other utility lines as seen in Appendix A. As per design requirements, all the utility lines that lie in the construction zone must be remove and relocated. More importantly is the existing sanity sewer line that runs in the construction area which is planned to be capped, removed, and redirected. Another utility underground that needs to be removed is a water line which falls directly under the building foot print of the Biological Research Lab.

The area is also a concern for pedestrian traffic through the site during football games (below) Figure 3. The Laboratory has a close proximity to the stadium as well as sits adjacent to current tailgating fields. Due to public safety during construction the fence around the site will be secured and locked anytime there is no competent person on site.

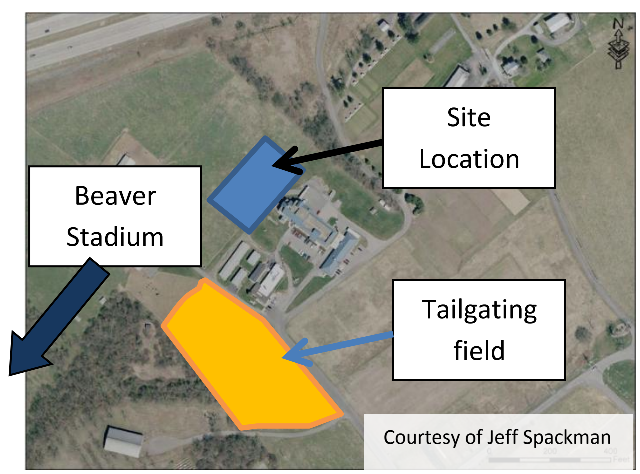

Figure 3: Arial Map of the BRL site

Site Layout Planning

In preparation for excavation plan (Appendix A-1), a site fence was placed around the construction area to enclose further work from the general public while maintaining all university protocols. Torcon, the Construction Manager on the project, placed their trailer near the gravel road leading up to the site. One of the first delays on the site involved getting temporary utilities to the trailer. On the site for the excavation phase will be dump trucks, bull dozers, and excavators preparing for foundations and the superstructure.

The soil stock pile will be located in the back corner of the site remaining out of the way for the duration of the project. One reason why the topsoil stock pile was placed in this region was to prevent labor and equipment moving material twice. During this phase a new parking lot was added, ultimately to be a paved lot for faculty parking at the facility. Temporary lighting was also provided in this lot for safety reasons. Material storage trailers are also placed on site and used by the sub-contractors for storage and equipment while working on the project. In an effect to make work more productive during the excavation phase of the project convenient bathroom locations were also planned to cut down on walking time to and from the bathrooms.

The construction of the superstructure involves moving certain equipment off site while preparing different areas for laydown in order to speed up the erection process. At the beginning of the superstructure phase, a mobile crane was introduced to the site in order to erect the structural columns and beams. During this phase the dump trucks and excavators are vacated from the site to reduce equipment costs on the project. The bull dozer, however, stays to ensure there is a solid and level base for the mobile crane as it travels around the site preforming steel picks. The site plan can be referenced in (Appendix A-2) for more detail.

Looking at the site logistics for the superstructure site plan also has changed in comparison to the previous excavation plan. First the portable bathrooms have moved to locations such as the material storage area to be closer to the work being performed. Dumpsters have also been dispersed around the site to not only comply with the LEED silver rating but also to keep the site clean with convenient locations around the building. Crane placement, material staging, and storage area was critical because it allows the project to have efficient production. The placement of the crane would have been better if place in front of the building but could not due to sloping topography. This resulted in placing the material storage and the crane behind the structure, allowing the crane to walk along the back of the building when preforming different steel picks. A downside to placing material in the back of the site is difficulty getting to and from the material storage area, slowing production.

Upon completing the project, the finishes site plan prepares and implements site re-grading and final paths for the site which can be referenced in more detail in (Appendix A-3). Bull dozers are brought back to the site in order to finish the top soil grading for final landscape and placing grass seed. Referencing the site plan the soil stock pile is split in half to increase efficiency to the left and the right of the laboratory. During this phase a compacted gravel road is installed leading up to the back of the facility. Concrete trucks are also on the site delivering material to both the front and back of the laboratory, finishing the walkways, steps and concrete pads for utilities.

The Pennsylvania State University, owner of the project, did not want to disclose the temporary services on the project. These temporary utilities were installed with every intention to be permanent. Other site changes for this phase included adding more dumpsters to account for added materials inside the building. These dumpsters were placed at the entrances to the facility as well as by the material storage area. The amount of portable bathrooms was also increased and relocated to shorten the distance for crews and increase their productivity. After the Finishes site plan the facility is ready to be turned over to the owner with only punch list items left to finish before the occupancy of the structure.

Local Conditions

Through research Centre Country does not contain any bylaws on construction. The permitting process in the region is however a bit difficult. Construction documents must be approved by the county which could take up to a couple of weeks to review. One fact about building permits in Centre Country is they do not expire so if a building is put on hold as long as the design does not change the permit is still valid. Looking at parking at the site, the construction area for the building allows for multiple parking for cars as well as a new parking lot installed in front of the proposed facility. Crews as well as the Construction Management team should have amble parking during times when peaks crews are preforming work on the structure which can be seen in Figure 4.

Figure 4: Future BRL Site

Penn State University's BRL is located in Centre Region County where they have their own guidelines for recycling and tipping fees. On the Centre County Solid Waste authority's website one can find specific prices and set weights for waste. The Fees for waste in Centre Country are priced at 70 dollars per ton for municipal waste. Recycling on the site states the removal of material is pro-rated at 5.00 per ton.

Geotechnical Report

The site of the project lies on top of Ordovician aged limestone which is a carbonate rock. As limestone decomposes it produces a variable layer of soil. Due to the irregular soil, rock condition of the site, and level of decomposition cavities or sink holes have a possibility of forming. After boring samples were taken from the site it was determined that rock was present at 1.5 to 19.0 feet below the ground. Excavating could be quite difficult in these areas and blasting, ripping, jackhammering, along with other methods might be needed to place foundations at the correct levels.

During the geological surveys no water was encountered when drilling for boring samples. The amount of stannic water on the site should be anticipated to change throughout the course of construction. The amount of water on site will ultimately be determined by the amount of precipitation, run-off, infiltration, site topography, and proper drainage. Drainage on the site should run away from the building preventing sinkholes from affecting the structure.

Client Information

The Pennsylvania State University is paving the way in infectious disease research where a lot of funding comes not only from government agencies but the NIH (National Institutes of Health) as well. The Huck Institutes of the Life Sciences, a college at the University, has been extensively hiring, funding faculty and making advancements in the infectious disease division. Over 100 faculty researchers, research associates, and postdoctoral researchers are involved with infectious disease research at The Pennsylvania State University. The University has also won many awards for their contribution in the infectious disease department from the USDA, NSF, DTRA and private Gates foundation.

Even with all of the staff employed by the University, the capacity for research with biosafety Level three (BSL-3) agents is limited. There is no ABSL-3 space, or Arthropod Containment Level three (ACL-3) space, while the only BSL-3 Space is a wet bench lab approximately 150 NSF located in the Life Science Building. An Animal Biological Safe Laboratory level 3 (ABSL-3) facility was always a goal for The Pennsylvania State University due to the increased amount of research funding. In 2007 the initial design for the laboratory was created and a preliminary site was chosen to be presented to the planning commission. The design incorporated each type of research space and with as much flexibility as possible while still following all of the constraints for a BSL-3 facility. All of the initial design steps were accepted except for the fact that the project cost estimates, which were nearly three times the amount budgeted. The immunology and infectious disease program at the University has been growing quite rapidly and in 2009-10 twelve new faculty members were recruited to work for the department.

In order for the University to build the proposed building they needed to obtain partial funding to subsidize the rest of the building cost. The National Institute of Health (NIH) which funds a lot of Penn State University's research in this area also provides grants for institutions that propose to expand, remodel, renovate, or alter biomedical or behavioral research facilities. The University allocated around $8 million from the project and through a grant from NIH which requested $15 million a total budget for the project came to $23 million making the construction of the project actually feasible.

Dealing with Penn State University their standards for quality and safety are above the rest. On all projects on campus any worker or visitor entering a jobsite must have a hard hat, safety glasses, and hard soled shoes. Also due to the Penn State Master Plan (beautification process) any construction must be surrounded with a blue wind screen fence to hide the ongoing construction from faculty, students and prospective students. The quality of work is also important to the university not so much as because of the buildings location but due to the fact that this is going to be a highly technical and unique project. The Biological Research Facility is one of the only structures in the country that's not modular or part of another building but stands on its own. Just as researchers from Penn State visited other facilities to come up with their own designs research professionals will visit Penn State University's state of the art facility. This makes quality more import because the BRL Laboratory is going to become the face of the universities research department for infectious diseases.

Project Delivery System

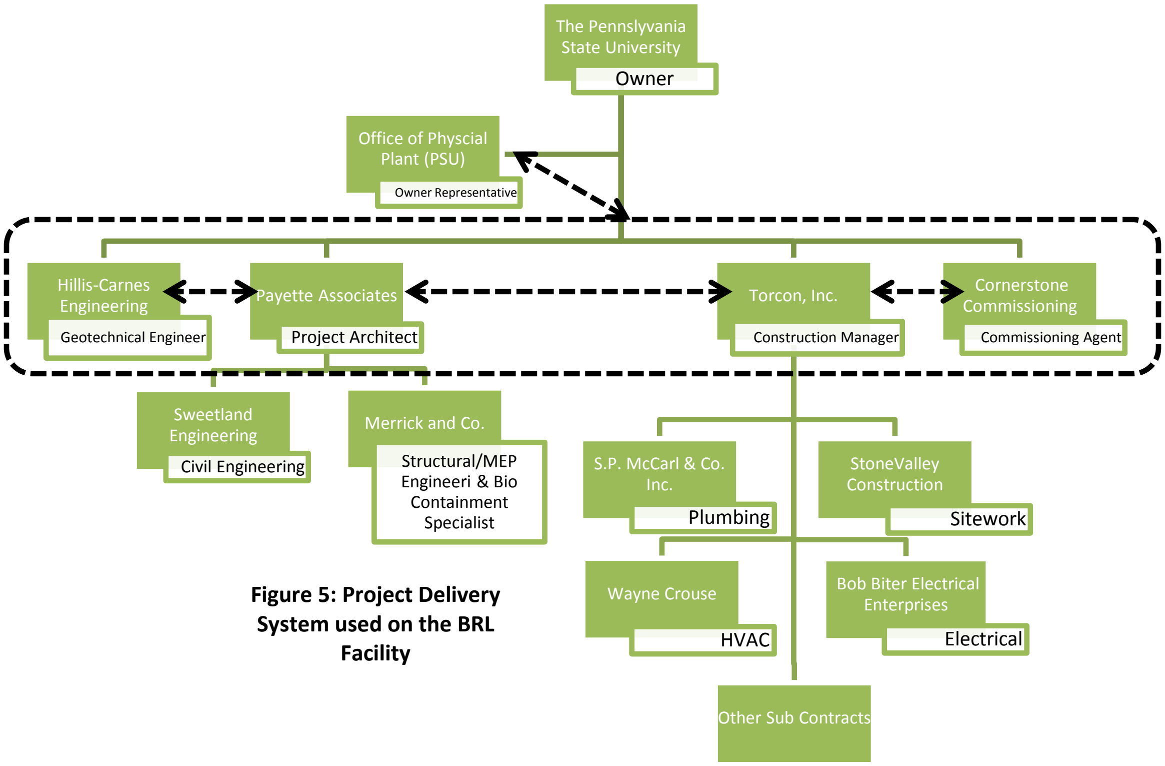

Figure 5: Project Delivery System used on the BRL Facility

The project delivery method for this project at the Pennsylvania State University falls under a Design-Bid-Build contract. This being a University project, Office of Physical plant acts as a owner's representative to the University and College of Life Sciences. The project was funded from two main sources one, the National Institutes of Health (NIH) along with Penn State University making this project a Guarenteed Maximum Price bid. NIH requires, in order to receive grants for ABSL-3 facilities, to have a geotechnical survey completed along with a environmental impact study . They also require to have a commissioning agent available during the course of the project.

Many Construction Management firms submitted a proposal for the project but based on the evaluation of capable firms, past experience with the University, and knowledge in ABSL-3 facilities, only the best suited was chosen. Torcon Inc., The Construction Manager on the project, issued a Guaranteed Maximum Price for construction and bids for all of the subcontractors are awarded to the lowest, prequalified bidder. Torcon will, as the Construction Manager at Risk, hold all of the Payment & Performance bonds on the project dealing with subcontractors. The CM firm will also collaborate closely and communicates with the Architect, Commissioning Agent, and Geotechnical Engineer to deliver a valued project to the University as seen in Figure 5. These four entities will similarly have direct communication with the owner's representative, Office of Physical Plant, in regards to schedule, cost and qualtity on the project.

Staffing Plan

The Torcon construction management service was selected to complete and construct the BSL-3 laboratory on the Pennsylvania State University Park campus. Torcon has had an extensive knowledge in BSL-3 and ABSL-3 facilities, laboratories, animal facilities, and manufacturing facilities to help apply technologies in a BSL/ABSL-3 design. The project team, in Figure 6, not only understands the architectural and HVAC requirements but also has growing knowledge in Biosafety cabinets, autoclaves, cage washes, water systems, incinerators and waste handling systems.

The project team's Scott Loureiro and John DeFazio will be involved with the project front the contract award untill the closeout of the project. Scott will serve as the primary contract with the University and OPP. John will have an executive oversight and in control of all of Torcon's resources to ensure the success of the project. Within the project team is a technical design review committee that are MEP specialists with extensive knowledge and experience with similar facilities. They will be in charge of performing technical reviews to ultimately add value to the product the client is receiving. Peter Gardener who manages the commissioning and sustainability services at Torcon will be in initial design reviews where his knowledge in vivariums will be valuable.

Torcon will also provide two full time staff members at all times first Mike Beatrice the project superintendent and Victor Ziobro the project engineer. Scott Loureiro will be on site at once a week maintaining his central involvement with the project. The job conference meeting will be held every two weeks led by John DeFazio along with the rest of the Torcon Project team on sight. The job conference meeting, depending on who is present at the meeting will either be held at the site or at another location.

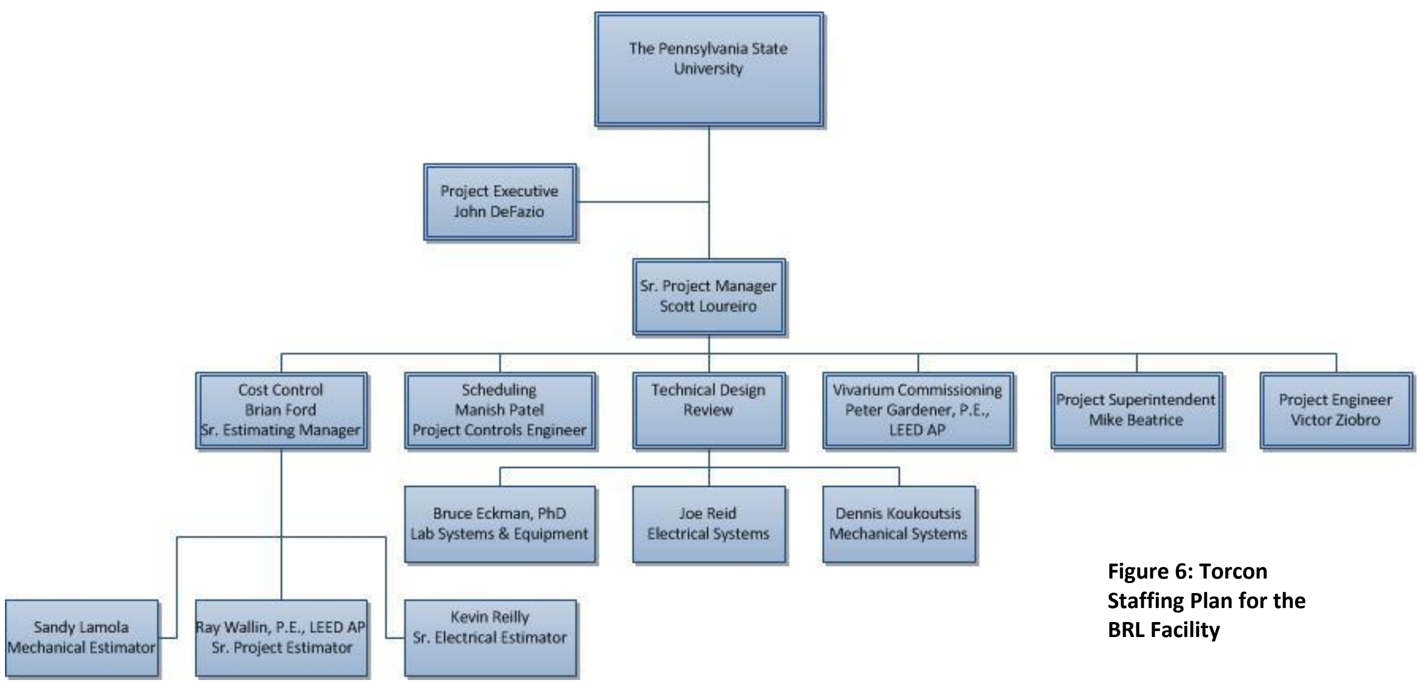

Figure 6: Torcon Staffing Plan for the BRL Facility

Building System Summary

Demolition

Removal of material from the site will consist of existing utilities lines that lie within the construction fence. These utilities will be relocated around the building footprint or just removed depending on their prior purpose.

Structural Steel Framing

The first floor was comprised of a 2 inch metal composite deck with 2.5 inches of lightweight concrete. The steel throughout the structure will be comprised of both HSS4x4x4x3/8 as well as a series of wide flanged columns, W8x31 being the most commonly used. The beams in the structure are also supported by a series of hollow core structural steel as well as different types of wide flanged beams. The roof is comprised of a 1 1/2 inch metal decking that is supported by joists and the joists transfer the load to the beams and ultimately the columns which is a typical loading path for this building. On the site a mobile crane will be used to perform the steel erection process.

Cast in Place Concrete

The building footprint sits on a series of reinforced spread footings for the steel columns where the spread footing reinforcement extends into the column footing. The other form of structural support for the building is continuous footings which support the concrete wall, CMU and split-faced block walls. According to the geotechnical survey of the site, the wall footings and column footings must be 18 and 24 inches respectively to avoid punching shear failures. Below the column and wall footers was a soil of 3000 lbs/sq ft. or if soils were not approved in the location of the foundation, an eight-inch compacted sand buffer placed over rock must be utilized. A minimum of a six inch slab was used for the basement floor which sat on 4 inches of compacted stone. The foundations walls are reinforced and modular slab form is used to cast the concrete walls.

Mechanical System

The Biological Research Lab is based upon NIH and Association for Assessment and Accreditation of Laboratory Animal Care (AAALAC) standards for interior cooling loads because of storage of animals inside the facility. The regulations were only applied to the labs and holding rooms inside the facility while ASHRAE was used for all of the remaining design conditions that were not addressed with NIH or AAALAC standards. The building utilizes two air cooled chillers supplying 44 degree Fahrenheit water to the five main Air Handling Units throughout the building. The chilled water pumps also have variable frequency drives for maximum flexibility with the pump/chiller operations. These five main Air Handling Unit's have heat recovery coils for 100% outside air units which supply fresh air to the containment labs. Along with the Air Handling Unit's, there are a series of fan coil boxes with no humidifiers to circulate air throughout the facility in the mechanical rooms, stairwells and corridors.

The hydronic systems in the research laboratory consist of two boilers rated to be 100% of the winter capacity which is the peak load for the building. The boiler pressure is 100psig and will be delivered at that pressure to the decontamination system. The effluent decontamination system used in the Animal Biological Safe Laboratory is a combination of steam and chemicals which completely destroys the targeted bacteria or pathogens. The system is applied to waste which is tested within the biocontainment lab. Using pressure reducing valves steam will be lowered from 100psig to 80 psig to supply and used as process steam throughout the building. The preheat, heat exchangers, humidifiers and heat exchangers utilize pressure reducing valves to reduce the 80psig steam down to 15 psig to serve the equipment.

Electrical System

The electrical service into the building will be a 480Y/277 service that feeds a 1600 Amp double-ended switchgear. The power flows downstream to a pair of 1200 Amp switchboards which are fed from separate sides of the 1600 Amp double-ended switchgear. These two switchboards will supply the power to the mechanical, lighting and receptacle panel boards. The panels boards for the ABSL3 and BSL3 will be supplied from different panels located outside the containment barrier. The service for the facility will be calculated as sized not only for the anticipated load but will include an additional 25% capacity for growth. A generator will also be placed on site for standby/emergency and all life safety loads will be redundantly wired alongside with normal power in case of an emergency.

The interior lighting will consist of high efficiency Light Emitting Diode fixtures and T8 fluorescent lamps placed in corridors and common areas. Lighting in all animal rooms will be individual controlled and have scheduled cycling which are all independent of each other. Throughout the facility emergency lighting will be placed, connected and powered by the life safety system. All of the luminance levels follow the IESNA and NIH requirements.

Masonry

The exterior masonry on the ABSL-3 is a CMU decorative veneer. The wall type will have a two inch air space behind the wall along with a two inch piece of polystyrene rigid insulation with an expected R-Value of 10. The wall is supported by hangers that attach to a cold formed steel stud wall, as seen in figure 7.

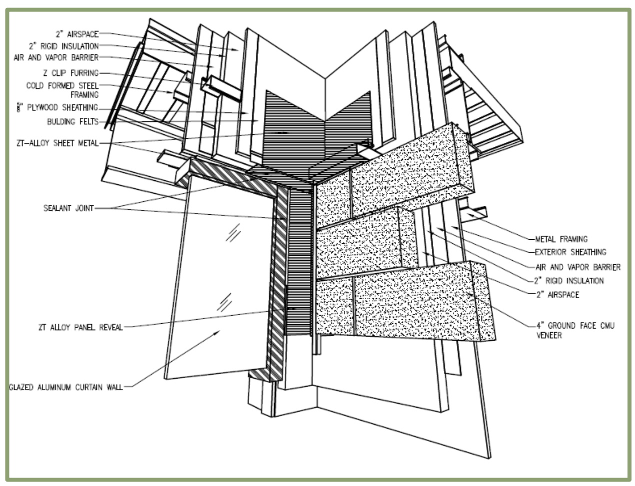

Figure 7: Geometric View - Courtesy of Payette Associates

Support of Excavation

The location of the site is on a slope with the grade level of the building in the front and an exposed basement to the rear. Excavated material towards the back of the building only needs to be below the frost line of the ground. The back of the building does not need to be supported with a trench box or benched walls because the excavated height is below 5 feet. The front and sides of the building utilized a benching method to comply with safety regulations when placing the footers and foundations. A geotechnical survey was also performed on the site and found no high water tables in the area which prevented the need for dewatering systems.

Project Cost Evaluation

The Estimate Provided by Torcon, the construction manager, was given to the owner representative, Office of Physical Plant (OPP), to show system costs as well as the cost of construction. These values do not represent the subcontracts on the project. The values however can be assumed to be within a reasonable range in relation to the actual estimate for the project.

Total Project Cost:

Construction Costs	Actual	Cost/SF
Square Footage of Project	**20,330 SF**	
Actual (without general requirements):	$ 15,541,043.00	$ 764.44
Actual (with general requirements):	$ 16,672,993.00	$ 820.12
Total GMP Cost:	**$ 23,000,000.00**	**$ 1,131.33**

Table 1: Construction Costs

Building System Costs:

Building System	Actual Cost	Cost/SF
Concrete	$ 782,891.00	$ 38.51
Masonry	$ 93,381.00	$ 4.59
Structural Steel	$ 510,670.00	$ 25.12
Metal Panels	$ 555,930.00	$ 27.35
Glass and Glazing	$ 344,415.00	$ 16.94
Plumbing	$ 1,194,547.00	$ 58.76
HVAC	$ 3,876,351.00	$ 190.67
Electrical	$ 1,921,420.00	$ 94.51

Table 2: Building System Costs

General Conditions

The cost of the Biological Research Laboratory was in part due to many general conditions established by Torcon, the construction manager, on the project. In the estimate below all figures are approximations and are not the actual contracted amounts between The Pennsylvania State University and Torcon Inc. Five categories make up the general conditions, outlined in Table 3, for the project which is the management and staff, Issuance and permits, temporary utilities, office trailer and supplies, and finally miscellaneous items.

General Conditions Breakdown	Cost
Management and Staff	**$ 413,400.61**
Insurance and Permits	**$ 308,297.03**
Temporary Utilities	**$ 129,814.17**
Office and Equipement	**$ 17,507.95**
Miscellaneous	**$ 143,360.12**
TOTAL	**$ 1,012,379.88**

Table 2: General Condition Costs

Full-time management and staff on the project consists of three members from Torcon, a Sr. Project Manager Scott Loureiro, a Project Superintendent Mike Beatrice, and a Project Engineer Victor Ziobro. On the CM team for the BRL facility is also the Project Executive John DeFazio who is not involved full time on the project as well as a BIM coordinator whose role is to lead the weekly 3-dimensional coordination meetings amongst the Subcontractors. Other part time staff includes a safety site manager who made visits once a week along with a desk clerk at Torcon's main office filing necessary paperwork. Hourly rates for the estimate were based off of Torcon's projections which are labeled under daily output in Appendix B.

Insurance and permitting under general conditions includes builders risk insurance, permits, and performance bonds. These values from RS Means were listed as a percentage of the total cost of the job alongwith including overhead and profit. When calculating the values of the insurance, permits and bonds, the bid cost of $23,000,000 was used to achieve the appropriate figure. Contractor's equipment, another item from RS Means placed insurance on rented equipment on the project. The only substantial equipment, incorporated into the General Conditions estimate was a 50'X12' trailer with air conditioning along with 3 portable bathrooms around the construction site.

The site needed the addition of temporary utilities including temporary heat, running an average 12 hours a day when needed and lighting including service lamps, wiring and outlets. The units for these quantities are presented in CSF which equates to every hundred square feet of building space. Other temporary utilities such as power for temporary lighting and power for construction over the duration of the job were calculated in the same fashion. Portable toilets, considered a temporary utility was rented and priced per unit per month during the duration of the 17 month project. A total projected cost for temporary utilities over the duration of the project amounted to $129,814.17.

General conditions on the project were also broken down into work space and materials. One line item which can be seen under office and storage trailer in Appendix C-1 is a 50 foot by 12 foot office trailer. The mobile workspace was rented by Torcon to house the project team as well as holding weekly contractor meetings about the progress of the BRL facility. The size of the trailer was estimated based on what actually was present in the field. In order to operate during construction, the construction manager incorporated office equipment, office supplies, a telephone for conference calls as well as lights and heating, ventilation and air conditioning. These takeoffs were referenced to RS Means and have a unit for price per month. The total projected cost for office and storage trailer takeoff on the general conditions estimate amounts to $17,507.95.

Miscellaneous items in general conditions such as vehicular access and parking, temporary fencing, signage on the project; cleaning and waste management and finally building commission were grouped together. In the beginning of construction access roads which led in and away from the site needed to be widened to allow room for the delivery of materials and equipment. The access routes were widened with crushed blue stone and through RS Means can be quantified as square yards of material, suggesting an 8" base layer. Project identification or signage fell under general conditions too, the CM provided safety and construction postings throughout the site to inform all necessary parties. Signage from R.S. Means quantified into total square feet of signs on a project. Clean sites are a necessity in construction; Torcon utilized a cleaning crew which through R.S Means can be calculated per thousand square feet of a structure. In the general condition estimate weekly cleaning crews were implemented as well as a dedicated crew before the turnover of the project. This section of general conditions also incorporated the building commissioning on the project which was a total percentage of the project. Miscellaneous line items in the general conditions estimate amounted to a total of $143,360.12.

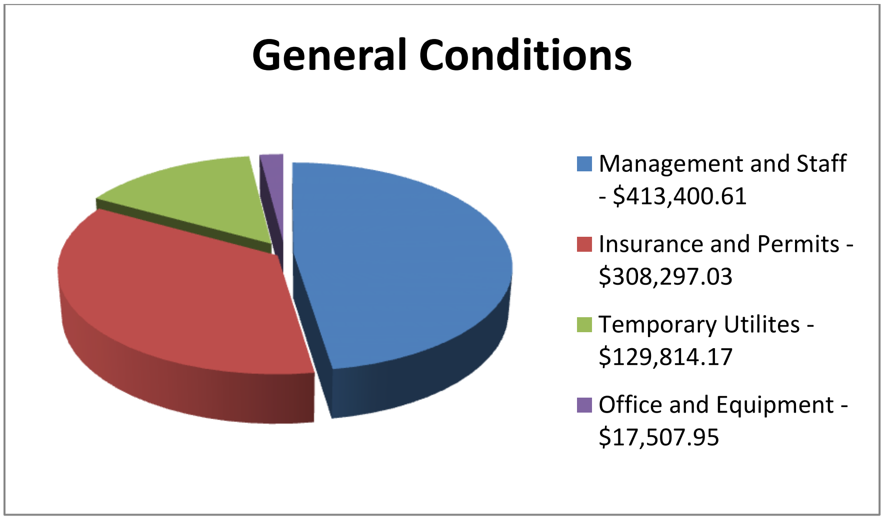

Table 4 : Breakdown of General Conditions in Percentages

The pie chart in Table 4 shows the breakdown of each of each section of general conditions which sums up to **$1,012,379.88**. An estimated projection for general conditions provided by Torcon totaled $1,131,950; this value should not be assumed to be the actual general conditions value submitted to Penn State. Comparing the estimate to the project reveals a difference of 10.5%. This inaccuracy can be associated from numerous reasons but management and staff seemed to be part of the discrepancy. When calculating the rate of several employees, many of the personal could not be found in R.S. Means so they were interpolated. Another discrepancy found was the hourly wage rate. Through R.S. Means, a comparable person's hourly rate was significantly lower than what Torcon claimed on their staffing plan. Adjusting these values would significantly decrease the difference in error, producing a better general conditions estimate.

The General conditions data was gathered from R.S. Means Costworks online. This online program uses the latest quarterly values so inflation was not calculated on top of the values regarding all of the line items. Costworks also takes into account the location of the project being constructed, adjusting values to appropriate levels. One item on the general conditions estimate was signage which estimated based on the total number of square feet of signs on site. Since this value was extremely difficult to calculate an assumption was made based on the size of the project to use 500 total square feet.

LEED Evaluation

LEED 2009 evaluates Green Building Design and Construction on several different categories including sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and design process, and regional priority credits. The Pennsylvania State University seeks LEED certification as a minimum on every new construction and renovation project on all university campuses. Areas of focus for the University are energy conservation, natural resources conservation, prevention of environmental degradation, people's health (well-being), comfort, and finally total cost of ownership.

Sustainable Sites

A focus category for LEED is Sustainable Sites (SS) which place an emphasis on reducing environmental damage and pollution associated with the construction of buildings. The Penn State Master governing how the campus is to be developed presently in the future, many times will not comply with the first three credits under sustainable sites. The Biological Research Lab's location was pre-determined well before design and fails to achieve SS credit 1, SS credit 2, SS credit 3 in Appendix D. These three credits promote not building on green fields, constructing in an already developed area with a density of 60,000 square feet per net area, and using brown field or contaminated sites according to the 2009 LEED reference handbook[1]. Different forms of transportation are not critical to university policy; university officials are more focused on bicycle transportation, providing changing rooms and showers over offering alternate low energy vehicles with lowering parking costs for carpooling. Only one out of thirteen points has a possibility for being achieved in this area because of the needs of the university.

Site development along with storm water design is very important to Penn State due to its size and environmental impact from students to faculty. Land development on the University Park campus falls under the Penn State's master plan and the beautification process, keeping the campus's topography and vegetation very selective. Storm water Design is mandated by the university, the Office of Physical Plant design services complete a storm water plan and project for every new project on Penn State campuses.

The energy consumption in recent years nearly has placed a strain on the steam plants, chiller plants, and ever increasing electric bill for Penn State, so the SS credit 7 from the LEED check list in Appendix D is important. The BRL laboratory is a high consuming facility because of the redundant mechanical systems, needed to run the laboratory rooms, so reducing energy is essential for this project. The heat island effect utilizes materials that have a high solar reflectance covering at least 75 percent of the roof surface in Figure 8.

$$\frac{\text{Area Roof Meeting Minimum SRI}}{\text{Total Roof Area}} \times \frac{\text{SRI of Installed Roof}}{\text{Required SRI}} \geq 75\%$$

Roof Type	Slope	SRI
Low-sloped roof	≤ 2:12	78
Steep-sloped roof	> 2:12	29

Figure 8: table used to calculate the solar reflectance index from the 2009 LEED reference Handbook.

The Sustainable sites section in the LEED 2009 Checklist achieved 4 points with the possibility to achieve 8 more points through restructuring transportation and light pollution reduction.

Water Efficiency

The Biological Research Lab in order to reduce water consumption was landscaped with native plants that require no water. This design of the landscape allows the BRL facility to obtain four points in water efficiency, two points for reducing water by 50% and two points for eliminating irrigation to the site for plants. The project also incorporates water efficient fixtures throughout the building which allows the building to achieve a point under water use reduction. Water use is calculated based on the current baseline for fixtures, an estimate of occupancy usage, which can be correlated to a percentage of reduction using the Figure 9 below according to the 2009 LEED reference handbook[1].

Commercial Fixtures, Fittings, and Appliances	Current Baseline
Commercial toilets	1.6 gallons per flush (gpf)* Except blow-out fixtures: 3.5 (gpf)
Commercial urinals	1.0 (gpf)
Commercial lavatory (restroom) faucets	2.2 gallons per minute (gpm) at 60 pounds per square inch (psi), private applications only (hotel or motel guest rooms, hospital patient rooms) 0.5 (gpm) at 60 (psi)** all others except private applications 0.25 gallons per cycle for metering faucets
Commercial prerinse spray valves (for food service applications)	Flow rate ≤ 1.6 (gpm) (no pressure specified; no performance requirement)

Figure 9: Table used to calculate water reduction from the 2009 LEED reference Handbook.

Energy and Atmosphere

LEED for 2009 requirements has increased the standards from the previous checklist created in 2002. The optimized energy performance credit now for this year in 2009 must achieve points in this category unless a reason of design impedes the increased efficiency. The base standard for evaluating LEED energy performance comes from ANSI/ASHRAE/IENSA standard 90.1 90.1-2007, obtained from the 2009 handbook. The BRL scores eleven points in this field with an improvement in energy performance of 32 percent.

The implemented design of the ABSL-3 facility contained no features of on-site renewable energy which can earn a total of three points. The site where the laboratory is being constructed is surrounded by open and green space. One suggestion to achieve points in this field is to create a solar based car canopy system. The photovoltaic system would fulfill more requirements than just generating renewable resources by having the ability to charge alternative powered vehicles, as well as fulfilling the preferred parking requirement creating the potential for an additional 8 more points. Under Energy and Atmosphere the research facility complied with enhanced commissioning, enhanced refrigerant, and measure and verification for a total of three points.

The Energy and Atmosphere checklist, which can be seen in Appendix D, for the BRL obtained 14 points out of a total of 35 points for this section of the 2009 LEED checklist.

Materials and Resources

The Animal Research Lab composition is strictly a new construction project which lacks the reuse of any existing walls, floors, or roof forfeiting 3 points of materials and resource section of the checklist. However, the facility is on track to achieve the standard for recycling 75 percent of waste on the site with the coordination of, the construction manager, Torcon Inc. leading the initiative. Material reuse is also apparent inside the structure with 20 percent of material derived from post and pre consumers. The design team also made an initiative to incorporate regional materials on the project as well as use certified woods which implements environmental forest management. The Materials and Resources checklist, which can be seen in Appendix D, for the BRL obtained 7 points out of a total of 14 points for this section of the 2009 LEED checklist.

Indoor Environmental Quality

In order for the project to receive funding in the form of grants for over half of the project sum, the National Institutes of Health (NIH) required the mechanical systems to be enlarged and incorporate redundancy in the BRL facility. These requirements helped to achieve air quality LEED points in outdoor air delivery monitoring and increased ventilation of the space. Torcon was also responsible for adequate ventilation for construction laborers during construction and before occupancy. Appropriate levels of ventilation during and after construction achieve four points for the LEED scorecard in the indoor quality section. Low emitting materials which reduce air contaminants were used; these materials focus on reducing vulgar odors, irritating chemicals which can be dangerous to the laborers installing the materials[1]. Thermal comfort design and verification are also incorporated into the design of the building with individual controls in the laboratory and in the conference spaces for comfort. A verification and monitoring system has also been incorporated into the mechanical system so a thermal conduct survey can be performed 18-24 months after occupancy. The Indoor environmental quality, which can be seen in Appendix D, for the BRL obtained 11 points out of a total of 15 points for this section of the 2009 LEED checklist.

Innovation and Design Process / Regional Priority Credits

On the Project of the Biological Research Laboratory a Low Energy Headhouse was utilized in the design process. Implementation of a site excavation strategy on the laboratory was also used to achieve exceptional performance in the area of bulk soil removal. Regional Priority Credits were also captured in the BRL project. When analyzing regional credits by area, specifically State College Pennsylvania, water efficiency for landscaping involving reduction of water and the elimination of water are acceptable for the priority credits category.

LEED Evaluation Conclusion

The Biological Research Lab when evaluated according to the 2009 LEED scorecard achieves a rating of LEED certified with a total score of 47 points. LEED Certified has a range of 40-49 points according to

USGBC while a rating of silver has a range of 50-59 points. When the project was designed, the LEED 2002 scorecard Appendix C was in effect and has been grandfathered for the BRL facility. The 2002 evaluation rating of LEED Silver was achieved for the project and awarded once the project is completed in January of 2013. One important item about LEED checklists, they are projections and are not guaranteed. These projections if not successful completed at the end of the project will be removed from the final score, lowering the LEED rating.

Detailed Project Schedule

The Biological Research Laboratory was first presented to the Centre Region Planning Agency which reviewed the land development plan, designed by Sweetland Engineering, in December of 2008 and at this time presented to the public. The College Township later reviewed and proposed comments on the land development plan which needed to be changed before the project could proceed. The architect Payette Associates worked with Penn State as well as Sweetland Engineering to correct the changes proposed by the township. In the beginning of March 2009, the township approved the preliminary plan and allowed the BRL facility to proceed in the design process. Penn State Board of Trustees were notified in late March of 2010 that $15 million dollars in funding by National Center for Research Resources (NCRR) was approved for the project on top of the existing $8 million funded by Penn State. This allowed the laboratory to be redesigned yet again because of the additional funding and new design requirements with accepting the grant.

On July 27, 2011, The Pennsylvania State University, Office of Physical Plant, presented the notice to proceed to Torcon Inc. which began planning and initializing the procurement process for the Bioresearch Laboratory. The detailed project schedule presented several issues with developing a timetable because of the size of the structure. Also, phasing was not apparent on the project since the gross square footage totaled 20330 sq ft., all trades completed their scope of work sequentially. The detailed schedule which can be referenced in Appendix E, contains the breakdown of procurement, construction as well as the closeout for the project. In the procurement stage contract awards are listed based off the division of work as well as the date awarded. In order to keep the schedule close to 200 line items, Table 5 can be referenced for the division of work. Also in the procurement part of the schedule are the submittal and reviews for all of the divisions of work on the project.

Award	Division of Work	Duration	Start Date	End Date
1.01	Sitework	5	19-Aug-11	25-Aug-11
1.02	Concrete	5	19-Aug-11	25-Aug-11
1.03	Masonry	5	19-Aug-11	25-Aug-11
1.04	Structural Steel	5	19-Aug-11	25-Aug-11
1.05	Miscellaneous Metals	5	19-Aug-11	25-Aug-11
1.06	Roofing and Metal Panels	5	19-Aug-11	25-Aug-11
1.08	Plumbing	5	19-Aug-11	25-Aug-11
1.09	HVAC	5	19-Aug-11	25-Aug-11
1.11	Electrical	5	19-Aug-11	25-Aug-11
1.14	Carpentry (incl. 1.16-19)	5	19-Aug-11	25-Aug-11
1.25	Membrane Roofing	5	19-Aug-11	25-Aug-11
1.07	Glass & Glazing	10	19-Aug-11	01-Sep-11
1.12	Fire Protection	10	19-Aug-11	01-Sep-11
1.13	Doors, Frames and Hard	10	19-Aug-11	01-Sep-11
1.15	Special Flooring	10	19-Aug-11	01-Sep-11
1.22	EDS	10	19-Aug-11	01-Sep-11
1.10	Building Automation Syst	15	19-Aug-11	09-Sep-11
1.20	Lab Casework	15	19-Aug-11	09-Sep-11
1.21	Lab Equipment	15	19-Aug-11	09-Sep-11
1.23	Sprayed Fireproofing	20	19-Aug-11	16-Sep-11
1.24	Landscaping	20	19-Aug-11	16-Sep-11

Table 5: Award dates for each division of work

One issue involved with the detailed estimate because the project size was relatively small meant that the detail in the different trades was increased. Especially in the work dealing with the Mechanical, Electrical, Plumbing, Telecom and the Fire Alarm systems, work performed was denoted on the schedule by floor. Abbreviations on the schedule were used of for these areas of work which can be referenced in Table 6.

Floor	Abbreviations
Basement Level	BL
First Floor	FF
Penthouse Level	PH
Mezzanine Level	ML
Utility Yard	UY

Table 6 : Abbreviations for floor levels when sequencing work

The schedule also contains critical milestones in the project denoting the end of different sequences of work. The substructure because of the design of the building, the BRL contains a full basement where the mechanical equipment is stored along with the slab on grade foundations on the first floor. This structural design impacted the way the work was performed, the foundations for the Biological Research Laboratory was completed by floor along the additional site work such as backfilling. The superstructure was also completed in using a floor to floor method which is typical to most construction projects. The building systems as stated above were performed by floor along with the interior compartments and the finishes associated with each space.

The substantial completion for the project set by Torcon is scheduled to be December 19 of 2012 with only project closeout and punch list items before the scheduled turnover. Start up and testing for the Biological Research Lab is essential because of the complicated mechanical systems as well as the different bio containment labs and holding areas. One of the reasons why Penn State chose Torcon is because of their experience in previous work with vivariums. On the schedule, start-up and testing has a duration of 43 days to ensure the building systems and the lab equipment are operating correctly. After testing the Commissioning Agent, Cornerstone Commissioning Inc., would then perform a final review of the finished laboratory with the intention to completing turnover by the January 31, 2013.

Analysis I: Modularization of the Laboratory Spaces

Problem Identification

The Quality of work on the Biological Research Laboratory has been a large concern for many parties during the design and construction phases of the project. Material finishes next to the coordination and installation of mechanical equipment are the most complicated to finish correctly. The contractors hired to complete and perform the drywall installation as well as the floor finishes have specific requirement which must be met in order for their work to be considered finished.

The implications of installing these laboratory finishes could be detrimental to the schedule of the project. Weather and other unforeseen conditions have already pushed the project behind one month. One suggestion is to implement module units for the laboratories and other spaces throughout the facility. This will eliminate inexperienced contractors as well as prevent the project schedule from suffering any more delays.

Research Goal

The goal of the analysis is to increase labor crews on certain activities to bring the project back on schedule. Length and widths of the module are typically designed as multiples of each other, providing easier flexibility for layout. Also, examining the units could suggest that each room be assembled separately because of size constraints with transportation. Modularizing the lab spaces would result in approximately 15 units, sized at 11' by 20'. Manufacturing the labs off site with a contractor who has experience with ABSL facilities ensures the primary goal of acceptable finishes which can significantly impact the schedule.
This Analysis will include the following:

- Background Information
- Case Studies
- Module Design
- Shipping & Installation
- Phasing/Work Flow Plans
- Connections to Utilities/Building Systems
- Schedule Review
- Summary

Modularization Case Study

The Army Corps of Engineers implemented modular construction in regards to the Base Realignment Closure Act of 2005. Their idea was to improve the delivery of buildings using modularization along with other innovative techniques for large scale construction projects. The data and experience

Figure 10: Sam Houston Army Base

from these case studies can be used to show how benefits in productivity, overall project budget, safety, as well as project quality can be achieved on the Biological Research Laboratory. Even though these projects are not research facilities they successfully implemented the design of modular units as well as modular implementation onto portions of site built projects.

Fort Sam Houston Medical Education and Training Complex Barracks

The barrack in Houston Texas was designed to hold 6,000 soldiers with a project schedule of 42 months and projected budget constraints. Hensel Phelps along with the other subcontractors on the project, helped design 5 four story 320,000 square foot facility which can be seen in figure 10. On the project about 220,000 square feet utilized modular units per building, creating a hybrid type construction. The foundation on the project was designed with void form foundations with the addition of steel piles. The superstructure was also field fabricated with steel decking. Once one wing of the structure was completed modular units were added. On the Fort Sam Education and Training Barracks modular components include:

- Classrooms
- Utility rooms
- Stairwells
- Sleeping/Living quarters

The purpose of exploring modularization on the Biological Research Laboratory is to ultimately shorten the schedule while delivering a better quality product to users and researchers of the Pennsylvania State University. Given that the Fort Sam project is a lot larger than the research facility and different types of modules used, the process to design, deliver, and install would still be very much similar.

Shipping and Installation of Modules

The typical modular unit on the Fort Sam project was 13.6 feet by 60 feet long weighing approximately 35,000 lbs seen in figure 11. Due to transportation issues these modules were the largest they could be which contributed to the break up and design of the rooms. On the BRL facility many of the modules will be smaller, broken down by room and by laboratory space. A crucial aspect for modularization to be successful is a plan in which Hensel Phelps utilized on the Fort Sam Project.


Figure 11: Transportation of Modular Units

Exploring deeper in the Army Barracks project, a facility in Belton Texas was manufacturing all of the different types of modular units on the complex. This manufacturing facility was approximately two and a half hours north of Fort Sam but offered other amenities. "The manufacturer was able to store hundreds of modules with no additional cost" stated Ed Zdon senior project manager. Another key item to note is even though the containers needed to be shipped 2.5 hours to site, productivity was not by the elements. Strengthening the point before Zdon also mentions "although shipping of the modules can be costly, they can be built at the factory rain or shine, un-like site built construction, which is subjected to weather delays."

Once on site, modules could be stacked directly atop the foundation using a 250-ton crawler crane into their final position. Utilities on the barrack project ran down the corridor so that it was easier for crews to access them and connecting them to the units. Once all of the essential utilities were connected crews installed drop ceilings to finish the hallway. The quality of work was also above standard on the project with every corridor wall lining up in the first building while in building two, only one corridor needed to be adjusted. A crew typically installed around 12 units a day and each building was comprised of 341 units taking approximately 8 weeks to finish one barrack.

Advantages for Project Schedule

One of the largest benefits to implementing modularization on a project is the impact to the project schedule. "Two-thirds of firms who currently use modularization experience reduced project schedules with 35% experiencing decreases of four week or more [7]." While on many projects, additional time is taken during the design phase to coordinate with different trades. This added tim in design results in shortening the overall schedule of the project. Implementing modularization on a project also allows for less staging of materials onsite as well as the ability to eliminate weather impacts. A study completed by McGraw hill below shows the benefits from contractors, architects and engineers. Contractors throughout the study displayed the biggest savings in the project schedule, when looking at a 2,3, and 4 week or more savings on a project. Due to modularization having an intensive design period, contractors in the study experienced greater saving because their involvement in the project did not start till construction. Integrating BIM with the design of modular units displayed greater saving at 4 weeks or more on more than 50% of all the projects [7].

Advantages for the Project Budget

Time in labor can severely affect the cost of a project especially when unforeseen conditions arise or weather conditions become excessive which halts work on a project. The use of modularized interior units on a project reduces the need for labor on a project as well as associated overtime for workers. Site utilities as in temporary bathrooms can also be reduced on the project because of the decrease in workers on site. The case performed by McGraw Constructions highlights that "65% of firms who currently use prefabrication/modularization report that it reduces their project budget. 42% of total respondents find that these techniques reduced their budget by 6% percent or more." If the design of the units and collaboration is completed correctly change orders can also be reduced. For many owners it is important to clearly know the value of a project by having a guaranteed price or fixed cost. Modularization allows for some avoidance in unexpected cost or change orders especially with owners how have a strict budget.

Miami Valley Cardiac Center

The Miami Valley Cardiac Center was the first major hospital to implement modular units in a large construction project. The project was 500,000 square feet, 12 stories with a total cost of 137 million dollars. Higher quality of construction, safer work environment and shorter construction schedule were some of the many benefits that modular construction provided for the Miami Valley Hospital. On the project Skanska implemented prefabrication/modularization on five key areas:

- Patient room toilets, case work, and head walls
- Integrated MEP racks above corridors
- Modular/mobile workstations for staff assistants
- Curtain wall dividers between patients rooms
- A large temporary footbridge between buildings

Skanska, the construction manager on the project have created a set of "Rules of Engagement when advancing forward with modularization in construction. One large benefit to using modular units is having a repetitive process. The Miami Valley Project had a 178 patient rooms, after several mockups it was easy for the subcontractor to deliver a quality room. These are the "rules of engagement" Skanska had to over on modular/prefabricated projects.

1. "Prefab must serve the design, not vice versa."
2. "Engage key subcontractors and suppliers early in the design process."
3. "Implement BIM-without it, it's almost impossible to do prefab right."
4. "Build a mockup, and test it on occupants and end-users."
5. "Employ just-in-time delivery of modules to keep the job site free of clutter."
6. "Make sure your modules can be delivered on conventional flatbed trucks or the equivalent. A miscalculation here could prove to be an embarrassing expense."

The construction manager Skanska already had experience with prefabrication of modules in the United Kingdom on hospital projects. The Miami Valley hospital would be the first inside the United States. The project managers at Skanska stressed to the users of the hospital that the design of the space was the most important not the modular room.

Design of the Module

Many constraints that came with modular units for the project team actually occurred with the transportation of the pieces. To keep costs low and avoid paying permitting for oversized loads the rooms had to be small enough to fit on the back of a standard flatbed truck. Mobility was also a concern for the project team because on site workers needed to be able to hoists the units and put them in place. Size and transportation constraints produced three major components which was a toilet unit, a headboard and casework unit.

A furniture warehouse was rented by Skanska, the construction manager, less than three miles from the hospital. Subcontractors, before starting the assembly line process created many field mockups for nurses, and other employees throughout the hospital to evaluate. These mockups allowed users of the new rooms to reposition lights and other equipment, making patient care and maintenance easier. The fabrication of the modules used conventional building material for the 178 patient rooms. Waste was also virtually eliminated on the project when constructing these specific modules. All the needed building materials such as metal studs, ductwork, conduits, and pipes were ordered to length creating green construction environment[1].

Lifting and flying these modules with a crane also needed to be incorporated into the structure of the module. The project executive of Skanska stated "We had to figure out how we were going to rig these components and fly them into the building." Someone on the project team had the idea of weighing the modules at a truck stop to figure their exact weight. This allowed the designers and subcontractors to create strong enough supports based on the weight of the module. Workers also on site fabricated special dollies to transport the blade walls and bathroom after they were flown into the building. Impressions of the bathrooms were also sunk into the concrete floor to help align the modules and all of the utility hookups[1]. This idea by the construction manager helped eliminate human error of incorrectly placing the units.

Implementing BIM with Modular Construction

Modular units needed to fit exactly into the structure so incorporating the use of 3-D coordination with Navisworks was necessary. The well-coordinated 3-D models showed the location of every fixture, pipe duct and beam, allowing design problems to be fixed well before fabrication. Subcontractors were also brought when construction drawings were 50% complete aiding in the BIM process (Miami). The additional input from subcontractors allowed for a higher quality of prefab components with few to none changes in the field.

Worker Productivity

On a typical construction project an average plumber installs around 200 feet of pipe above the ceiling per day. On the Miami Valley Hospital project, workers in the fabrication shops were installing approximately 600 hundred feet of pipe, daily. The difference in worker productivity was almost three times greater in the fabrication shops. Salaries for workers in the furniture warehouse also differed; on average 40 dollars per hour was the rate which fabrication workers received compared to 50 dollars per hour out in the field. As the project progressed Skanska had to acquire more space to hold the dividing walls as well as the bathroom units because construction on site could not keep up.

Skanska's Closure on Prefab

In recent years module designs have become more flexible and manufacturers are fabricating off the shelf modules such as bathrooms and other repetitive rooms. This allows for the design for buildings to move through design faster because a product has already been created along with a model to be implemented in construction. Another important concept that Marty Corrado from Skanska mentions is the idea of "just in time production". On the project extra space had to be acquired since the project team under estimated how fast the crews completed the modules. If "just in time production" were implemented on future construction projects a smaller space could be utilized, lowering project costs. After successfully completing the Miami Valley hospital project, the project team for Skanska stated they could have finished and delivered the module in a more completed state with equipment and cabinetry. Another areas where Skanska is considering using prefabrication and modularization is on renovation projects. Utilizing modular units are renovation projects allows components of the project to be completed while still in demolition phase drastically cutting time off the schedule of the project.

Off Site Production

One of the most crucial aspects to a successful modularization process according to a case study performed by the Massachusetts Institute of Technology is a productive factory. Throughout the State College area, presents many opportunities for offsite construction of the laboratory units less than 5 miles away from the site. One location that is promising for the modularization of the facilities lab units is located on Benner Pike in State College approximately 4.5 miles away. This warehouse in the past was used by a lighting subcontractor and contains four loading docks for the transportation of the units. Usable area of the building amounts to 38,000 square feet with a price of $7 per square foot per year. Co-Founder of the RCM Modular stated "Moving production lines are better because it allows each station to become more specialized and faster. You don't have to move, your tools don't have to move and you know that you have a fixed period of time to do your task before it moves to the next station. Static lines feel a lot like building on site to me[3]." The Benner Pike ware house offers enough space to have moving production lines of the laboratory and other spaces.

Transportation

On average certain manufacturers will deliver anywhere up to 400 miles from the site of manufacturing [3]. While the facility chosen to support the Biological Research Facility is only 5 miles away other constraints are also apparent when transporting the pods to the site. Sometimes a transporter many have to deal with multiple government agencies in order to process the module across certain roads and highways. Limitations include potential time delays due to delayed transportation permits from oversized loads and possible dimension restrictions on the modules being transported. According to the Pennsylvania Department of Transportation under Chapter 49: Size Weight and Load within Subchapter B states:

General Rule for the Width of a Vehicle:

> "Commercial implements of husbandry not exceeding **12 feet in width**, including wheels and tires, may be driven, hauled or towed between sunrise and sunset on highways other than freeways."

General Rule for the Height of a Vehicle:

> "No vehicle, including any load, shall exceed a height of **13 feet 6 inches**. This provision shall not be construed to require public authorities to provide sufficient vertical clearance to permit the operation of such vehicles."

Rule for Length of a Tractor Trailer:

> "The length of a single trailer being towed by a truck tractor shall not exceed **53 feet** provided the distance between the kingpin and the center line of the rear axle or rear axle group does not exceed 41 feet or, in the case of a trailer used exclusively or primarily to transport vehicles in connection with motor sports competition events, does not exceed 46 feet."

The total weight you can place on the type of vehicles also differs depending on the truck and the trailer it is attached too.

Combinations of vehicles- No combination shall, when operated upon a highway, have a gross weight exceeding the following:

Combination of Vehicles	Maximum Gross Weight In Pounds
Two-axle truck tractor & single-axle semitrailer	58,400
Two-axle truck tractor & two-axle semitrailer	73,280
Three-axle truck tractor & single-axle semitrailer	73,280
Two-axle truck & two-axle trailer	73,280

Table 7: Maximum Transportation Weight

Modular Space Breakdown

The Biological Research Laboratory is comprised of several different spaces the important one that will be focused on in the modularization depth are outlined in red in figure 12 below. Spaces that won't be focused on in detail are outlined in blue. These spaces consist of showers, offices, storage and equipment rooms. The areas outlines in red are comprised Biological Safe Level two and three labs along with an insectary. Support rooms for each laboratory consist of Animal Holding Rooms and Procedure rooms for each lab.

Figure 12: Modular Space Breaksdown

The size of each room is approximately 11' by 21' which can be transported easily on the back of a tractor trailer. Approximately two units should be able to fit on the back of a standard flat trailer for transportation.

Laboratory Takeoffs

Building Construction Cost Data was used to quantify the total cost of each of the spaces in red in figure 12 above. Spaces consisted of Animal Holding Rooms, Procedure Rooms, Gowning Rooms as well as Biological Safe laboratories level 2 and 3. Many Items were directly matched and found within the Building Construction Cost Data book. Other items such as equipment were priced based on the Construction Manager. Cost of equipment came directly from the GMP proposal, where lists of laboratory pieces were priced in order to achieve the total cost of the building.

In figure 13 below which is a typical wall detail for the laboratory spaces was comprised of two man wall types. The first was a light weight metal stud 2x4 construction of the room walls. This is noted in the Z and Z1 caption in figure 14. Comprised within the wall is a layer of bat insulation specifically R13. Surrounding the insulation are layers of impact resistant gypsum wall board, approximately 5/8" thick with a finishing coating. The floor is also comprised with a resistant epoxy that could not be determined using the Building Construction Cost Data. Resilient vinyl flooring with a thickness of 1/8" was substituted instead to offset the cost of the epoxy floor coating. The second type of wall construction consisted of a 2x6 lightweight metal stud construction Z2 and Z3 in figure 14 . This type of wall construction was used along the perimeter of the bio-containment zone. The bio-containment zone consists of any wall facing the exterior of the building along with the wall which separates the labs from offices and storage spaces.

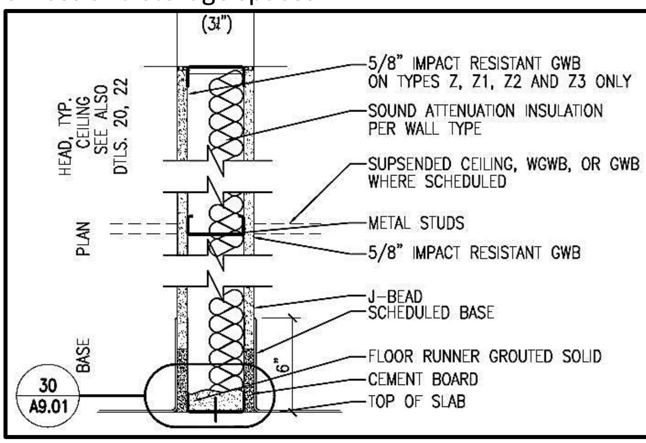

Figure 13: Wall Detail

Z	4 7/8" (3 5/8" STUD) W/ SOUND ATTENUATION INSUL. 1 HOUR FIRE – UL# U465
Z1	4 7/8" (3 5/8" STUD) W/OUT SOUND ATTENUATION INSUL 1 HOUR FIRE – UL# U465
Z2	7 1/4" (6" STUD) W/ SOUND ATTENUATION INSUL. 1 HOUR FIRE – UL# U465
Z3	7 1/4" (6" STUD) W/OUT SOUND ATTENUATION INSUL. 1 HOUR FIRE – UL# U465

Figure 14: Wall Specification

Due to the modularization of the units special floor designs had to be created in order to support the modular as well create a level floor. A ¼" steel plate was used to stiffen the based as a temporary floor as well as 2 X 3 backing under the steel plate at every 12" O.C. to provide additional stiffness. Resilient floor was then placed on top of the steel plate to create a usable floor. The ceiling in most of the rooms was typical except for two layers of gypsum wall board to account for the 30 lbs per square inch positive and negative pressure.

Subcontractor Selection

One of the major reasons why modularization was chosen on this project was to keep the quality of finishes at the level in which NIH requires. Local subcontractors such as the mechanical, electrical, and plumbing contractors can be used but drywall and floor finishing contractors need to be prequalified. These contractors will be required to have laboratory experience in order to submit a bid for the scope of work.

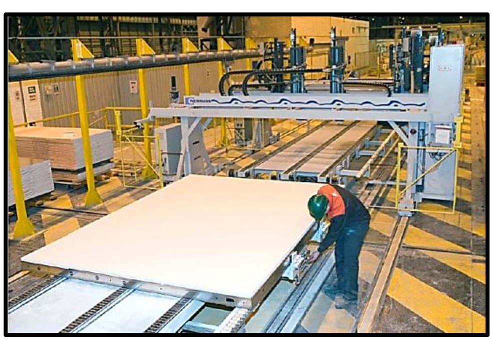

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Figure 15: Manufactured Wall

Design

The design for the lab also needed to be considered for lifting and transportation. A X braced configuration must be attached to the module so that when lifting each pod the weight will be evenly distributed. To eliminate cracking of the Gypsum Wall Board, air lock doors won't be installed at the ware house. Instead extra drywall will be exposed in the door frames as in figure 16. This will provide more rigidity where door opening and windows are most prone to cracking [3].

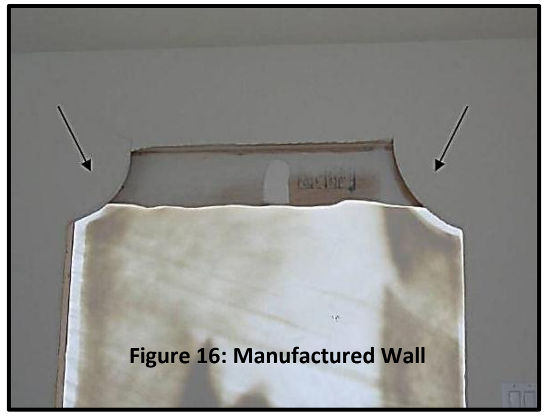
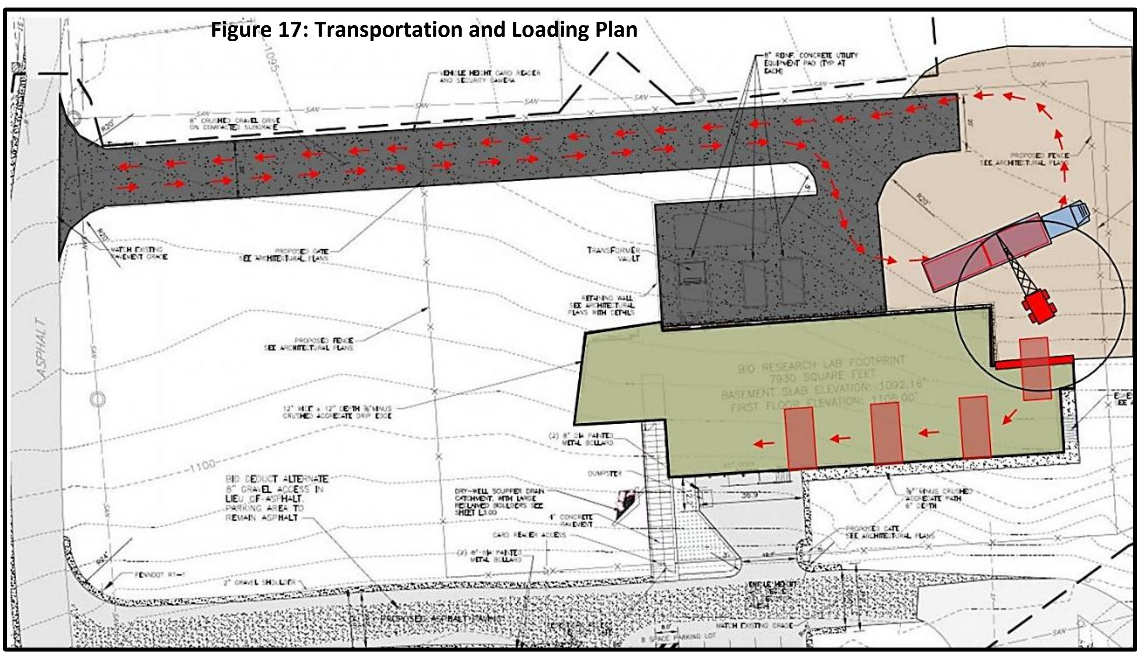


Figure 16: Manufactured Wall

Modular Staging

Once the Modular pods have been finished, they are then transported by tractor trailer to the site which is less than five miles away. The site as one can see from figure 17 has two entrances one in front of the building and one behind. The highlighted entrance on the map will be the delivery point for all of the modular units. Each tractor trailer will contain two pods and be delivered at the north east corner of the building in figure 17. Due to the fact that most of the exterior of the building is a composition of split faced CMU and metal stud walls, the north east corner was the easiest location to postpone. The north

Figure 17: Transportation and Loading Plan



east corner's wall structure is a combination of aluminum cladding and metal studs, which in no way affects the masonry on the exterior of the structure. Postponing the fit out of the exterior allows modular pods to be brought in, set and placed without disturbing the rest of the trades. Another benefit to using the north east corner as an entrance for the modular pods is the fact that only a hallway is opposite the wall allowing trades to easily construct the wall when all of the pods have been installed. In order to successfully transfer each pod a crane on the exterior of the building will hoist the modular unit off the truck and into the building. Waiting in the building, personal will safely guide the modules onto dollies to be transported inside the laboratory. The delivery of the modules will arrive from the left to the right of the building as to not block the entrance in to the building.

Utilities and Installation

One of the largest project constraints with implementing modularization is the idea of planning the layout of utilities. Many times in typical modular project hallways and other areas where utilizes are installed, consist of ACT tile or a typical drop down ceiling. This method of construction for finishing the modular hallways won't work because of the +/- pressures of 30 pounds subjected to the bio containment laboratory. Gypsum wall board must be used throughout the laboratory hallways in specifically 5/8 GWB to all support the change in pressures which was in the spec book. One problem which stems from this is the idea according to NEC 2008 splices or electrical connections cannot be hidden without access for maintenance. A drop down ceiling leaves access for maintenance but gypsum wall board does not. One way to solve this would be to install an electrical bank just above the modular units in the penthouse of the BRL facility as seen in figure 18. This will provide two benefits the first is that it will allow maintenance or access to the electrical connections. The second is that if maintenance is ever preformed it will be outside the containment zone which was a big design issue for OPP and the research department. Power and lighting will be designed to come from a single point within the module with a long enough to reach the electrical bank and make a connection.

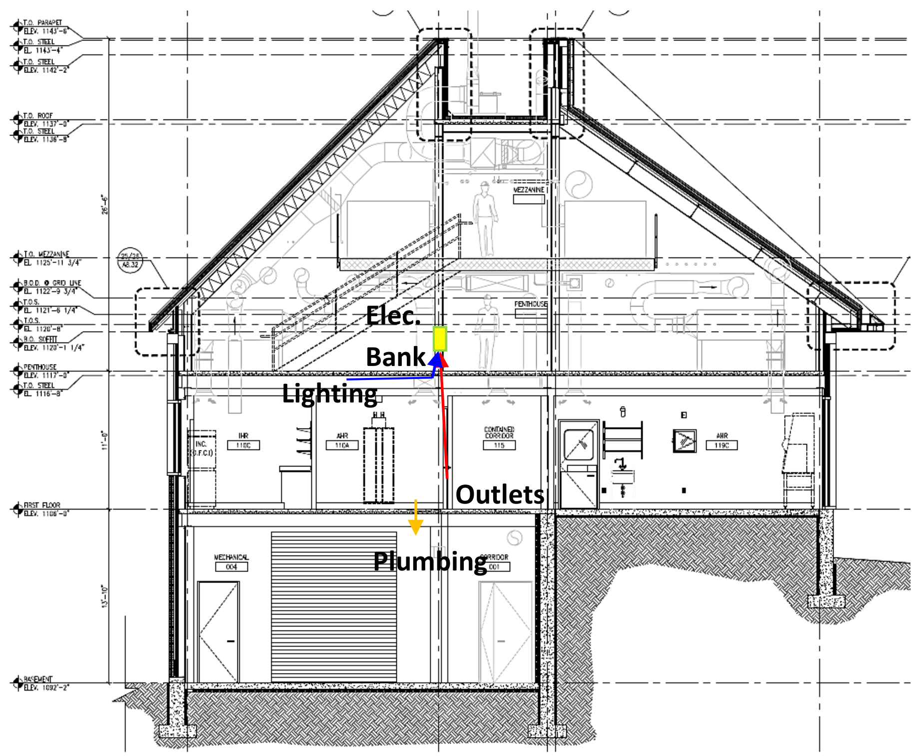


Figure 18: Utility Plan

Plumbing connections as per the original design will be made in the basement or wet mechanical room. This is to ensure that any leaks will not enter or affect the containment space. Coordination for this part of connecting plumbing utilities is extremely important. Hot, cold water and drains will need to penetrate the steel decking and connected in the basement. HVAC connections will also be different because of the lack of room and movability within the ceiling above. Metal duck work which is running in the ceiling above will be connected to diffusers within the room via flexible ductwork. Using short pieces of flexible ductwork should not create a pressure drop in the connections. Once the module is in place, installing the connection consists of removing the diffuser and connecting the flexible duct to the metal duct work. Once the ductwork is connected to the diffuser and the diffuser is then to be fastened in the ceiling. An important note is that all connections must be properly sealed with sheet metal tape, epoxy, or other specified material in order to keep the bio-containment area airtight.

After the modules laboratory spaces have been placed and utilities have been connected, the module unit can be fastened down to the slab. A power actuated tool is to be used in connecting the baseplate of the module unit to the concrete slab. The amount of fasteners to be used will be according to the manufacturer's specification.

Concrete Sequencing

On the Miami Valley Hospital, Skanska utilized slab impressions to layout the modular walls and bathrooms. On the biological Research Laboratory the same approach will be taken in order for the modules to be at the same level as the hallway. Looking at the structure of the facility the front half of the building in the figure19 below which is highlighted in orange is slab on grade. The area highlighted

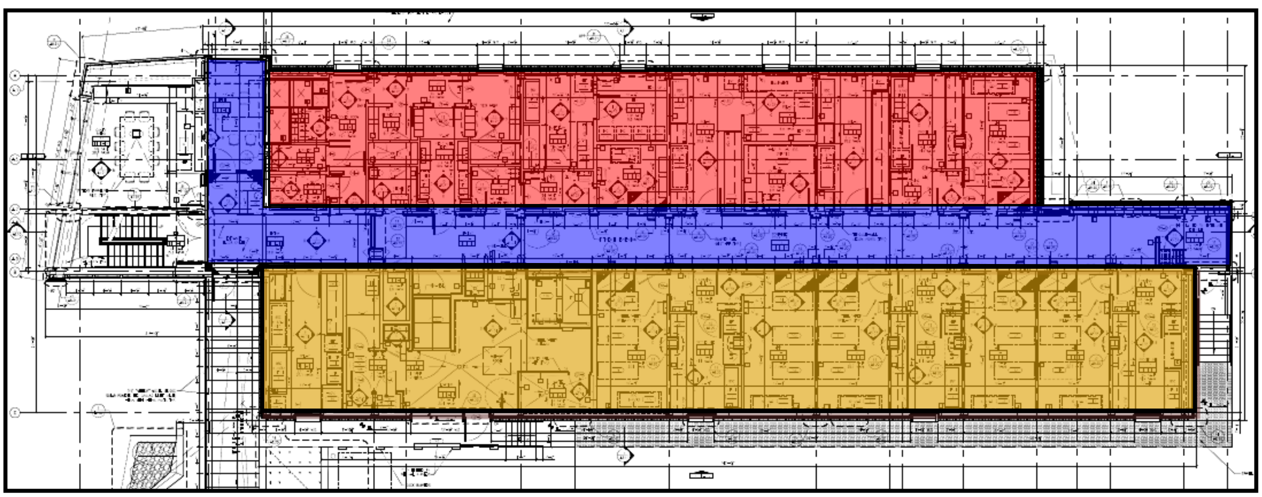


Figure 19: Concrete Sequencing Plan

in blue is the main hallway throughout the facility. Half of the building is also metal decking with normal weight concrete which is highlighted in red. In order to place the modules level with the hallway, two separate pours for the hallway and slab on deck will be needed.

The first concrete pour will consist of both the slab on grade which is the orange section as well as the red section. By completing these two slabs allows for the last concrete pour of the hallway to be complete with 2.5 inches more of concrete, so that the modules and the hallways will be level when it pertains to the finishes of the space.

Finished Product

The Material finishes of each of the laboratory spaces will be completed at turnover quality. Items such as paint and wall finish materials completed in the ware should meet NIH specifications as well as the design criteria. One area of importance which needs to be focused on during the construction phase within the factory are wall details and wall penetrations. Wall penetrations are one of the main reasons why modularization was implemented on this project. Valve cabinets in figure 20 are located in the hallways of the bio containment area and are one location where improper construction of the wall details could set the project back a considerable amount of time. The valve cabinets are fabricated within a steel box but penetrate the gypsum wall board into the hallway. The process to seal the laboratory space from the hallway involves implementing a pipe escutcheon, used to cover a gap between a penetrating pipe or control valve and the finished wall. Along with the placed escutcheon, the pipe is to be welded to the inside of the valve cabinet as seen in figure 20, to the right. Silicon is used as well to seal the wall penetration between the pipe and the drywall and along the perimeter of the escutcheon.

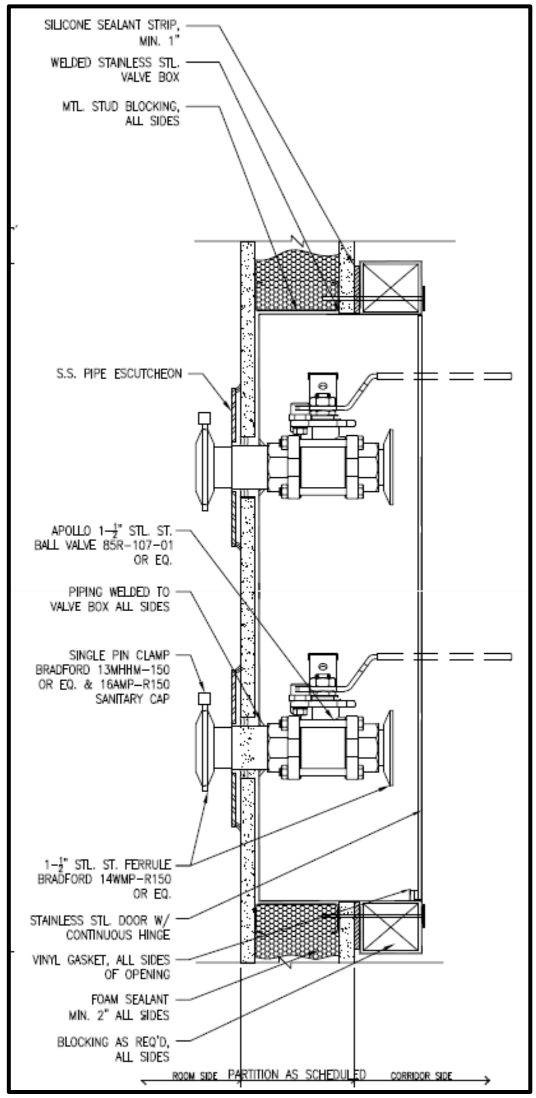


Figure 20: Valve Cabinets

Bottom of laboratory wall finishes are also a crucial aspect of keeping the pressure between laboratories constant. In each of the rooms drywall is not placed to the bottom of floor, instead cement board is used for several reasons including durability and protection against moisture. As in figure 21below grout is also place between walls as to provide a solid base for impact as well as preventing differential pressure between laboratory rooms.

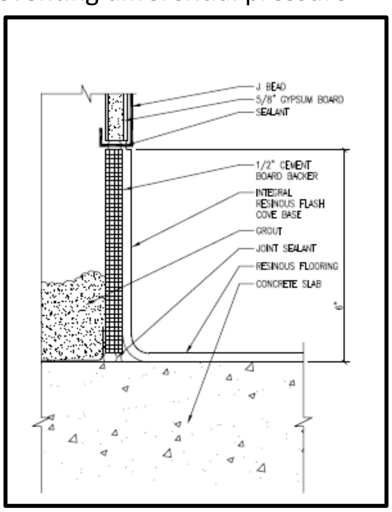


Figure 21: Grout in Floor

Quality Control

Cornerstone Commissioning along with the modular subcontractor will be preform assembly line checks as stated in the case studies above. Depending on the procurement of materials, a moving production line will be utilized in the prefabricating process. Through each stage of completion wall details shall be checked including layering of drywall for fireproofing to the smoothness of the walls. Wall penetrations are also to be checked before each module leaves the shop, so that mistakes can be fixed immediately preventing a setback in the schedule.

Schedule Acceleration

The process of the original schedule has a total duration of 10 months from partition framing to wall and floor finishes. Implementing modularization on the project could potentially save months on the project schedule.

Laboratory Compartments	Duration	Start	Finish
Partition Layout & Top Track	68 days	Fri 2/24/12	Tue 5/29/12
Partition Framing	47 days	Fri 4/6/12	Mon 6/11/12
HM Door Frames	15 days	Fri 4/6/12	Thu 4/26/12
Partition Grouting	5 days	Fri 5/4/12	Thu 5/10/12
HM Door Frames	5 days	Tue 6/5/12	Mon 6/11/12
Partition GWB	15 days	Tue 6/12/12	Mon 7/2/12
Ceiling Framing	5 days	Tue 6/19/12	Mon 6/25/12
Roll-up Doors	5 days	Tue 6/19/12	Mon 6/25/12
Ceiling GWB	17 days	Tue 6/26/12	Wed 7/18/12
Ceiling Framing	10 days	Tue 6/19/12	Mon 7/2/12
Tape & Finish	40 days	Tue 7/3/12	Mon 8/27/12
Tel/Com Wiring and Devices [FF]	15 days	Thu 7/19/12	Wed 8/8/12
Fire Alarm Wiring and Devices [FF]	15 days	Thu 7/19/12	Wed 8/8/12
Lighting Wiring and Devices [FF]	20 days	Thu 7/19/12	Wed 8/15/12
Power Wiring and Devices [FF]	20 days	Thu 7/19/12	Wed 8/15/12
CCTV/AC Wiring and Devices [FF]	20 days	Thu 7/19/12	Wed 8/15/12
Prime Paint & First Coat [FF]	5 days	Thu 8/16/12	Wed 8/22/12
Ceramic Tile [FF]	5 days	Thu 8/23/12	Wed 8/29/12
Polished Floors [FF]	5 days	Thu 8/23/12	Wed 8/29/12
Entrance Mat [FF]	5 days	Wed 9/26/12	Tue 10/2/12
Touch-up and Finish Paint [FF]	8 days	Wed 10/3/12	Fri 10/12/12
Resinous Flooring [FF]	16 days	Wed 10/3/12	Wed 10/24/12
Fiberglass Grating [FF]	5 days	Thu 10/25/12	Wed 10/31/12
Lab Casework [FF]	12 days	Thu 10/25/12	Fri 11/9/12
Doors & Hardware [FF]	12 days	Thu 10/25/12	Fri 11/9/12
Wall Coatings Topcoat [FF]	17 days	Tue 11/13/12	Wed 12/5/12
Hepa Filters [FF]	5 days	Thu 12/6/12	Wed 12/12/12
Wall Protection [FF]	5 days	Thu 12/6/12	Wed 12/12/12
Joint Sealants [FF]	5 days	Thu 12/13/12	Wed 12/19/12
Total	**417 days**		

Table 8: Modularization Schedule

Table 8 above denotes the tasks in the original schedule to create the interior rooms and partitions. Lines in green can be directly taken out of the schedule because they will have been completed modularly in the shop. Line items in yellow are still will need to be completed once the modules are placed in to the facility. The yellow items are because the modules won't be transported with doors or hardware to ensure there are less drywall cracks as stated above. Another large area which will need to be finished is the hallway because dropdown ceilings in a bio containment laboratory are unacceptable. Accounting for all of the areas in yellow equates to approximately 3 months.

A typical crew according to data from the Fort Sam project above can install around 12 units or modular pods per day [7]. The Biological Research Facility contains approximately 25 modular units 9 of which are not laboratory spaces. Transportation and installation of the modular units should take approximately 1 week which includes 2 days extra for unforeseen conditions. The average weight of each pod is approximately 6 tons depending on the type of equipment inside of the laboratory spaces. A truck mounted lattice boom crane was chosen with a capacity of 25 tons at a 10 foot radius. The takeoff below in table 9 shows the cost of the crane from Building Construction Cost Data.

Crane	Crew	Daily Output	Labor Hours	Unit	Days	Labor	Equipment	Total	Total Incl O&P	Cost
truck mounted lattice boom crane 25 tons/10 foot radius	A-31	1	8	Day	5	355	1025	1380	1650	8250

Table 9: Crane Selection

Calculating a conservative figure for the schedule and allowing an additional month for punch list items regarding the modular units leaves 6 months for accelerating the schedule. Looking at the detailed schedule which can be seen in Appendix E shows a milestone of the middle of May for completing the building enclosure for the Biological Research Laboratory. Traditionally the interior rooms and laboratories are completed by the middle of January, by allowing the modular pods to be installed after the building is enclosed saves 6 months on the schedule. One negative to saving 6 months on the project schedule is cost. Additional Costs such as renting a crane for an additional week as well as employing more onsite labor during the period of installing the modules.

Cost Breakdown

Evaluating the cost is the governing factor to whether the modularization of the BRL facility is economically viable for the construction team. Each of the modularized lab units is made up of a series of metal studs, gypsum wall board, bat insulation, a steel plate in place of concrete and 2 X 3 underneath the flooring for rigidity. These rooms also contain electrical equipment such as wiring, lighting fixtures and receptacles. Plumbing is also present in each of the spaces with hot and cold water to each of the scrub in sinks as well as accounting for all of the drains. Where cost saving is calculate is in the labor of assembling all of these items within each of the spaces. This is the difference between field work and shop fabrication productivity. Other areas where savings can be generated are in overhead reduction, transportation as well as installation efficiencies [6]. The use of prefabrication or modularization found a reduction in 25% for onsite labor and 5-10% in the overall project (preliminary prefab). Many of these factors which affect the onsite labor productivity are amount of ground level work compared to time spent on a ladder, weather conditions and consistent lighting. Amount of personal present in a modular workspace also decrease because field supervision has to normally cover a larger area. The same is said for tools in the field, many times these pieces of equipment have to travel further distances to accomplish the same task.

ABSL-3+				
Room	**Reduced Material Cost**	**Material Cost**	**Reduced labor Cost**	**Labor Cost**
Animal Holding Room 1	$ 10,852.29	$ 11,423.46	$ 12,732.46	$ 16,976.61
Animal Holding Room 2	$ 10,852.29	$ 11,423.46	$ 12,732.46	$ 16,976.61
Procedure Room	$ 16,669.77	$ 17,547.13	$ 8,927.78	$ 11,903.70
Gowning Room	$ 19,485.73	$ 20,511.29	$ 3,471.24	$ 4,628.32
Total	$ 57,860.07	$ 60,905.34	$ 37,863.93	$ 50,485.24
Total Saving	$ 3,045.27	+	$ 12,621.31	**$ 15,666.58**
ABSL-3				
Room	**Reduced Material Cost**	**Material Cost**	**Reduced labor Cost**	**Labor Cost**
Animal Holding Room 1	$ 10,852.29	$ 11,423.46	$ 12,732.46	$ 16,976.61
Procedure Room	$ 16,669.77	$ 17,547.13	$ 8,927.78	$ 11,903.70
Gowning Room	$ 19,485.73	$ 20,511.29	$ 3,471.24	$ 4,628.32
Total	$ 47,007.79	$ 49,481.88	$ 25,131.47	$ 33,508.63
Total Saving	$ 2,474.09	+	$ 8,377.16	**$ 10,851.25**
BSL-3				
Room	**Reduced Material Cost**	**Material Cost**	**Reduced labor Cost**	**Labor Cost**
Procedure Room	$ 16,669.77	$ 17,547.13	$ 8,927.78	$ 11,903.70
Gowning Room	$ 19,485.73	$ 20,511.29	$ 3,471.24	$ 4,628.32
BSL 2/3 Rooms	$ 8,348.89	$ 8,788.31	$ 12,578.00	$ 16,770.66
BSL 2/3 Rooms	$ 8,348.89	$ 8,788.31	$ 12,578.00	$ 16,770.66
Total	$ 52,853.29	$ 55,635.04	$ 37,555.01	$ 50,073.34
Total Saving	$ 2,781.75	+	$ 12,518.34	**$ 15,300.09**
BSL-2				
Room	**Reduced Material Cost**	**Material Cost**	**Reduced labor Cost**	**Labor Cost**
BSL 2/3 Rooms	$ 8,348.89	$ 8,788.31	$ 12,578.00	$ 16,770.66
Total	$ 8,348.89	$ 8,788.31	$ 12,578.00	$ 16,770.66
Total Saving	$ 439.42	+	$ 4,192.67	**$ 4,632.08**
ACL-3				
Room	**Reduced Material Cost**	**Material Cost**	**Reduced labor Cost**	**Labor Cost**
AHR and IHR	$ 10,852.29	$ 11,423.46	$ 12,732.46	$ 16,976.61
Procedure Room	$ 16,669.77	$ 17,547.13	$ 8,927.78	$ 11,903.70
Gowning Room	$ 19,485.73	$ 20,511.29	$ 3,471.24	$ 4,628.32
Total	$ 47,007.79	$ 49,481.88	$ 25,131.47	$ 33,508.63
Total Saving	$ 2,474.09	+	$ 8,377.16	**$ 10,851.25**

Table 10: Crane Selection

While only the lab spaces were quantified, a total savings of $ 83,800.00 was calculated. These lab spaces consist of two ABSL -3+, two ABSL -3, one BSL-3, one BSL-2, and one ACL-3 which can be seen in table 10. A further breakdown of each room can be seen in Appendix F-I. Other spaces in the facility such as offices, storage and bathrooms were not quantified but in the same aspect they would also attribute savings in the modularization process.

Structural Breadth

The implementation of modular units poses the problem of additional weight added to the composite deck along with the original beams and girders. Structurally, the Biological Research laboratory is designed on a slope creating a slab on grade for half of the building while a steel structure with metal decking on the back half. A typical bay for the structure is comprised of a 22' span by 20' in length with an addition bay for the hall way with a dimension of 22' by 8'. This set up creates a problem for the newly designed units. Since two and half inches of concrete being removed from the decking structural integrity becomes a concern. The bays were redesigned to from two W12x19 to a single W14x30. This changed allowed the wall of the modular rooms which had a size of 11 x 20 to fall directly on a beam or girder. Up-scaling the beams also allowed for the removal of 12 steel beams. The same redesigned was imposed for the short span of 8ft in figure 22 to the right. That beam was designed to a W8 X 13. A girder was also resized which is in blue apparent in the figure 22 to the right. This girder also had to be upsized due to the point loads of the two beams.

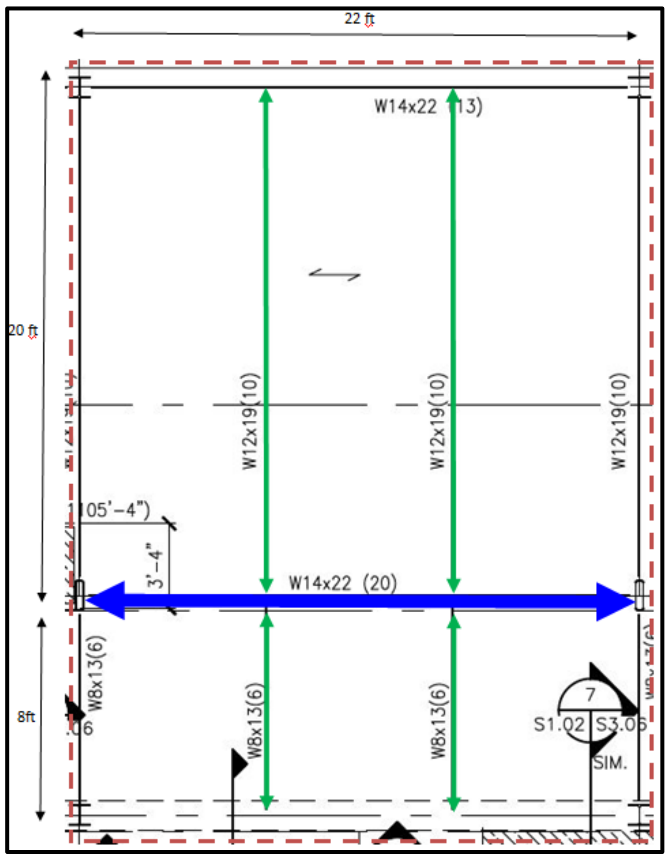


Figure 22: Steel Layout

Beams sizes were calculated as non-composite members which was learned in AE 404. Maximum moments as well as maximum shears was determined and compared to the ASIC manual. The steel manual also provided moment of inertia values and the Constant E=29,000KSI for steel. Calculated deflections were then compared to the standard L/360 or LL deflection and L/240 or the total deflection. All of these calculations were performed that vibrations were not an issue in the laboratory space. The girder was also sized in the same manner and sized based on strength and deflection.

Column calculations were also performed where the tributary area around the columns along the blue line in figure 22 was calculated. The tributary area was multiplied by the factored live and dead load to determine a total in kips which was exerted on the columns. The box beams or HSS10 and 14 columns proved to be more than adequate from the additional load of the modular units. The load calculated was approximately 48.5 kips on each column. The total allowable axial load which is allowed according to the steel manual is 416 kips for the HSS10X6X1/2 which is well in the allowable limits.

Deck selection was one of the most influential decisions of the analysis of the structural breadth. Eliminating one beam in the typical bay allows for the use of less steel but also provides another problem of spanning the additional length to the center beam. Originally the Biological Research Laboratory had a composite metal deck of 2VLI20 which signifies that the metal decking consisted of 20 gauge steel. A major problem when trying to implement the use of the same deck again was the fact it could not span the length. One characteristic for the metal deck which needed to be evaluated was concrete thickness. The thickness of the concrete under the modules needed to be 2.5 inches less than the amount of concrete within the hallways. This difference in concrete provides a level finish between the hallway and the rooms after the module has been placed in its proper position.

Through examination the deck 3VLI met the requirements for the concrete decking. Decking for the modular area with a covering of 2 inches and at a span of 11' could support 131 pounds per square foot at a set gauge 19. The hallway consists of 4.5 inches of covering and could hold a total weight of 175 pounds per square foot well above the calculated 120 lbs/S.F. Fireproofing will also be needed to bring have a two hour fire rating with the reduced concrete. In the takeoff which can be seen in appendix H show a breakdown of the cost for the structural system chosen using Building Construction Cost Data Catalogue. The total savings per typical bay from the modifications made for the modularized pods amounted to $818.72. While this savings might not be much it shows that modularization of the laboratory spaces does not hinder the cost of the other systems affected.

*For detailed calculations please visit appendix J where the non-composite method was used to size both the beams and girders for a typical bay. *

Recommendations and Conclusion

The implementation of modular units on the Biological Research Laboratory has many benefits. The ability to be constructed in a controlled environment not only delivers a better overall product but it also requires fewer workers present. Quality control checks also can be performed before at different phases of construction and right before each laboratory spaces leaves the warehouse. On these quality control checks superintendents will inspect smoothness of wall and ceiling finishes, quality of the floor finishes as well as wall penetrations. Eliminating these mistakes will prevent costly set back in the commissioning of the building during turnover. The modular units also have a large impact on the schedule of the project. Fabricating these units in a warehouse and shipping them to the site saves approximately 6 months on the overall schedule. A cost breakdown was also preformed of just the laboratory spaces which amounted to a total saving of $ 83,500.00. This cost saving incorporated a 25% reduction in labor as well as a 5% reduction in the materials used to make each laboratory module. Items that were excluded in the estimate were large pieces of equipment such as bio containment cabinets and pass through cabinets. Modularization of the laboratory spaces will ultimately provide a better product by being constructed within a warehouse along with both cutting the overall project schedule and cost for the interior partitions.

Analysis II: BIM

Problem Identification

On any construction project, the uses of BIM highly depend on how much the construction manager wants to integrate these practices throughout the job. The Pennsylvania State University as an owner set as one of their requirements to implement BIM somewhere on the project. Another requirement is to produce an As-built model where the Office of Physical Plant of Penn State can maintain. Clash detection along with three dimensional coordination for Torcon, the construction manager, was the highest priority on the BRL facility. Cadnetics developed the structural and architectural model to prepare for MEP coordination. Once a week all the trades presented their models and combined them to the Cadnetics base model to create a clash report. Besides coordination and clash detection using Navisworks, the implementation of BIM extended no further on the Project.

Flow of work for researcher and users are really important in a prominent research facility like this ABSL-3 laboratory. Virtual Mockups, one way to lay out laboratory space, is a BIM use which has not fully been explored throughout the industry. Seeing labs and other work spaces late in design to early construction gives users the ability to improve their workspace. Implementation of virtual mockups can also lead to a greener construction project by creating less field mockups.

Research Goal

The goal of the analysis is to implement virtual mockups and reduce field mockups while obtaining a better quality and design of the space. A series of the different laboratory spaces will be modeled in Revit Architecture including the holding areas, procedure rooms and prep spaces to be evaluated by the users. Virtual mockups would eliminate the need for much iteration of field constructed model spaces, reducing waste and cutting cost to the owner and the construction team. Another goal is to reduce change order in the final months of construction, which usually increase the cost and the duration of the schedule. Due to the simplicity of virtual models imposing changes based upon the researcher's preferences is easy creating a better designed laboratory space.

Project Background

The Biological Research Laboratory, once completed will be one of the University's greatest assets in animal testing and research. The 8,500 square feet of useable lab space makes it imperative that users are able to perform their work at the highest standards. Since the budget was limited, the facility had its limitation on size as well as the number of BSL-2 and BSL-3 laboratories inside. Throughout the country there are only a handful of these facilities but this will be the first that is achieving a LEED rating. The project utilized traditional field mock up during construction for the researchers and users to evaluate the details, lab casework, bio-containment cabinets along with other desired equipment. Negatives to traditional mockups are that they usually are on average more expensive as well as create waste affecting the potential LEED rating on a building.

Virtual Mockups on the BRL facility will allow the project team along with the users to solve design and construction problems earlier into the project. Presenting the virtual mockup to will allow the users and project team to evaluate the aesthetics and layout during the design review in an immersive environment. The owner's direct needs could also be evaluated in the use of representing different materials for facility maintenance or durability. Successful implementation of virtual mockups in the design of the BRL facility will ultimately delivers a buildings which functions better.

Case Studies

The value of physical mockups to researchers and users are essential in determining usability and adequate space but are designed late and waste materials. Virtual mockups while still new in the construction industry offer a slightly different alternative to traditional mockups, showing users a digital representation of their space. One important note is virtual mockups are still new because of the advancement in technology. These case studies might not be similar in project type but they review virtual mock ups, offering insight in design and lessons learned when experimenting with virtual modeling.

Concept of Virtual Mock-Up

The idea to be more efficient and new technology recently made it possible for digital and computer models to be viewed at a larger scale. "The use of virtual prototypes and creation of realistic computer generated images is often faster, cheaper and a more effective means to see preliminary design results than physical prototypes, and often allows review of more alternatives [14]." A traditional mock has three many purposes, the first is that users of the space will find the completed mock-up satisfactory according to their standards. The second purpose is to test new materials in an actual environment or space. The last is for education, by education the general contractor can correctly see how to fabricate details in the field or to show the construction manager about mistakes which needs to be fixed.

Medical Facility

A case study by Architectural Engineering professors looks at virtual mockups within a medical office facility. The four floor facility is approximately 150,000 square feet consisting of a tenant fit-out with a project budget of $30 million. Other departments contained in the building are operating suites, procedure rooms, medical exam rooms, radiology, and a pharmacy [14]. The pharmacy was one area in the facility where a virtual mockup was composed based off of the drawing and building information model (BIM). After the mock-up was generated by researchers, a review was performed in the Immersive Construction (Icon) Lab at the Pennsylvania State University, on three large screens with 3-dimensional abilities. All of the results and responses in regards to the simulation are recorded as well 4as onlooker's impression of the virtual mock-process [15].

Many different programs can be used to model the pharmacy, in this case the researcher chose to use Autodesk Revit. The architecture file can then be export to a CAD package where assigning different material properties take place[14]. Creating the virtual mock-up was no easy task because in order to achieve the same effect, the quality of detail needed to be the same as a traditional field mockup. Once the BIM model have been completed, a review of the level of detail and focus areas were determined. Two areas of interest for the design of the pharmacy was the casework as well as the cabinetry. The placements of the electrical outlets as well as data ports were also defined within the model.

Transferring the model throughout the different file formats proved to also be challenging during the design process. The original file or model came from Autodesk Revit with a file extension ".rvt". Google sketch up also played a role in the odd geometric shapes throughout the pharmacy. Once the file has been completed and ready to be exported, the file name is changed to .FBX. As an .FBX file, a person could bring the model into 3ds max where many attributes of the file are stripped. Lighting options as well as texturing were re-applied once inside 3ds max to raise the level of detail. The file was later saved and exported using the VR4MAX plug-in as a .VMX file [14]. Once all textures were rendered and transferred to the plug-in an executable vermal file was created. For viewing purposes the model was displayed in the Icon Lab with a stereo display which can be seen in figure 23 below.

Figure 23: View of Medical Facility

Virtual Review of Mock-Up

Multiple users including two pharmacists, the facility manager, owner's project manager, the general contractor's project team, project architect, and the casework subcontractor all attended the presentation. The participants in the room started the mockup tour from the customer desk working clockwise around the modeled space, examining all the highlighted areas. The team of reviewers came across nine concerns or changes during the review. One of the areas of interest was where partition walls met two sale stations and the proposed solution was to shift walls to the north by 1' creating a divide between costumers and adjacent stations [15]. Along with each of the highlight areas is a description of the concerns as well as an imposed cost impact from the change. The idea of a cost impact is to show benefits by completing changes early. Many of the areas in the pharmacy with concerns had no-cost change because these changes were made well before construction. Other areas that had added costs incorporated more shelving and cabinetry for a better flexibility within the work environment. An area where a particular savings was calculated came from removing shelves for the layout of office printers [15].

Researcher also made clear in the case study that neither the model nor the perception of the 11 attendees was perfect. Five viewers during the presentation recommended adding more detail which to better understanding the model. Problem of addition detailing partially stems from the different programs, converting files and the ability to properly export while taking lighting and textures in as attributes. Avoiding false representation was another reason why researcher creating the model did not go extremely in depth. If textures varied too much from the model, users could have incorrect perception of what the space looks like possibly creating problems after construction.

Layout of the pharmacy was also brought in to the discussion when reviewing the model. Some viewers had concerns about room sizes and improvements. In this aspect just plans were suggested to be provided alongside of the mockup. One suggestion was to provide a plan table with drawings or implement another projector with a smart board. This allows individuals sitting in the presentation to coincide and simultaneously interact with more knowledge as to where they are within the model. Other suggestion on how to improve the environment of the virtual mockup was to change the seating which would provide better viewing angles of the mockup space [15]. The main difference learned from a field mockup to a virtual mockup was the perspective and the amount of information provided throughout the model. In a field model any person had the ability to walk, touch and percept depth. When displaying a virtual mockup those features that are so easily achieved in a field mockup can be more difficult to represent.

Medical Facility Summary

The use of virtual mockups by Penn State Professors proved to be an excellent experiment which included most of the project team. Many of the participants responded well to the stereoscopic environment by interacting with the model and even trying to touch the screen and objects [14]). Users were also able to evaluate certain details in the model consisting of electrical outlets and cabinetry. These details provided users to notice immediate changes like wall partitions for privacy. One suggestion by the professors and researchers was "future work should further delve into the planning of the mock-up review process to identify the focus of the review tasks purpose and identifying the necessary level of detail for meeting that purpose [15]."
Immersive Environment – Court Room

Immersive Environment – Court Room

The General Service Administration and Jacobs Engineering in the past had the opportunity to experiment with Virtual Mockups along with the Penn State professors and researchers. The project consisted of a federal courthouse in Virginia where sight lines from the judge's bench were not to be hindered in any way which can be seen in figure 24. Modeling the courtroom was also going to provide insight in furniture configurations, the jury box location, public seating quantities, the bench design, and technology integration within the court room.

Court Room Mockups

In order to conceptualize how the virtual mockup was completed, a closer evaluation into the field mockup must be evaluated. First the design of plywood mockups are created and reviewed by the project team as well as the users. This type of mockup usually does not pass lighting requirements or finish material tolerances. Then the full finish material mockups are created, allowing users to touch and see the product which they will be receiving. Fully finished mockups can be used to work out constructability issues prior to the final product being installed. Since sight lines are the biggest concern, the plywood mockups fulfilled the need for determining special requirements or the court room. The virtual mockup or three dimensional model of the court room can integrate key elements from the physical mockup earlier in design. Two dimensional drawings are taken, modeled into three dimensions to show space and sight lines from the judge's bench. Flexibility of virtual prototypes also offer more by having the ability to zoom in and out as well as having multiple viewpoints. Alterations in design can be accomplished in 3D models and testing in the form of walkthroughs can be carried out well before construction even begins. Once the model had been completed, its exported and brought into VRML. Interactions, textures, and highlighted elements can be added to the VRML model to show the importance of certain areas at any given time. Avatars and lighting fixtures were also added with in the model to show scale and display a more realistic space. Jacob's Engineering spent approximately 100 hours on the model while researchers at Penn State spent 24 hours and 3 hours on the VRML coding [14].

Figure 24: View of Court Room from the Judges Bench

Court Room Summary

Presentation in a virtual mockup can be extremely important in conveying detail as well as other information to viewers. The ability to have a multi-screen presentation allows for the elimination paper drawings, making it more user friendly to follow the walkthrough or presentation[15]. Presentation along with the collaboration of the project team including researchers at Penn State were able to successfully implement virtual mockups on this federal court. Through design and interactivity they proved physical mockups can be created in a nontraditional manner and still have the same positive affect. With practice through modeling and representation can supplement the physical mockups at a lower cost, in less time and have the flexibility to provide more options while wasting fewer materials [14]. The mockup procedure is what's most important because it is where all of the valuable information is obtained. In the courtroom case study criteria was ranked most important looking at sightlines, aesthetics, lighting, security, and ergonomics. Through these key areas, users and the project team were able to identify problems or eliminate concerns but most importantly develop solutions with a virtual mockup.

Background on Users

Girish, an assistant professor at the Penn State University will be leading research at the new Biological Research Laboratory, once the lab has been completed and certified. His research at the university deals with a specific strain of bacteria, which affects approximately 100 people per year. Transmission of the bacteria is usually caused by a tic bite or mosquito bite creating a lesion clearing itself within days. Where this bacterium is deadly is if it becomes air borne and inhaled, taking only one bacterium to kill a human being. This strain of bacteria was developed as a biological warfare weapon by both the United States and Soviet Union during the Cold War. While the United States has since destroyed it is believed that the Soviet Union or common day Russia has lost their stockpiles to bioterrorists across the world. After the cold war an investigation in the country Georgia revealed large stockpiles of the Soviet's biological weapon, which was housed in sheds.

Bio-defense is currently Girish's main goal at the University. Identifying strains of the bacteria along with developing vaccinations and therapeutics is the role which researchers of the new facility will take on. Also understanding what makes this bacteria so deadly compared other bacteria's which take approximately 20,000 to millions of bacteria to infect a person. According to Girish the new facility will have the proper ventilation to work on these rare forms of bacteria. The of BSL space in is determined by how much preventative measures are available such as vaccinations and antibiotics.
In the facility there are two gowning areas; the first is immediately when you enter the bio-containment. This gowning areas's purpose is to keep your work or business cloths free from contamination. These scrubs are worn until a user reaches the laboratory they are working in which has their own gowning room. The laboratory is designed for flow of work. Since equipment can be so expensive each room will have incubators and refrigerators. Other equipment, which is more specialized, will be contained within the procedure rooms of the facility. This is to ensure that all researchers have access to every piece of equipment in their research.

Model Exploration

Opening Unity, a gaming engine, allows any user to create an interactive environment with a premade model from most modeling programs. Girish was unfamiliar with any modeling programs or pieces of software which allows a person to virtually model the space. Before the model was executed a brief plan view was shown describing both animal holding rooms, procedure room as well as the gowning room.

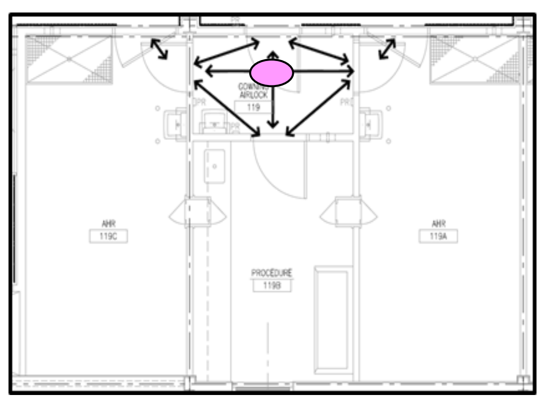


Figure 25: View of Medical Facility

When executing or running the model, one of the first questions that arose were material finishes of items in the laboratory spaces. The first person controller starts out within the gowning room which can be seen in figure 25 as the pick ellipse. While walking though the virtual model, the appearance of some of the materials came into question. Due to the types of materials with in the procedure room, showing a variety in color was difficult. Each of the laboratories are completely encompassed with equipment, shelves, and cabinetry completely fabricated out of stainless steel. One question which was asked of Girish was "Looking through both the plans and the spec books why are all of the pieces of equipment stainless steel?" Girsh responded "It is always better to have equipment and cabinetry as stainless steel because it's easier to decontaminate?"

Since specifics of the bio containment cabinets are not mentioned because they are usually bought late into the construction period, modeling these pieces of equipment was difficult. While walking through the virtual model, a question was asked on the appearance of the cabinet. Although it was not detailed with the electronic touch screen, Girish stated that the model was pretty true to a large bio-containment cabinet. Differential pressure gauges which are located in the gowning room were also modeled because of standard procedures for entering the laboratory space.

Another area which came into question was the animal racks for each of the holding rooms. In the interview the question was asked "were the animal racks modeled in the correct fashion?" The animal racks that were modeled can be seen in figure 26. Looking at the drawings specifics are not specified in any location, making modeling the racks difficult. The only information which was obtained was the length, width, and height for the overall shelving. Girish asked "how many levels of shelving was there?" The response to the question was 8 levels of shelving. Typically, animal holding racks normally have 6 levels of shelving stated Girish. This is due to each of the animal cages having individual supply tubes for ventilation. Another detailed which was missed in modeling the racks was the ventilation system. The ventilation system hooks up to the shelving on the wall behind. The hookup was modeled and can be seen in the figure to the right, highlighted by the red box in the photo. While the ventilation system did not seem to be a concern for Girish, he was more concerned with special movement throughout the lab. One benefit in conducting an interview with the assistant professor was in finding out that the animal holding racks are actually mobile. In speaking with Girish and finding out that these racks were moved frequently gave this model created in Unity another benefit. Making a first person controller into the animal racks can show the maneuverability throughout the space. Since these racks are moved throughout the laboratory, once a week it essential that a clear path be established. If these racks were constantly bumping into walls and doors not only would it be difficult to move throughout the space but

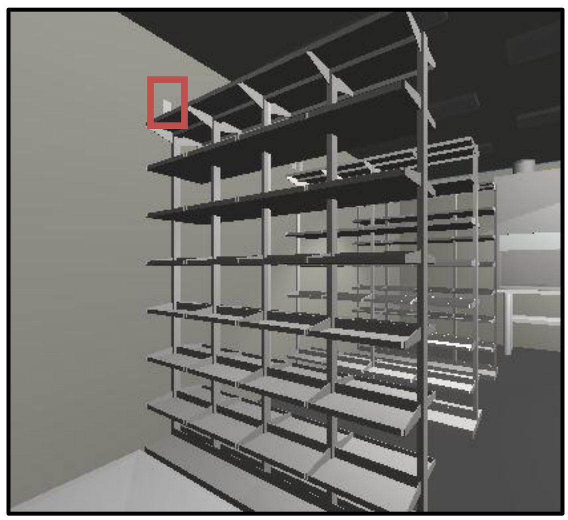


Figure 26: Modeled Animal Racks

maintenance becomes an issue. If walls and other features of the room are compromised through being damaged, the positive and negative air pressures of each space may fluctuate causing cross contamination. The damaged surfaces themselves might be compromised with bacterium and moisture creating an unsafe work environment.

Missing Items

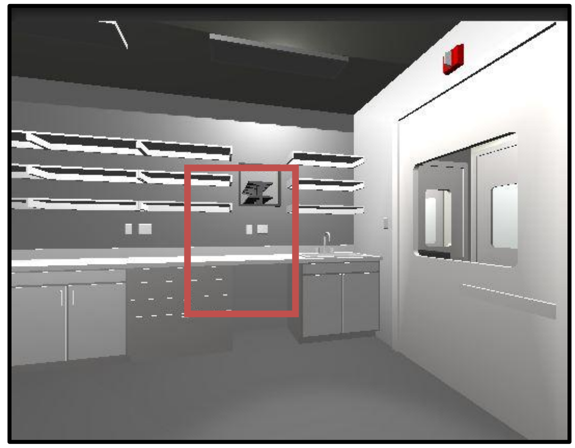


Figure 27: View of Procedure Room

While creating the model in Revit Architecture many items were forgotten because common pieces of furniture are not included within drawings. After speaking with Girish, key pieces such as chairs and garbage cans posed the biggest issue to users of the work space. Figure 27 illustrates the procedure room for one of the laboratory spaces modeled within unity. While the space looks clean and spacious, in an everyday work environment it is the complete opposite. In figure 28 one will notice a highlighted red box below the cabinetry. This box denotes the missing chair and trash cans which Girish would have liked to see as the primary user. Under this counter top would contain two trashcans one pertaining to typical garbage and the second would be used for bio-hazardous waste. While these trash cans are just places to dispose of waste they are a hindrance to the user.

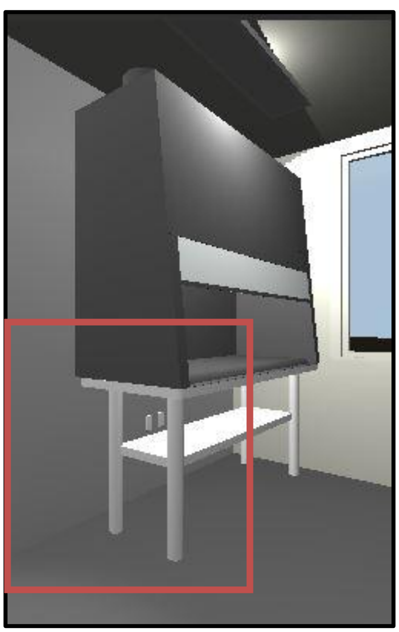


Figure 28: View of missing chair

These trash cans as Girish stated impede the chair from being place all the way under the countertop, making walking around in only the 11' wide procedure room difficult. Another area where chairs become a problem is the other side of the procedure room. As seen in figure 29 below the biosafety cabinet can also pose problems for maneuverability of the users. In the red box next to the biosafety cabinet are two trash cans again also hindering the

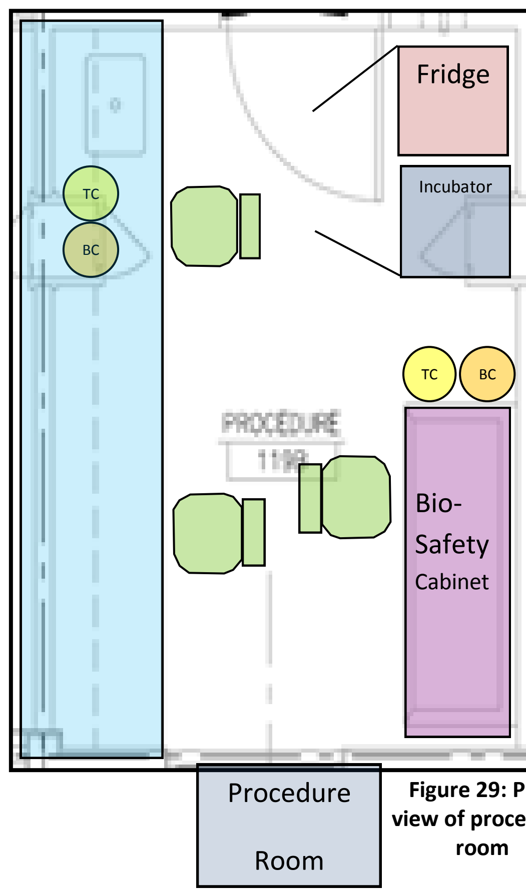


Figure 29: Plan view of procedure room

amount of space in the tiny procedure room. Another chair is also located in in front of the cabinet. In the plan view within figure 29 shows space with all of the necessary equipment as well as Girish's suggestions. As one can see the procedure room to the right with chairs and trash cans become cluttered especially when the refrigerator and incubators are added. The doors from these pieces of equipment can pose clearance issues with the door of the room as well as walking room between chairs.

Rendering of Lighting

Lighting also posed an issue in the presentation for the user. Throughout out the modeled laboratory space, 14 lights were present in the two animal holding room, 4 lights in the procedure room, and a 2X4 four lamp florescent in the gowning room which can be seen in figure 30. In order to make the appearance of each room acceptable many different aspect of how each light is rendered needed to be manipulated. When assigning lighting properties in unity, the modeler has must go to (1.component 2.rendering 3.light) in the drop down menu to properly assign a lighting property. Once added, three different lighting options can be chosen between (spot, directional, point). One challenge when distributing the light in the room, was Unity's inability to provide a simulated florescent tube or trougher light. Instead spot lights were used to represent artificial lighting and were adjusted based on their range, spot angle, and intensity. These three features were manipulated and adjusted to eliminate scalps on walls as well as distribute the light as best as possible within each space. Adding lights to each of the rooms combined with different materials offers a realistic rendering in which the users such as Girish, associate professor at Penn State, can evaluate the space he will be working in.

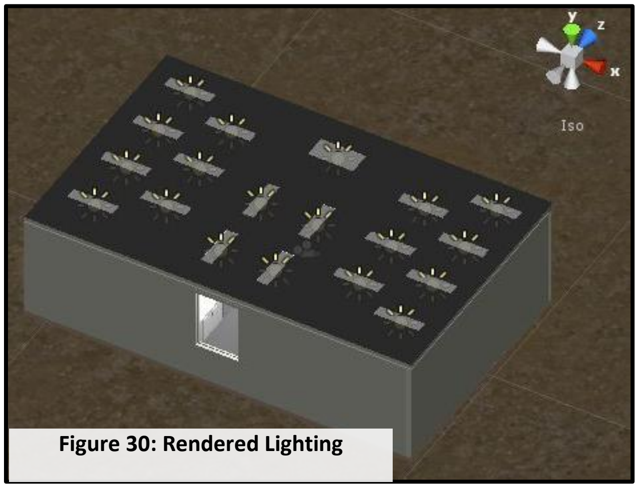


Figure 30: Rendered Lighting

Movement throughout the lab

One area which again was mentioned above was moving items around throughout the facility. Girish explained that carts such as in figure 31 below were used to transport water, food along with other items needed for the animal holding rooms. One potential problem looks at moving the cart around items such as the trashcans mentioned above which can be seen in figure 32. These trash cans are larger and must contain a cover because of the BSL-3 safety requirements. Also sinks potential can pose an issue because of their location within the laboratory. Both of the sinks within the


Figure 31: Laboratory Carts


Figure 32: Bio hazardous Trashcan

animal holding rooms could pose a problem when transporting or moving large items because they are directly across from the door. If a virtual mockup was implemented on this project a better space could be designed. Trash cans and other items impeding into the work space could have possible been designed for better work flow and a more open space environment.

Red Flags

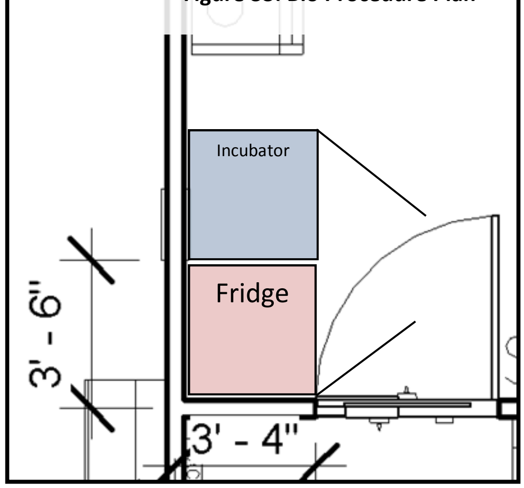


Figure 33: Bio Procedure Plan

The purpose of the creating a virtual mockup is to potentially catch any possible problems before the project moves into construction or before the construction of a field mockup. Towards the end of the interview, Girish brought up that in the procedure room the refrigerator might be conflicting with the airlock door. He noted this finding based on the model created in unity figure 34, stating "this is something I would not have picked up on just by looking at the plans." Looking at the picture of the plan drawing in figure 33 illustrates that if the refrigerator is any bigger than 3' by 3'6" there will be a conflict with procedure room door. On the interview with Girish he showed other laboratories in the Millennium Science Complex which contained the same equipment. Walking through one of the labs, Girish pointed out a refrigerator in figure 35 which would be comparable to the one placed in the Biological Research Laboratory.

Figure 35: Typical Refrigerator

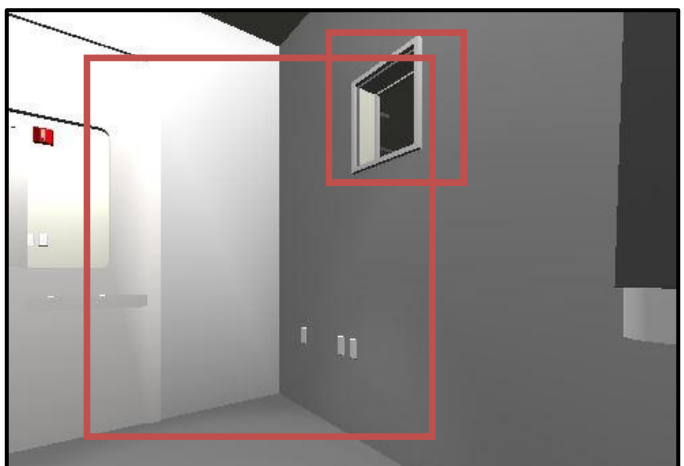


Figure 33: Unity Model

Another area which proved to potentially cause a problem is the pass through cabinet highlighted in figure 33, above. Girish explained that the design of the procedure room should allow enough room for a laboratory grade refrigerator as well as an incubator which can also be seen in the plan view figure. After the interview and by examining the plans and model, placing the incubator creates multiple problems. The first is that any user who would to retrieve specimens or samples from the pass through cabinet, have to lean over an incubator that is approximately three feet deep. Another possible problem is that in most laboratory spaces these incubators are stacked on top of each other which can be seen in figure 36. By stacking incubators on top of each other the incubators block the pass through cabinet to the animal holding room. Blocking the pass through cabinet eliminates materials and samples from traveling quickly between rooms.

Figure 36: Incubator

Cost Savings

On the project, field mockups were implemented to show the layout and finished quality of each room. In the previous modularization analysis a takeoff of the laboratory spaces was completed to differentiate between non-union and union rates. The cost break down of each room was calculated excluding equipment. Equipment was excluded because of the idea that it would be reused in the actual laboratory space once complete. Savings for the mock up would come in replacing the construction of the field mockup. The price for materials of the space as well as labor was calculated in the table 11 below to determine the total cost saved.

Room	Material Cost	Labor Cost
Animal Holding Room 1	$ 11,423.46	$ 16,976.61
Animal Holding Room 2	$ 11,423.46	$ 16,976.61
Procedure Room	$ 17,547.13	$ 11,903.70
Gowning Room	$ 20,511.29	$ 4,628.32
Total	$ 60,905.34	$ 50,485.24
Total Saving		**$ 111,390.58**

Table 11: Cost Savings

The cost savings in table 11 totaled to $ 110,000.00, which on this project is approximately .5% percent of the total project budget. While that might not seem like much, for researcher and other members of the university who struggled for 3 years to generate enough money for the project it is a lot. The extra $ 110,000.00 could potentially be used for additional equipment such as bio containment cabinets or incubators which would add value to the building.

Recommendations and Conclusion

The Virtual Mockup on the Biological Research Laboratory was designed in Revit Architecture and brought into a gaming engine called Unity 3D. The purpose of the gaming engine was to allow the user to virtually explore the model while also reviewing the future lab space. One of the goals which was accomplished in the walkthrough with the user was coming across a red flag which wouldn't be noticed on another project till it was too late to change. The problem dealt with the procedure rooms and the ability to fit certain equipment next to the airlock doors. Walking through the space with the user also provided valuable insight on missing items such as chairs and garbage cans. Examining the cost aspect, if the model could directly replace a field mockup approximately $ 110,000.00 could be saved in material and labor. Waste could also be reduced on site by eliminating field mockup which could potentially affect the LEED rating. Virtual mockups should be implemented on the Biological Research Laboratory because these mockups are able to provide the user with an earlier finished product as well as offer potentially large cost savings for the University.

Analysis III: Sustainability

Problem Identification

Research facilities across the country are using extreme amounts of energy to keep their daily operations functioning. The Biological Research Laboratory (BRL) at Penn State is similar in the fact that system redundancy and safety protocols force the consumption of additional use of electricity and gas. The Biological Research Laboratory has approximately 8,000 square feet of usable roof area in the application of some form of solar energy recovery system. A solar system on top of the BRL along with the integration of other systems such as car canopies with photo voltaic cells could greatly reduce energy as well as addition LEED points in reducing the Heat Island Effect, multiple points in alternative transportation, as well as points for creating on-site renewable energy.

Due to the rarity of this type of facility, image is extremely important to the research department at Penn State. Along with being the front runner on this type of animal research, energy conservation and innovation have also been a focus for the University. The use of a solar system can possibly provide many benefits but should be evaluated to determine the best combination or design in regards to the BRL.

Research Goal

The goal of the analysis is to implement a renewable energy system, evaluate the potential savings of the building as well as compose a financial strategy to fund the project. Through using a photovoltaic system, a certification of LEED Gold would be obtained from installing the new energy harvesting system. The photovoltaic system will be placed in multiple areas around and on the building serving multiple functions by have the possibility to charge alternative vehicles through car canopies to the traditional roof design.

Background Information

The energy consuming BRL facility has been under scrutiny recently because of the amount of energy it will use once completed. Unfortunately due to NIH and the 15 million dollar grant that was received, redundancy in systems cannot be avoided to meet safety regulations and well as requirements for the grant itself. One way to help buffer the energy use is through a solar system. The geographical location of the building is perfect because it was placed on a cow pasture on the agricultural part of Penn State's campus. This area consists of no trees or other structures high enough to pose large shadows on the building's roof.

Maintenance also is a key issue when looking into the addition of a solar system on the roof of the BRL. Since the facility will have limited access for maintenance, batteries along with other temporary storage systems will not be evaluated for the system. The major systems that will be considered for the project are solar thermal, modular photovoltaic panels, and car canopies in a combination. Locations for the system will be on the front of the building directed to true south along with parking spaces across the street. Since reliability also is a big concern for the critical research conducted in the building the system will be designed as a secondary or subsidiary system which offsets by dumping energy back on the grid when there is a surplus during peak hours. These implementations would ultimately affect the net energy use of the building along with potentially increasing the LEED accreditation to GOLD from the originally estimated SILVER rating.

Case Study

A relevant piece of information to aid in the design and implementation of a solar system on the BRL facility is a case study performed on Birmingham City Center, in the United Kingdom. The case study talks about different solar options including solar thermal along with photovoltaic, weighing both the benefits as well as the negatives of each. The U.K. also has approximately the same lighting levels as central Pennsylvania, making the benefits of a solar system and the system design very similar.

Solar Thermal

The process in which energy sun heats water or other solution in a solar collector is considered a solar thermal system. Once the fluid is heated to certain temperature, the naturally heated water is then stored in a special hot water tank inside the building [12]. When implementing solar thermal, they should face due south or south east [12]. Using a typical sized solar thermal panel can offer many benefits throughout the life of a building. A 4 meter by 4 meter panel or in U.S. measurements 13.12 feet by 13.12 feet can provide usually provide 20 to 80 percent of the water, depending on the demand at that part of the day seen in figure 37. Different types of collectors are also available ranging from flat panel collectors to evacuated tube collectors. The flat panel collectors are usually cheaper to manufacture while evacuated tube collectors are higher price but allow better performance during the winter months [12].

Figure 37: Picture of a flat panel collector. Obtained from the Birmingham Case Study

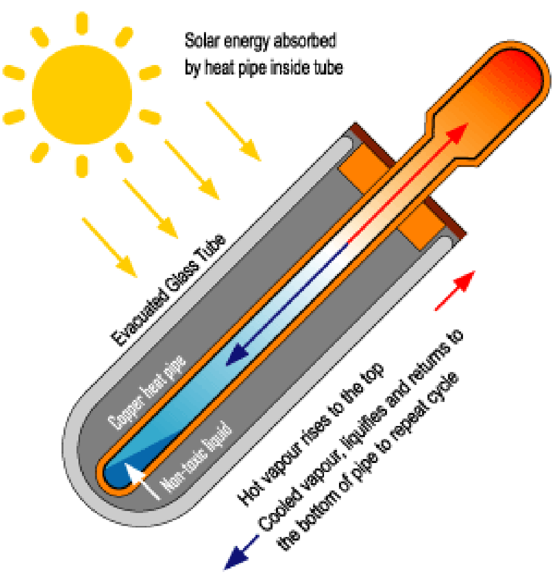


Figure 38: Illustration of how vacuum solar tubes work cited from Solartubes.com

The design of a flat panel collector consists of a rectangular fabricated box with pipes running between the back and clear surface. Light absorbing material is usually incorporated into the design of the solar thermal in order to generate more heat as well as a good conductor. A water/ antifreeze mixture is usually incorporated into the system because of the possibility that water will freeze in the winter months [12]. Over the course of exposure to the sun the plate is heated which then transfers the energy directly to the sun. The surrounding sides of the box are insulated to thwart thermal bridging and maintain a higher level of heat transfer. A glass or plastic cover is then placed over the absorber allowing light to enter the box and generate heat but also traps the heat once inside, serving multiples purposes.

Vacuum tube collectors design is significantly more sophisticated then the simple flat panel collectors as seen in figure 38, above. This type of system utilizes a solar absorber plate that is placed within a glass vacuum tube. While in a vacuum, water is placed inside the copper heat pipes. The vacuum conditions allow the water to boiler at a much lower rate approximately around 30 Celsius or 111.6 Fahrenheit much lower than the typical 212 Fahrenheit temperature [12]. This allows for a higher rate of heat transfer as well as better operation during the colder winter months.

An application where vacuum solar tubes can be related to the Biological Research Laboratory is through preheating water for boilers. The Leicester City Council implemented active solar to reduce the energy usage in one of their major office buildings, Phoenix House. The vacuum tube collection system was installed in the late 1990's in order to subsidize the new gas fired boiler installed within the building [12]. Initially the water temperature fed from outside had a temperature of 3-10 degrees Celsius (63-75.6 degrees Fahrenheit). After the water passed through the collector, the stored water reached temperatures up to 45 degrees Celsius or (138.6 degrees Fahrenheit) [12]. Payback on the project was calculated in the reduction of gas bills with a payback period of approximately 3 years.

Photovoltaics

Photovoltaics or (PV) systems use light emitted from the sun and create electricity through the use of conductor cells on the panel [12] which can be seen in figure 39. In many cases PV systems can be connected to any load or the grid while serving the main purpose of providing additional electric power. Due to the additional cost of batteries as well as their short lifespan and unreliability, PV systems are typically fed back into the grid when generating too much power. Like the United Kingdom, Pennsylvania's weather is not the best but fortunately, many PV system designs can generate power on overcast days. The idea of photovoltaics is also versatile because of the flexibility for places they can be installed [12]. Optimal designs usually have PV panels angled at 30-40 degrees to achieve 90 percent efficiency.

Figure 39: Photovoltaic Panel cited from panel cut sheet

Due to the cost of energy in recent years, benefits of photovoltaics have increased substantially along with provide clean energy. Maintenance on renewable energy systems can be difficult because of the availability of experienced contractors. PV systems utilize no moving parts so maintenance is minimal, with the only major requirement of keeping the panels dirt free. Installation is another perk because suppliers have modularized many of the units. As technology gets better PV systems also get to be more reliable with an average life span of approximately 10-25 years [12]. Renewable energy is one of the largest benefits to installing a PV system. Harvesting energy from the sun produces no emissions or greenhouse gases which can market well to certain government agencies or groups. Renewable energy targets are put in place each year, the installation of a PV system helps meet government requirements . While the benefits seem endless with Photovoltaic systems, cost is the largest downfall because technology is still relatively expensive. Projects teams may also be unwilling to work or have the ability to install PV systems correctly due to the lack of experience designing and installing these systems[12] .

Types of Photovoltaics/Configurations

Technology over the past years has allowed for many different types of photovoltaic designs which span in price as well as efficiency. Mono-crystalline silicon has the highest efficiency at 15 percent. This product also is very expensive due to the manufacturing process. In the fabrication process a single crystal of silicon is drawn from molten silicon and sliced down into wafers[12]. This type of product is only made in batches and in not desirable for massive amounts of production. Poly-crystalline silicon has an efficiency of around 8-12 percent. The cost of Poly-crystalline is cheaper than Mono-crystaliine, the most efficient, again is not well suited for mass production. In the fabrication process the molten silicon is cast into blocks and then sliced into wafers [12]. Amorphous silicon has the lowest efficiency at approximately 4-6 percent. The Amorphous silicon utilizes very thin layers and can be placed on objects such as glass or plastic. In recent years this material became to be known as thin-film. Thin-film is actually cheap to manufacture compared to the other forms of silicon, don't require sawing or slicing but need lower temperatures to operate [12]. Cadmium telluride and copper indium diselenide have an efficiency of approximately 7-9 percent and are more expensive than, the previously discussed amorphous silicon. Small amounts of production and the expense of raw materials have inflated the cost to these types of silicon but they also have the ability to be placed on flexible objects which is similar to thin-film [12].

The Optimal design for a photovoltaic system consist of installing panels on a flat roof, inclined at an angle which delivers the most direct sunlight. Other design can incorporate placing systems on sloped roofs which are facing due south or in the range from south east to south west [12]. Photovoltaics can also be added to other areas of a building including facades and windows. When PV systems are incorporated into the façade of a building, areas on the roof are either not sufficient or are too small. A benefit of incorporating a PV system into the façade of a building, as in figure 40, allows the solar panels to provide shading during the summer months [12].

Figure 40: Solar panels on the facade of an office building, Image obtained from Eastside casestudy

Designing each photovoltaic system requires the use of Inverters. These inverters transform DC (direct current) electricity to AC (alternate current). These components of the system tend to be the most unreliable with the amount of noise produce along with paralleling the system with the grid voltage. Multiple meters are also required to monitor the net energy use of the building along with isolation switches to cut power during maintenance [12].

Site Issues

A solar array should be placed at an elevation from 30-40 degrees while facing south. Shading also plays a large part of site issues when designing and installing a system. The best location for any solar array occurs where no shading occurs throughout the day. A feasibility study of the roof should be performed analyzing all of the potential problems such as chimneys, cables, TV aerials, trees and other buildings in the vicinity with regards to shading [12]. One example the case study provides about the possible danger of shading deals with a TV satellite cable. Shading can reduce the output of energy generated by the solar cells, this occurs because of the increased resistance to the flow of electric current which reduces the overall current when the cells are joined together [12]. Besides adequate space proper ventilation between panels which would prevent them from overheating. Overheating can have a strong effect on efficiency of the cells and shorten the life of the system [12]. Maintenance and uncontaminated panels surfaces are also significantly important especial in areas with high amounts of birds and dust. The panels need to be absolutely spotless to provide the highest output because dirt, dust and grime can have the same effect as shadows.

Shade Evaluation

In the evaluation of Photovoltaics for the BRL facility, locations of the panels are imperative to the success and high efficiency of the system. Around the Biological Research Facility there are several key building which could pose a shadows on the new parking lot. These modular trailers are only 10 feet in height but could potentially affect the proposed solar parking canopy.

In the figure 41 below, is a diagram of the usable areas where panels could possibly be placed in green. Areas in red denote buildings which could possible impose shading on the parking for either the solar canopy or the building itself. The blue area of the map signifies non useable space.

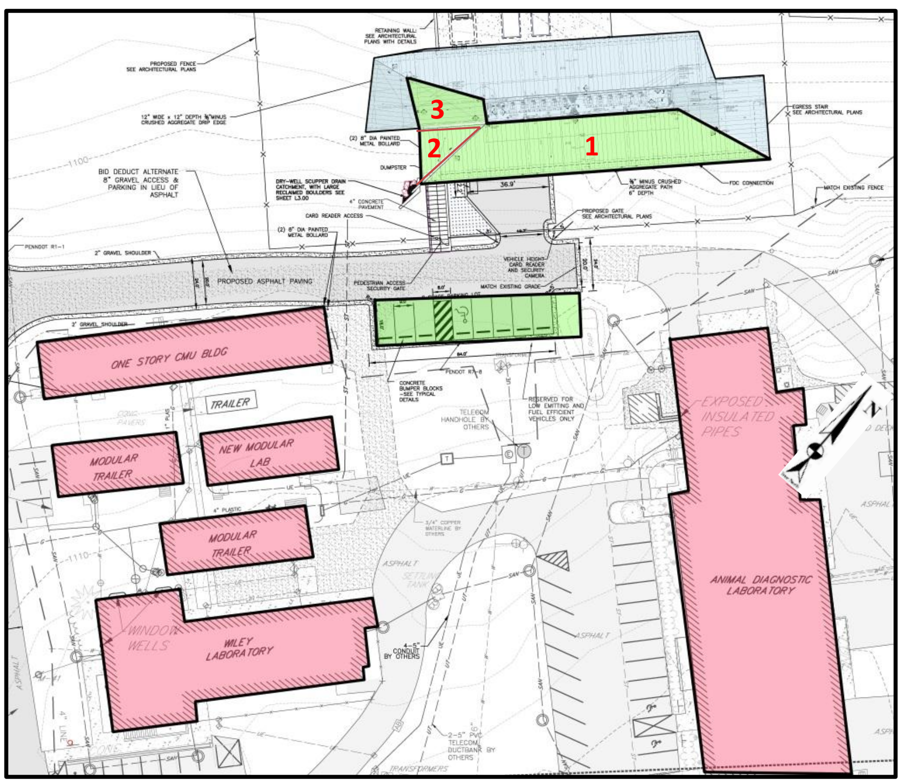


Figure 21: Site plan displaying usable solar area

One noticeable difficulty to will be in the design of the panel location. The roof pitch on the BRL where panels are to be placed is approximately has an approximate slope of 32 degrees. Other smaller roofs where panels are going to be placed on the BRL facility consist of roofs with multiple angles in different directions. These roofs are approximately 20 degrees south- west of the azimuth with a roof slope of 35 degrees. The small parking lot will also undergo a slight change with regards to layout. Instead of parking perpendicular to the street, parking spots will ultimately be rotated so that patrons park on a 45 degree angle. This allows for several changes, the first are the solar canopies will now be pointed directly due south. Second by parking at a 45 degree angle more space can be utilized making room for an additional space. The total space will also affect the amount of power generated and the table 11 below defines the usable area or green areas in figure 41.

Location	Slope of roof	Total Area
BRL Roof 1	32°	3486 sf
BRL Roof 2	35°	429 sf
BRL Roof 3	35°	529 sf
Parking Canopy	10°	2588 sf
Total Square Feet		6852 sf

Table 11: Roof Slope and Area

A model of the Biological Research Laboratory was fabricated using Google Sketch-up 8. The purpose of the model was to evaluate the shading of the surrounding buildings from figure 41 above in further detail. Drawing C3 from the bid documents was used to denote the general location of the buildings as well as new proposed parking lot in figure 41 from the previous page. Google Earth was used in determining the Latitude and Longitude of the building for the solar angle analysis as seen in table 12, below.

Google Earth Location	State College, PA	ADL and Wiley Complex
Site Characteristics	**Degrees, Mins, Secs**	**Degree**
Latitude	40°49’23” N	40.823°
Longitude	77°51’29” W	77.858°
Elevation	1107 ft	1107 ft

Table 12: Google Earth

Using the Geo-location tool within Google Sketch-up and assigning the key features from Google Earth produces accurate shadows throughout the year in regards to the location of the building. Shadows from the surrounding building make the most significant impact during the summer and winter solstice along with the fall and spring equinox. The dates are June 21st and December 22nd for the Summer/Winter Solstices to March 20th and September 23rd for the Spring/Fall Equinoxes. Images were taken at 8:00 AM and 4:00 PM on all the major dates above.

Summer Solstice June 21st

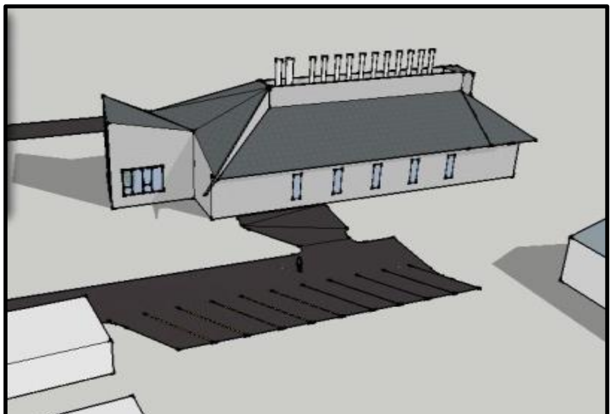


Figure 42: Shadowing during the Summer Solstice at 8:00 A.M.

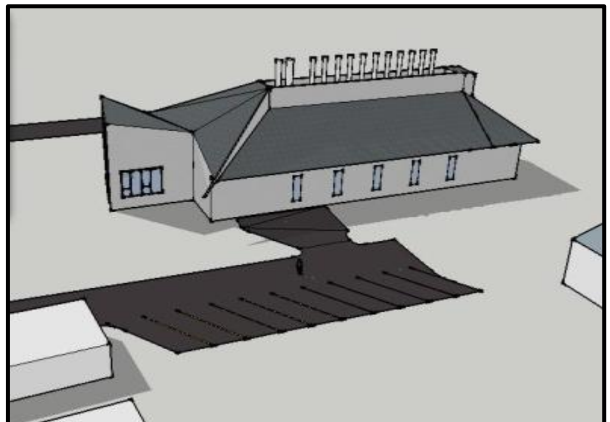
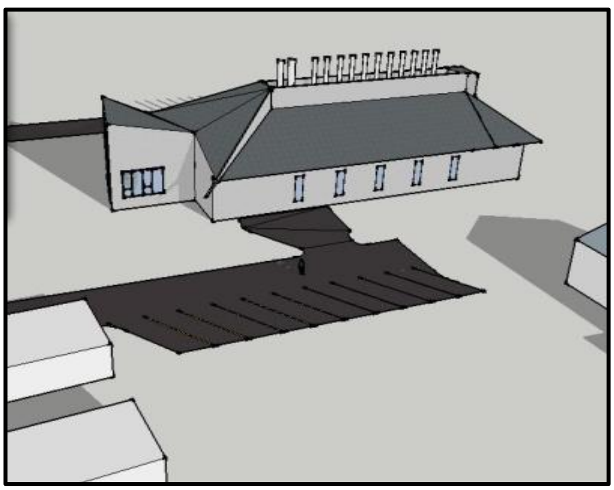


Figure 43: Shadowing during the Summer Solstice at 4:00 P.M.

Examining both figure 42 and figure 43, one can tell there is no shading during the summer solstice and on the BRL facility. The parking lot where the solar canopies are to be placed also experience no shading throughout the course of the day.

Fall Equinox September 23rd



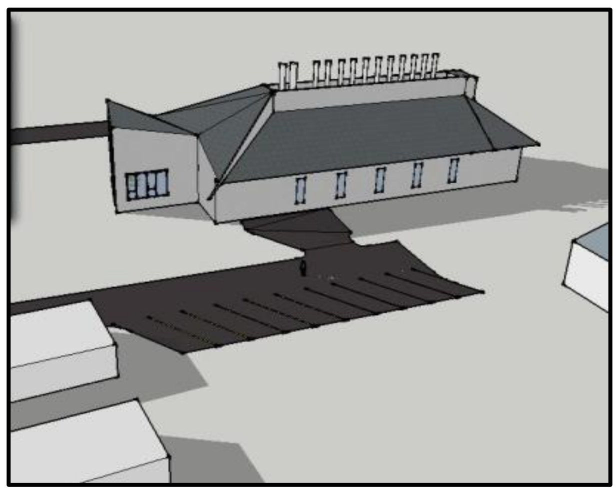


Figure 44: Shado

Figure 45: Shadowing during the Fall Equinox at 4:00 P.M.

Examining both figure 44 and figure 45, one can tell there is slight shading during the Fall Equinox and the BRL facility at this time does not incur any shadows. However, the parking lot where the solar canopies are to be placed experience slight shading in the lower left hand corner of figure 8.

Winter Solstice December 21nd

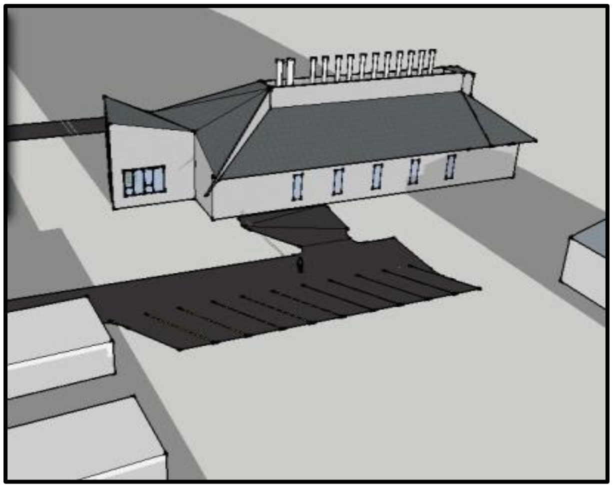


Figure 46: Shadowing during the Winter Solstice at 8:00 A.M.

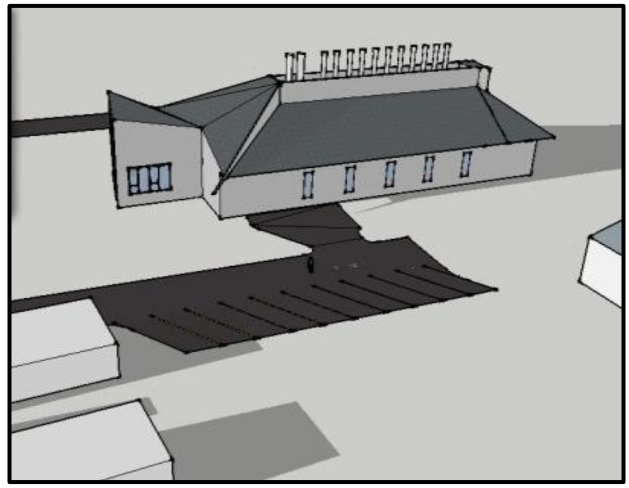


Figure 47: Shadowing during the Winter Solstice at 4:00 P.M.

During the winter solstice at 8:00 A.M., shadowing does not encompassed the building or the parking as one can see in figure 46 and 47. As 9:00 A.M. approached the shadows became even less significant to where the solar system was proposed. At 4:00 P.M. there was also minimal shading in figure 10 in the left corner of the parking lot.

Spring Equinox March 20th

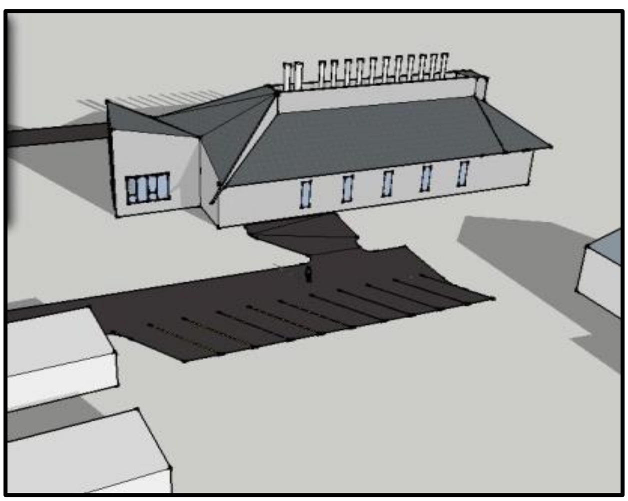


Figure 48: Shadowing during the Spring Equinox at 8:00 A.M.

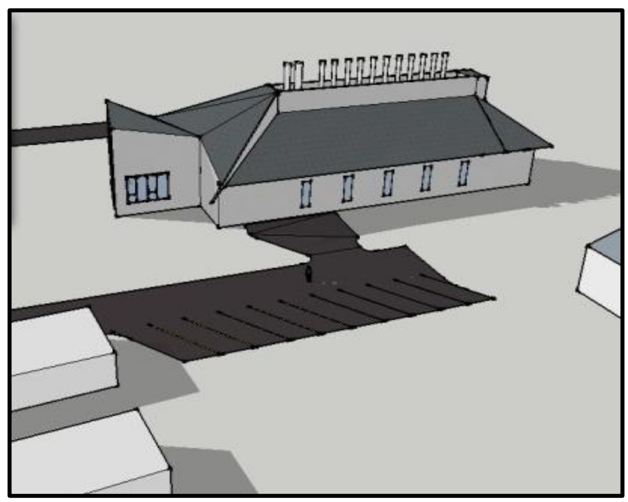


Figure 49: Shadowing during the Spring Equinox at 4:00 P.M.

Examining both figure 48 and figure 49, one can tell there is slight shading during the Spring Equinox but the BRL facility at this time does not incur any shadows. However, the parking lot where the solar canopies are to be placed experiences slight shading in both of the figures above. This amount of shading should be insignificant because that is the amount of shade projected on the floor while the canopies are elevated.

Calculating Energy Loads

The Whitehead Biomedical Research Center for Emory University similar to the BRL is also a Vivarium containing Biological Safe 2 and 3 Laboratories. In the case study energy is broken down per square foot according to design conditions. The breakdown of energy is ventilation, cooling, lighting process/plug and heating. The ventilation calculations are broken down into the Supply and Return. The study also provides information related to cooling, lighting processes/plug, and heating plant. The table below shows estimated electrical values for each system at Research Center at Emory University.

System	Key Design Parameters	Annual Energy Estimate (based on design data)
Ventilation (sum of wattage of all the supply fans and all the exhaust fans	Supply = 1.0 W/cfm Exhaust = 1.25 W/cfm Total = 1.13W/cfm (1.0 cfm/gross ft^2; 1.5 cfm/net ft^2 and 2.1 cfm/gross ft^2 of labs)	19.8 kWh/gross ft^2
Cooling Plant	2300 tons, 1.0kW/ton	20.4 kWh/gross ft^2
Lighting	1.6Wft^2	7.25 kWh/gross ft^2
Process/Plug	11 W/net ft^2	32.4 kWh/gross ft^2
heating Plant	Not available	Not available
Total		79.85 kWh/gross ft^2/yr (estimate based on design data for electricity only)

Table 13: Energy Load Calculations

The Biological Research Laboratory load, which was calculated in a similar way to the Emory University facility, produced a figure of **80.33 kWh/gross ft^2/yr** and can be seen in more detail in Appendix N. The load for the Biomedical Research Center was 79.85 kWh/gross ft^2/yr which different by only .48 kWh/gross ft^2/yr. One of the differences in the lighting value was the BRL facility lighting allowances was capped at 1.0 W/ ft^2 while the Emory facility had a design allowance of 1.6 W/sf. Ventilation in the BRL facility is also a little elevated because of the redundancies in systems which need to be accounted for with a NIH grant. In comparison the values between the two vivariums are quite similarly per square foot. After completion of the Research Center in Emory facilities managers noted that the metered electrical data equated to 63.3 kWh/gross sf/yr. This reduction from the designed parameters is approximately 20.8 percent for total electricity used per year.

Photovoltaic Array Design

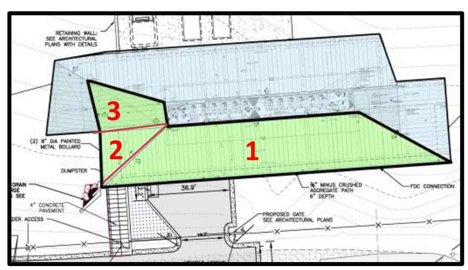


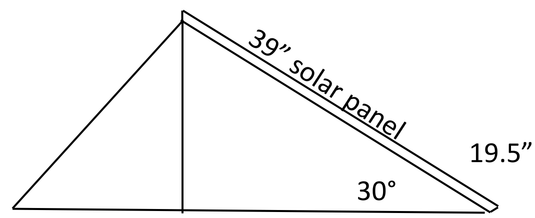
Figure 50: Available Roof Space

Determining an array configuration because of the orientation of the building as well as angled roofs proved to be difficult. Two options were examined for the orientation of the solar panels. The first was involved laying panels direction on the roof which for areas 2 and 3 was optimal because it faces due south with an optimal angle of 35 degrees. On the largest roof which faces approximately south-west by 45 has a roof pitch of 30 degrees. Exploring different options led to two solutions that could possible deliver the best outcome. The first was to orient the panels 45 degrees off of due south. The second option was to redirect the panels on roof 1 from figure 50 above to due south. One problem which occurs when orienting the panels directly due south is that a shadow is created which needs to be calculated, lowering the density of panels. At the location of state college with Latitude of 40 degrees creates a solar altitude angle of 14° and a solar azimuth angle of 42° which can be seen in appendix M. Since the building is 45° off of due south adding and subtracting this angle is important for determining the shade produced. At 9 AM the azimuth angle between the solar azimuth and the array azimuth is (42°+45°)= 87°. Around 3 PM the angle is reversed (42°-45°)= -3°. The calculations can be seen in equation 1 and 2 below.

City (lat°)	Opt. Tilt; kWh/ m²/ day	Hor./ Opt.	% 45° Off/ Opt.	% 90° Off/ Opt.	% 25% L & 45° Off/ Opt.	% 25% L & 90° Off/ Opt.	% 50% L & 90° Off/ Opt.
Rivas (11.4°N)	14°;5.11	97.5%	98.9%	96%	98.9%	96.9%	97.4%
Miami (25.8°N)	24.5°;5.26	93.0%	96.9%	89%	97.1%	90.1%	92.2%
Cairo (30.1°N)	24.5°;5.68	92.6%	96.4%	87.7%	96.7%	89.8%	91.5%
Tuscon (32.1°N)	27.5°;6.59	87.7%	95%	82%	95.1%	84.5%	86.4%
Atlanta (33.6°N)	30°;5.19	89.8%	95.4%	84%	95.8%	86.5%	88.3%
Boulder (40°N)	38°;5.56	83.1%	93.3%	76.5%	93.3%	79.2%	81.4%
Madrid (40.5°N)	33°;5.08	87.2%	94%	79.4%	94.4%	82.7%	85.2%
Boston (42.2°N)	37°;4.63	84.7%	93.4%	77.6%	93.5%	80.7%	82.7%
Seattle (47.4°N)	34°;3.83	87.2%	94.6%	80.5%	94.8%	83.4%	85.7%
London (51.2°N)	34.5°;3.17	87.4%	93.8%	79%	94.3%	82.3%	84.9%
Fairbanks (64.8°N)	51°;3.43	74.6%	91.5%	70.7%	91%	72.4%	73.5%

The cities countries are named and the table abbreviations are explained here: 2.

Figure 51: Solar Tilt



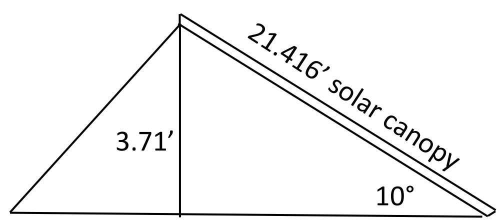
Eq.1 $d = h * \frac{cos\varphi}{tan\alpha} = 19.5" * \frac{cos87°}{tan14°} = .341' \; of \; shading \; at \; 9 \; AM$

Eq.2 $d = h * \frac{cos\varphi}{tan\alpha} = 19.5" * \frac{cos-3°}{tan14°} = 6.5' \; of \; shading \; at \; 3 \; PM$

Spacing between panels now needs to be 6.5 feet as to assure that shading does not affect the efficiency of the module. Choosing this option decreases the amount of solar panel on roof 1 from figure 50 by approximately 50%. The first option of just placing panels on the roof at 30° has a better outcome in the amount of electricity generated. An online study evaluated the benefit of either placing panels directed at true south or off the azimuth by 45°. The examination of cities and buildings with solar systems that didn't face true south did not show significant differences in the amount of power generated. The Biological Research Lab is situated at 40° N latitude and the optimal angle for a solar panel is 40°. In the Importance of Tilt Angle study it discusses that if panels are not

placed directly due south, panel angles should be reduce by approximately 25% [13]. The chart to the left, figure 51, depicts the solar generation of different cities with array designs. The different array design are placing panels at a Horizontal angle, 45° off the optimal (due south), 90° degrees off the optimal (due south), lowering the optimal tilt by 25% as well as 45° off the optimal (due south), lowering the optimal tilt by 25% as well as 90° off the optimal (due south), and lowering the optimal tilt by 50% as well as 90° off the optimal (due south).
The city which most closely matches the site location of the BRL facility is Madrid, Spain. The location of Madrid has a 40.5° N latitude which closely matches that of State College. Lowering the tilt angle by 25% with having the modules 45° off the optimal (due south) delivers 94% efficiency with a degradation of only 6%.

Setting the panels on the roof was decided on the fact the system will only experience a loss of 6 percent in generation throughout each year. The four parking canopies are facing due south at a 10° angle to minimize shading between canopies. The design of the parking lot has a lot to do with the placement and location of the parking canopies. Each parking canopy is 10 feet high and covering two spots. Spots in the enlarged parking lot consist of 11 foot wide spaces. Calculations for the canopy can be seen on the next page for shading of the parking canopies.



Using the same equation from above, the shading for the parking canopy can be determined. In the solar altitude angle equation, no adjustments need to be made because the panels are directed due south.

$$\text{Eq.3 } d = h * \frac{cos\varphi}{tan\alpha} = 3.71' * \frac{cos42°}{tan14°} = 11.05'$$

The panel chosen to be placed on the BRL Facility was a Crystalline PV module with a model number of CHSM6612P which was briefly discussed earlier in the analysis. Important characteristics of the panel consist of the STC rated output of the module of 295 Wp. The size of the panels also important equates to 77” in length to 39” in width with a weight of 51 lbs. or 2.44 lbs. /per square foot. All other specification for the solar module can be referred back to Appendix P under the 295 W modular.

The parking space design incorporates one parking spot that is not covered to allow 11 feet of shading from the previous parking canopy. A Google Sketch up model was created in order to show the design of the parking lot as well as to confirm the shading of the canopies. Even though the average vehicle is only 15, the canopy is sized larger to allow for more panels as well as larger vehicles. The actual size of the canopy is 21 feet wide by 25 feet long which can incorporate approximately 25 panels one each canopy which can be viewed in the figure 52. The capacity in which could be generated by an individual solar canopy is 7.375 kW and 29.5 kW for all four canopies.

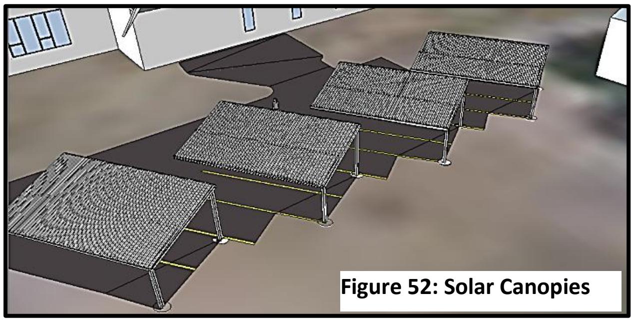


Figure 52: Solar Canopies

The larger area of the roof has a total of 120 panels and concentrated towards the bottom of the roof as to avoid any shadows, figure 53. For architectural purposes as well as achieving more power the panels were not tilted toward due south. In the figure below, the 120 solar modules have the capacity to generate approximately 35.4 kW on the roof which is sloped at 32°.

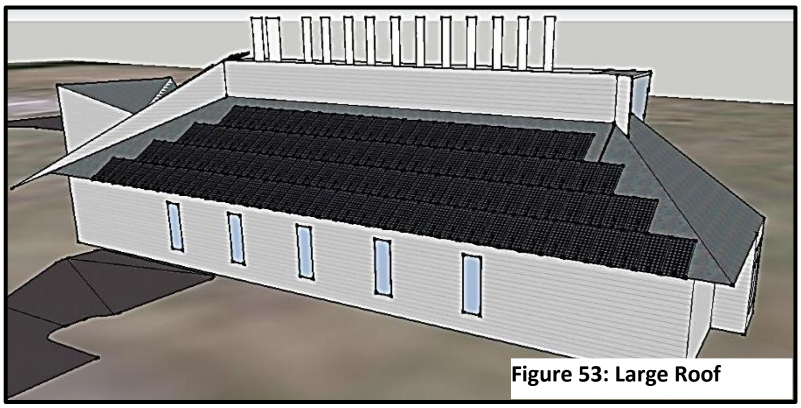


Figure 53: Large Roof

The smaller roof area of the Biological Research Laboratory which can be seen in figure 54, solar panels were added to the face oriented due south. On this side of the roof, no shading affected the placement of the solar panels. The arrangement of the 30 panels has the potential to generate approximately 8.85 kW. This roof also has a optimal pitch of 35° which can be seen in the image below.

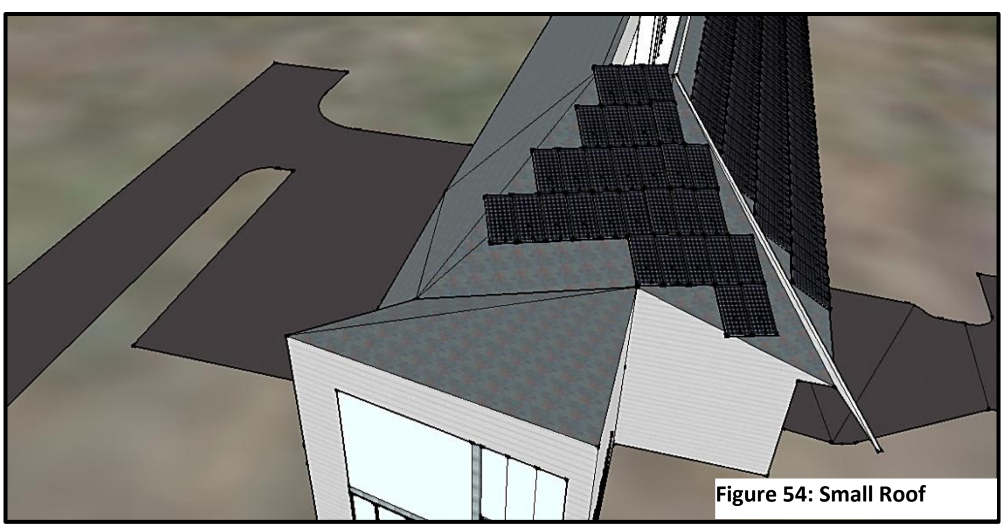


Figure 54: Small Roof

Solar Energy Impact Using PV Watts

PV watts is an online based program which contains a performance calculator for Grid connected PV systems. This program allows the user to develop a total amount of energy in kW depending on the orientation of the system. One the Biological Research Laboratory there are three main locations for which needs to be calculated separately because of the orientation of the PV modules. The data points which are entered into the system consist of the rated size of the system, the tilt of the array in degrees, array azimuth and the average cost of electricity for the area. Since PV Watts does not have State College as a city within the program, Williamsport was used because it shares some very similar solar characteristics over any other locations within Pennsylvania.

Running the PV Watt calculator generate a total system output of approximately 77.7 kW, this was spread across the 250 panels that the system consists of. One of the concerns with the system is the Energy Value. The University has a contract with West Penn Power for receiving reduced rates of electricity. The rate is approximately 6.0 ¢/kWh while the state average for Pennsylvania is around 12.0 ¢/kWh. This reduction in costs in table 14 can significantly hurt the payback period of the system.

Summary Station Identification	
City:	Williamsport
State:	Pennsylvania
Latitude:	41.27° N
Longitude:	77.05° W
Elevation:	243 m
PV System Specifications	
DC Rating:	29.5 kW + 8.9 kW + 35.4 kW = **73.7 kW**
DC to AC Derate Factor:	0.77
AC Rating:	27.3 kW
Array Type:	Fixed Tilt
Array Tilt:	10.0°, 32.0° 35.0°
Array Azimuth:	135.0°, 180°
Energy Specifications	
Cost of Electricity:	**6.0 ¢/kWh**

Summary Results			
Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	2.55	4388	263.28
2	3.21	5071	304.26
3	4.22	7213	432.78
4	4.63	7499	449.94
5	5.43	8901	534.06
6	5.68	8814	528.84
7	5.70	8926	535.56
8	5.22	8103	486.18
9	4.38	6762	405.72
10	3.36	5335	320.1
11	2.23	3455	207.3
12	1.99	3243	194.58
Year	**4.05**	**77710**	**4662.6**

Table 14: Solar System Inputs

Feasibility Analysis

A Solar project development course was recently taught at the University where SAM, a solar advisory model tool, was used to determine the payback period and individual rate of returns for the project. Some of the raw data that the program determined was the total project cost of $ 307,512.34 as well as a $ 4.76 per Watt cost. The Payback period is the most important factor in regards to the owner of the project. Tax incentives along with grants and rebates have made solar projects in the past affordable as well as help generate an acceptable payback period.

The financial structure of the photovoltaic system was set up in the form of a Private Purchase Agreement of 15 years in order to take full advantage of incentives. In this scenario property tax on the estate can be negated because Penn State is partially state owned. A utility incentive can also be applied to the project with West End Power for a total of $ 25,000. A large rebate program falling under the Pennsylvania Sunshine Solar Rebate program offers $2.25/W or a maximum incentive of $1,000,000. SREC's were also implemented in the design of the financial study but they did not have much of an impact due to the 20 $ per MWh price. Where the system was able to capitalize from being a PPA was in the Federal Depreciation. Since the project in under construction now, 50% bonus depreciation can be implemented making the system financially viable. The final finding of the system contains a nominal LCOE of 6.73 cents/kwh and a real LCOE of 5.88 cents/kWh. In a PPA a payback period is really not the concern but a positive net present value which in the case of the photo voltaic system is $5,077.71 and can be seen in figure 55.

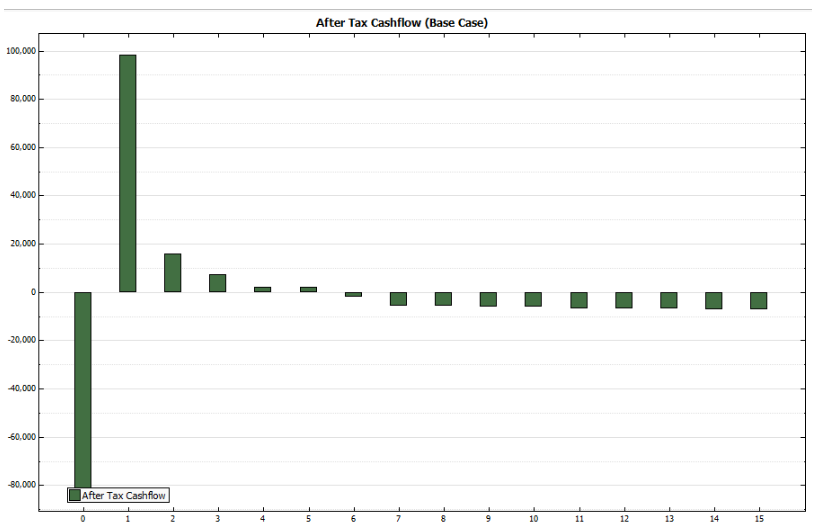


Figure 55: Cash flow of Photovoltaic System

LEED Evaluation

LEED 2009 evaluates Green Building Design and Construction on several different categories including sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and design process, and regional priority credits. The Pennsylvania State University seeks LEED certification as a minimum on every new construction and renovation project on all university campuses. Areas of focus for the University are energy conservation, natural resources conservation, prevention of environmental degradation, people's health (well-being), comfort, and finally total cost of ownership.

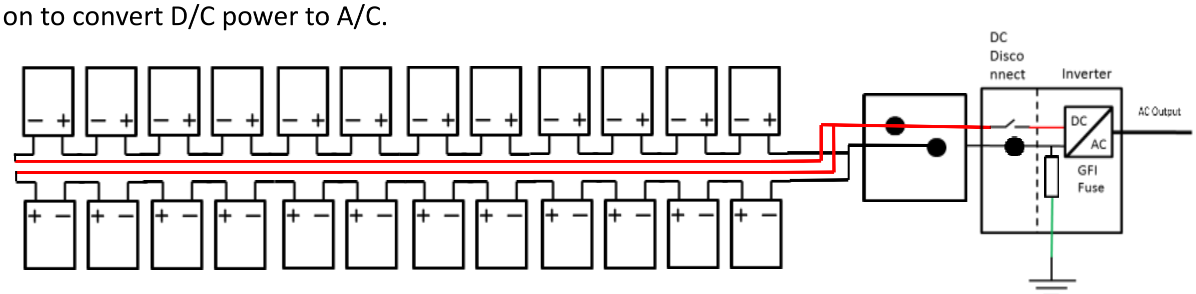
One credit where points could be achieved because of the new parking canopies is Credit 4.3 Alternative transportation – Low emitting and fuel efficient vehicles. This credit states through the use of installing alternative fueling stations or by providing preferred parking a building could potentially achieve three extra points. Credit 7.1: Heat Island Effect-Nonroof's intent is to minimize impacts on microclimates and human wildlife habitats. Under Credit 7.1 by placing at least 50% of parking spaces under cover as well as with the addition of solar panels, adds an addition point. Renewable Energy is another area where the Biological Research laboratory can earn points for the addition of its renewable energy harvesting system. The solar panel system generates approximately around 77,700 KWHs for the entire year while the building overall consumes around 2.1 Million KWH for the year. The photovoltaic system generates approximately 3% of the total consumption of the building which according to the LEED score card achieves an additional 2 points.

Originally, the BRL facility had a LEED rating of silver with a total score of 47 points. The LEED scorecard states, a score of Silver on a new construction project has to earn between 40 and 49 points. Through the addition of the photovoltaic and canopy system an additional 6 points can be earned as a secondary benefit to generating electricity. A total of 53 points places the Biological Research Laboratory in the area of LEED Gold which has a range of 50-59 points on the LEED scorecard. A rating of Gold on the BRL facility implies a lot for a state of the art vivarium. In the future not only will many professors and researchers visit this laboratory but to see it has a LEED rating of Gold only sets the bar higher for other research institutions.

Electrical Breadth

The 250 panel system is broken into several components around the roof along with the addition of parking canopies covering the parking lot. The parking canopies required the most work along with the most amount of materials in order to hook up correctly. Each of the four parking canopies consists of 24 panels. The type of panels was derived from a Crystalline PV Panel rated at 295Wp. Once the panels were sized and determined the amount per strings as well as the number of strings needed to be determined in order to properly hook up the system to the grid. A table was created in order to incorporate location inputs as well as solar panels module types. The solar module inputs calculate Pmax, Vmpp, Impp, Voc, ISC and the Temp Coeff of each panel.

Once the data is entered into the chart, the modules per string need to be calculated as well as the number of strings. In calculating the number of modules per string max voltage of each string cannot exceed a maximum of 600 volts. The inverter must also be taken into consideration when determining voltage with respect to the minimum and maximum allowable voltage of the inverter. If the high temperature voltage is less than the minimum voltage allowed by the inverter the system will not turn on to convert D/C power to A/C.



In a photovoltaic system there are a series of components in order for the system to pass code and operate with the necessary safety protocols. Sizing of the wires between the modules the Isc value or 9.16 A which is taken off the specifications sheet of the solar module can be found in Appendix L . This value is then multiplied by 1.25 for safety as well as 1.25 for wires and fuses. This value of 14.31 amps is then used to size the wires between each individual panel. Table 310.16 from the NEC 2008 shows a table of the different grades of wire. In the purpose of outdoor connections 90°C wire was utilized. Degradation of the wire also had to be accounted for because of the ambient temperature which is the maximum roof temperature plus the conduit temperature. An ambient temperature of 60°C causes a degradation of .71, the wire sizing of #12 AWG needs to be able to hold 14.31 Amps with the degradation.

- Max wire amp for 1 string= Isc*1.25*1.25=9.16*1.25*1.25=14.31 A
- #12 AWG @ 90°C= 30A* .71= 21.3 A > 14.31 A ok to uses for connecting string to combiner box

Calculating the wire size between the connector box and the DC disconnect is carried out with the same process. The amperage for each string of modules is then added up and a new wire size is calculated as in the calculations illustrated below.

- Max Wire Amp for 2 strings= Isc*1.25*1.25*2= 9.16*1.25*1.25*2=28.62
- #8 AWG @ 90°C= 50A * .71= 35.5 A> 28.62 (Max wire Amp), so wire is OK to use between the combiner box and inverter

Once Direct Current power has reached the inverter; it is transformed into alternating current which then can power receptacles and lights within the building. When the power leaves the inverter wires can be sized according to the output voltage and amperage of the inverter. Output amperage of the inverter is 27.1 amps multiplying by a factor of 1.25 for growth in the circuit breaker of the panel.

- 27.1*1.25(growth)=33.875 Amp
- #10 AWG @ 90°C= 40A > 33.875 (Max wire Amp), so wire is OK to use between A/C disconnect and underground splice box

Once these wires have reached the underground splice box for the parking canopies they are combined and travel as one wire into the building. After the inverter and before the panel board an A/C disconnect is required by law before the panel board which can be seen in figure 56 below. The inside breaker panel is then sized based of the current from the inverter on8the alternating current side.

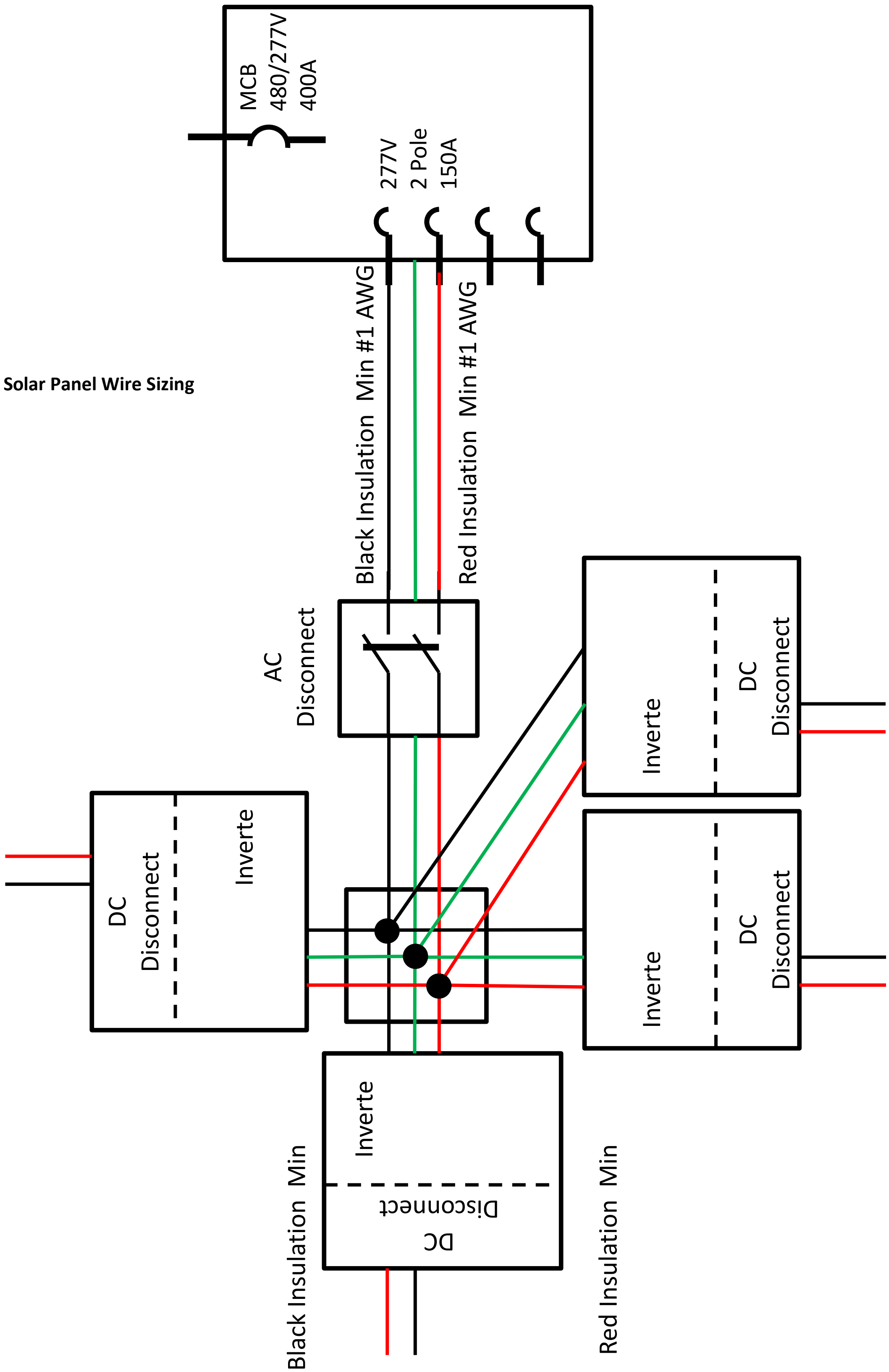
- 33.875*4=135.5 Amps wire sizing from parking canopy to electrical box inside building
- 135.5 A < 150 A so #1 AWG in a 2" rigid PVC pipe
- Next breaker size 150Amp
- Assumed THWN 90°C from table 310.16
- #1 Wire 135.5 Amps = 150 A Breaker size so OK to use
- When connecting to an electrical panel a 150 A breaker is to be used to sufficiently take the load.

This process is repeated for the large roof and small roofs where photovoltaic panels are on the BRL roof. The three circuits, then travel down into the electrical room which is in the basement of the BRL facility. The panel board within the basement in which the three circuits will be fed consists of a 400 amp panel board. Before and after the panel will be A/C disconnects for safety and code regulations. Table 15 below illustrates the calculated wire sizes between each connection.

ROOF	NUMBER OF PANELS	NUMBER OF STRINGS	WIRE SIZE BETWEEN MODULES	WIRE SIZE FROM D/C DISCONNECT TO INVERTER	WIRE SIZE FROM INVERTER TO A/C DISCONNECT	WIRE SIZE FROM A/C DISCONNECT TO SPLICE BOX	WIRE SIZE FROM TO SPLICE BOX TO PANEL BOARD
PARKING CANOPIES	24	2	12 AWG	8 AWG	10 AWG	10 AWG	1 AWG
SMALL ROOF	30	3	12 AWG	6 AWG	8 AWG	8 AWG	8 AWG
LARGE ROOF	120	12	12 AWG	6 AWG	8 AWG	8 AWG	2/0 AWG

Table 15: Solar Panel Wire Sizing

Figure 56: Solar Panel Wire Sizing



Recommendations and Conclusion

Installing a Photovoltaic array on the Biological Research Laboratory has many benefits other than just generating power for the facility. The array utilizes multiple components including solar powered car canopies and properly sized inverters to generate around 3% percent or 77,700 kWh of energy. An electrical breadth was also performed where wire sizing and panel boards were determined in order to power the lights in the facility at 277V. The implications of LEED are also impacted with the addition of solar panels on the project. With the addition of not only solar panels on the roof but solar parking canopies, a LEED rating of Gold can be obtained over the original LEED silver rating. One problem with installing the system on university property is calculating a feasible payback period. A PPA agreement allows the University take advantage of tax incentives as well as offer a positive net present value for the voltaic system.

Analysis IV: Schedule Acceleration (Critical Path)

Problem

The Biological Research Laboratory is approximately two months into construction when permitting issues involving Labor and Industry set the project behind schedule. Problems permitting with the Labor and Industry and the inability to receive and start work caused the project to be delayed from the start. Another difficulty that imposed a scheduling delay was the weather in late August to the end of October, rain forced the excavation of the site to stop as well as the utility banks to be delayed. If the project does not finish on schedule both the owner and Torcon, the Construction Manager, would likely incur damages.

Research Goal

The goal of the analysis is to develop a schedule acceleration scenario while incorporating labor efficiency, and the added cost for overtime. An activity where time can be reduced was in steel erection and the placement of metal decking. Along with the increased number of crews re-sequencing will be evaluated in order to properly redistribute the crews so that their productivity remains higher than working a normal work week. Work flow on the project will also be evaluated because of the direct correlation to a crews inefficient work hours. The steel fabricating crews overall productivity ultimately determines a breakeven point, where working overtime is not beneficial and the acceleration of another activity may need to be assessed.

On the Biological Research Facility there are many trades which could be evaluated to effectively speed up the schedule of the project. The focus was to concentrate on critical path trades, the first was the structural steel of the laboratory. Without the completion of the superstructure other trades such as the fit out for Mechanical, Electrical, and Plumbing trades cannot be started along with other key subcontractors to completely enclose the building. Productivity of the crews as well as considering overtime scenarios for the steel construction will be evaluated.

Case Study

Overtime productivity is determined to be the amount of work completed in the amount of hours above a standard workweek. In many studies, 40 hour work weeks show to be the most productive while any amount of time after that would lead to reduced productivity. However recently in several case studies the idea of working more than 40 hours per week can actually lead workers to be more productive. This statement becomes more accurate when related to each single day of working more than 8 hours. Manipulating work hours during the week can produce a higher level of output without increasing overall workforce size which has the potential to save on labor costs.

Breakdown of Construction Productivity

While the breakdown of productivity cannot be easily determined one place to start would be to breakdown worker productivity into Human, External and Management. Humans factors of productivity such as worker motivation, worker boredom and fatique, worker attitude and morale, workers physical limitations, worker absenteeism, worker learning curve, worker experience, and worker skills as well as the team spirit of crew can affect the schedule of the project [9].

External factors also affect the productivity of workers which includes union rules and influences adverse weather conditions, noise, dust, radiation, congested work area, change in drawings and specifications, changes in contract, demand for over-quality work and nature of the project [9]).

The last way worker productivity can diminish is through management factors including protective gear, unrealistic schedules, overtime, multiple shifts, excessive shift length, disrespectful treatment of workers, parking facilities, salary and benefits, site layouts, tearing out and reinstalling work, discontinuity in crew make up, useless personnel, overcrowded work environment, hazardous work conditions, insufficient equipment, insufficient supervision, crew, constructability, subcontracting, change in labor, lack schedule planning, insufficient materials, tools and equipment [9].

The Arizona State University conducted research where they analyzed collecting data for crew productivity. These researchers made it apparent to prevent the Hawthorne effect from happening with worker on the site. The Hawthorne effect is when subjects improve or modify an aspect of their everyday behavior because they know they are being watched [9]. This aspect was crucial in order to keep figures true and eliminate bias from the data. After the data was collected a graph was formulated which displayed a productivity trend line. The purpose of the trend line is to show optimal overtime and theoretical optimum productivity in increments above a 40 hour work week. In the average of the crews, maximum productivity is attained around 22% of overtime. While this crew might reach maximum work potential at 49 hours from a management standpoint this might not be the most economical in terms of labor costs, this can be seen in figure 57, below [9].

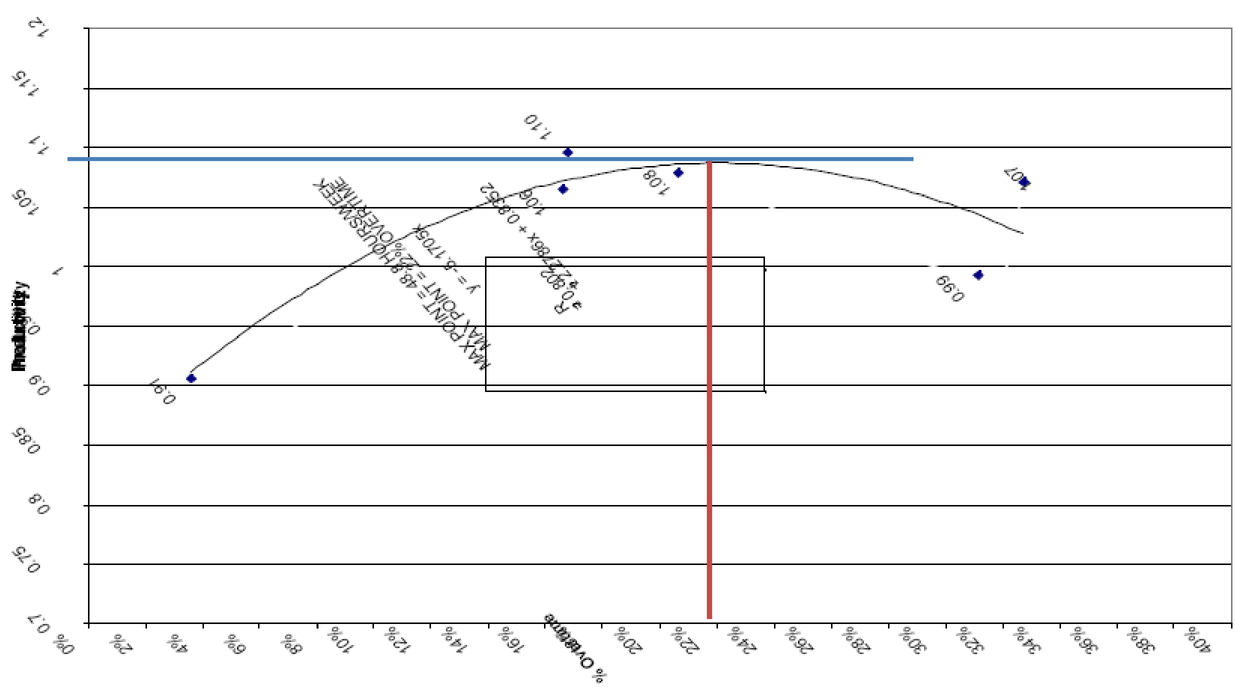


Figure 57: Optimization of Overtime

Incorporating Cost within Productivity

Evaluating this concept of increase labor hours from a Construction Management standpoint should also incorporate lowest overall job costs. An efficiency factor which is the productivity at some percentage of overtime divided by the productivity at 40 hours/week can be used to determine cost. Once the efficiency factor has been calculated, an average cost can be taken and multiplied by the factor. Productivity is also affected by the amount of overtime pay a worker receives, for example a worker which receives pay and a half for overtime has a higher productivity than a worker who receives pay and a quarter.

One reason why the study shows increasing productivity throughout overtime is from the process of getting into work as well as leaving. In some of the data presented crews took approximately an hour to travel to their place of work as well as set up their work stations. This same amount of time was taken to pack up when the crew of workers was leaving for the day. In a typical work day this only leaves 6 hours when crews are actually working not taking into account their lunches or other unproductive task such as using the restrooms. By increasing the amount of hours per day worked, more time will be spent actually completing work then preparing a workstation or transportation to the site.

Examining this method of effective work, if a crew would complete 30 productive hours with a total of 10 travel hours their productivity would be 15 units per hour. Staitistics were from the case study by Arizona State University which assumes in the first 40 hours of work per week a crew is able to produce 20 units of work per hour, while only 18 units of works a week are preformed after overtime.

$$\frac{(30\ prod.hrs.)*(20\ units\ of\ work)}{40\ hrs.per\ week} = 15\ units\ per\ hour$$

$$\frac{(30\ prod.hrs.)*(20\ units\ of\ work)+(10\ Ovr.hrs.)*(18\ units\ of\ work)}{50\ hrs.per\ week} = 15.6\ units\ per\ hour$$

This idea on a project would yield an increase in productivity of approximately 4% by continuing to work instead of leaving for the day.

According to the Bureau of Labor Statistics which conducted a study on overtime and workweeks included data from 78 different cases and 3,500 people had diminishing returns on long workweeks. Looking at different work weeks specifically 50 hour, 60 hour, and 70 hour within the Bureau of Labor Statistics shows returns of 92%, 82%, and 78% respectively. The Director of Construction of the Foster Wheeler Corporation, L.V. O'Connor developed his

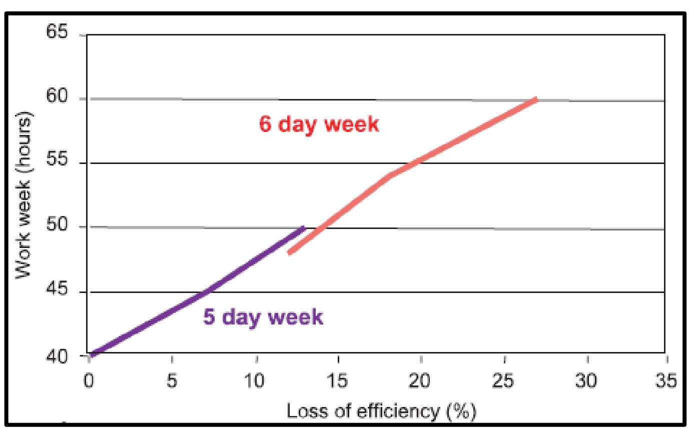


Figure 58: Overtime 5 day and 6 day Week

own labor inefficiency curves for productivity of 5-10 hour days and 6-10 hour days. The productivity for the 50 hour work week equated to 87% while the 60 hour work week equated to 73% [10]. This chart for the work week compared to the loss of efficiencies can be seen in figure 58.

Another source, The Business Roundtable (BRT), produced a report on "Scheduled Overtime Effect on Construction Projects." In this report 50 and 60 hour work weeks were described in detail measures productivity and the actual work hours. One important item to note is the ratios of productive return to overtime hours. "it is important to note that the effect of reduced labor productivity reaches the point of nor productive returns on overtime hours, which is earlier for a 50 hour schedule than for a 60 hour schedule." This can be seen in figures 59 and 60 to the right which is denoted by where the red line crosses the x axis.

Different Work Schedules

The construction industry institute also performed a study changing the amount of days in a work week for a typical crew. They used the concept on a chemical plant of rolling 4-10 hour days with two days off. In this scenario at least three crews were implemented so that at least two crews were on site each day of the working week. The concept of rolling 4-10 hours days show high productivity throughout the weeks but can be proven seen in figure 61. In the previous case studies less days and more hours means more productive time as well as tool time. The rolling 4 day concept also debunks high absenteeism at work because crews are receiving three days off. One last major key point is examining the fact that many hours during the week are being completed like overtime but yet not one crew is actually working or receiving money. This also conforms with the construction management point of view by implementing cost saving into overtime scenarios.

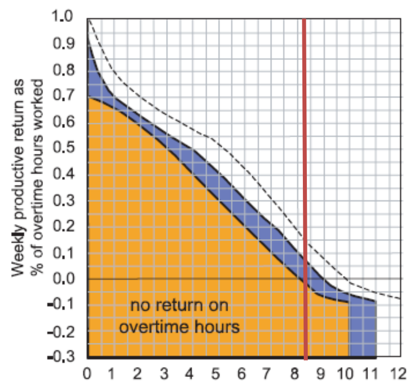


Figure 59: 60 Hour Job Schedule

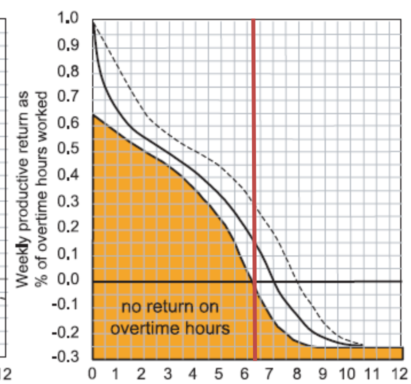


Figure 60: 50 Hour Job Schedule

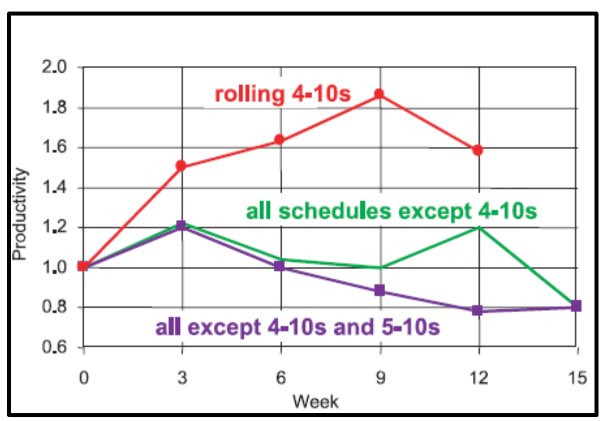


Figure 61: Rolling 4-10 hour days

Bringing into question the performance factor of working different days per week was promising for the 4 day work week schedule. The Construction Industry Institute over a three to four week duration gathered data. The cause for the spread of workweek scenarios was caused by weather. Within in the data collected a 7 day work week was omitted to keep the data more consistent. The 2 and 3 day work weeks had an efficiency of approximately .58 and .62. The severe deficiency with performance dealt again with the in climate weather. Looking at 5 and 6 day work weeks only showed a 15% percent loss in efficiency for both days.

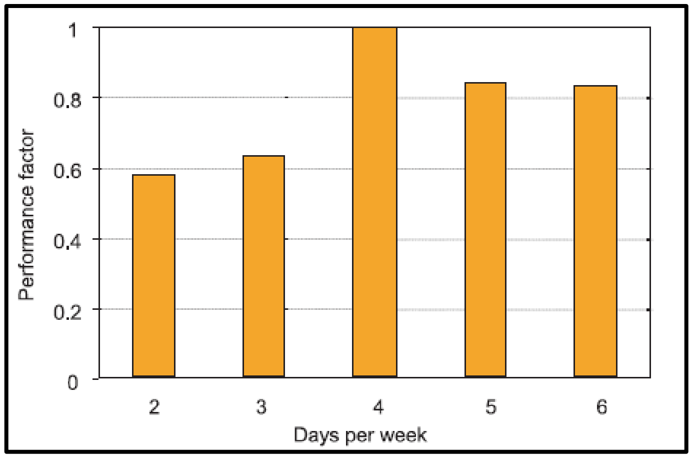


Figure 62: Variable Days of Overtime

Other schedule scenarios consist of 5 days at 9 hours, 6 days at 8 hours, and 5 days at 10 hours all having an efficiency of .96-.98 at an interval of 4 weeks as seen in figure 62. While these overtime scenarios have a high efficiency related to productivity they are only working approximately 5-10 hours a week extra in overtime. The next area which was calculated is a work week containing 6 days at 9 hours having an efficiency of 87 percent. Working efficiency again drops between 76-78% for working schedules of 6 days at 10 hours, 5 days at 12 hours, and 7 days at 8 hours after four weeks of working. At 70 percent efficiency after weeks, work schedules at 7 days while working nine hour days and 6 days at 12 hours are some of the least preferred working scenarios. The work schedule with the worst efficiency after four weeks is a 7 day work week at 10 hours a day.

Structural Schedule

On the Biological Research Facility, the schedule for steel construction and placement of metal decking is approximately 5 weeks. The typical work week of a crew is 5 days at 8 hours for each day. Budgeted within the original schedule was 10 days or two weeks for installing all of the structural steel within the building and steel decking was allotted three weeks in the schedule. Total work hours for the regular schedule amounted to 200 but the actual effective work hours added up to approximately 194.8 hours. In the problem description above, the BRL facility is around 6 weeks behind and in order to successfully make up lost time an overtime scenario must be implemented. The overtime work schedule must both be economical because of the size of the project as well as effective. Reevaluating the idea of the rolling 4-10 hour days which can be seen in figure 63 below, has the highest percentage of productivity out of any other overtime option.

Other options which will be evaluated as to compare work hours with the concept of the 4-10 days with a rolling schedule are 6-10 hour days as well as a normal 5-8 hour day schedule. Rolling 4-10 work schedule produces an average efficiency of 1.34 over the course of 3 weeks. Effective work hours surpasses the standard 5 day 8 hour work week in two weeks and three days which can be seen in table 17 compare to table 18. Comparing

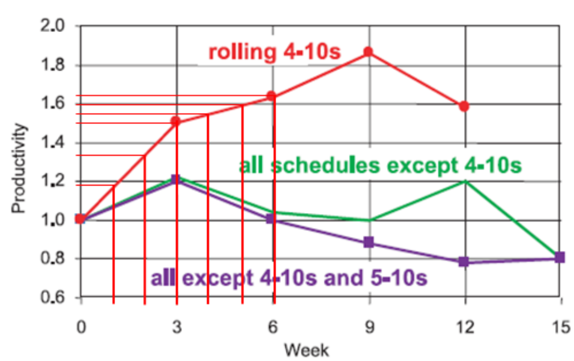


Figure 63: Interpolation of the Rolling Schedule

the effective hours yields:

$$5\ day - 8\ hour\ weeks\ =\ 194.8\ eff\ wrk.hrs.\ < 4\ day - 10\ hour\ rolling\ 195.6\ \ eff\ wrk.hrs.$$

The comparable work schedule of 6 days -10 hour days shows rate of return for productivity is a lot lower but ultimate works the same hour weeks as three crews. Since the 6 day 10 hour crews are working 60 hours not only in this scenario are they getting paid time and one half for overtime their productivity is also significantly lower as can be seen in table 16.

6-10's	Productivity	Hours	Effective
Week 1	0.95	60	57
Week 2	0.9	60	54
Week 3	0.87	60	52.2
Week 4	0.83	60	49.8
Week 5	0.79	60	47.4
Week 6	0.75	60	45
Total	0.848333333	360	305.4

Table 16: 6 Day-10 Hour Shifts

Rolling 4-10	Productivity	Hours	Effective
Week 1	1.18	60	70.8
Week 2	1.33	60	79.8
Week 3	1.5	60	90
Week 4	1.55	60	93
Week 5	1.6	60	96
Week 6	1.65	60	99
Total	1.468333333	360	528.6

Table 17: Rolling 4 Day-10 Hour Shifts

5-8's	Productivity	Hours	Effective
Week 1	0.99	40	39.6
Week 2	0.98	40	39.2
Week 3	0.97	40	38.8
Week 4	0.97	40	38.8
Week 5	0.96	40	38.4
Total	0.541111111	200	194.8

Table 18: Normal 5 Day-8 Hour Shifts

Crew Weekly Schedule and Makeup

Implementing the three crews over the course of every week can be difficult to visualize. Using the rolling 4-10 schedule can offer two very visually different work calendars; the first is a standard schedule where the three crews work the same times during the week. However, this can become a problem because while crews one and three reap the benefit of having three days off around the weekend; crew two is always in the position of having Wednesday and Thursday off but they have to work every Saturday. While the overall productivity of the three crews are still very

WEEK	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	Crew 1 Crew 2	Crew 1 Crew 2	Crew 1 Crew 3	Crew 1 Crew 3	Crew 2 Crew 3	Crew 2 Crew 3	
2	Crew 1 Crew 2	Crew 1 Crew 2	Crew 1 Crew 3	Crew 1 Crew 3	Crew 2 Crew 3	Crew 2 Crew 3	NO WORK
3	Crew 1 Crew 2	Crew 1 Crew 2	Crew 1 Crew 3	Crew 1 Crew 3	Crew 2 Crew 3	Crew 2 Crew 3	
4	Crew 1 Crew 2	Crew 1 Crew 2	Crew 1 Crew 3	Crew 1 Crew 3	Crew 2 Crew 3	Crew 2 Crew 3	
5	Crew 1 Crew 2	Crew 1 Crew 2	Crew 1 Crew 3	Crew 1 Crew 3	Crew 2 Crew 3	Crew 2 Crew 3	
6	Crew 1 Crew 2	Crew 1 Crew 2	Crew 1 Crew 3	Crew 1 Crew 3	Crew 2 Crew 3	Crew 2 Crew 3	

Table 19: Nominal Rolling 4 Day 10 Hour Schedule

productive, crew to might be the least productive out of them all. The first weekly schedule can be seen in table 19 as well as the days off for crew two.

The second schedule which would be better for longer work periods utilizes more of the idea for a rolling schedule by shifting one day every week when the crews start working. If crew one on the first week would work Monday through Thursday, than the second week there schedule would consist of working Tuesday through Friday and the third Wednesday through Saturday. This allows crew two who has the potentially the worst work week to have Friday through Saturday off because of the rotation.

WEEK	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	Crew 1	Crew 1	Crew 1	Crew 1	Crew 2	Crew 2	
	Crew 2	Crew 2	Crew 3	Crew 3	Crew 3	Crew 3	
2	Crew 2	Crew 1	Crew 1	Crew 1	Crew 1	Crew 2	
	Crew 3	Crew 2	Crew 2	Crew 3	Crew 3	Crew 3	
3	Crew 2	Crew 2	Crew 1	Crew 1	Crew 1	Crew 1	
	Crew 3	Crew 3	Crew 2	Crew 2	Crew 3	Crew 3	NO
4	Crew 1	Crew 2	Crew 2	Crew 1	Crew 1	Crew 1	WORK
	Crew 3	Crew 3	Crew 3	Crew 2	Crew 2	Crew 3	
5	Crew 1	Crew 1	Crew 2	Crew 2	Crew 1	Crew 1	
	Crew 3	Crew 3	Crew 3	Crew 3	Crew 2	Crew 2	
6	Crew 1	Crew 1	Crew 1	Crew 2	Crew 2	Crew 1	
	Crew 2	Crew 3	Crew 3	Crew 3	Crew 3	Crew 2	

Table 20: Staggering Rolling 4 Day 10 Hour Schedule

Cost Breakdown

The structural steel crew on the Biological Research Laboratory consists of a foreman, four structural steel workers, a crane operator, an equipment operator, and a lattice boom crane. The total labor hours for each crew are 56 labor hours when looking at the regular 5 day 8 hour schedule.

Implementing the rolling 4 day 10 hour shifts incurs an additional 14 additional labor hours per day because of the 10 hour work period. Having two reduced crews working on the same day also poses the problem of how to structure the Steel foreman across the week. In order to allow each foreman to work 40 hour a week as well as supervise progress being made on site, it is proposed that they effectively work 40 hours and are separate from the structural steel workers. Steel foreman 1 will work Monday to Thursday and Steel foreman 2 will work Wednesday to Saturday. On the two days where both foremen are working together, they will have the ability to plan and make sure the schedule and shakeout areas are planned out for the following week. They will also have the ability to resolve any problems with quality of work while the other foreman is there.

The Crane will also be utilized on Saturdays instead of sitting dormant for the entire weekend. Two crews will be set up for the crane which will only work 30 hours per week. The first crew is proposed to work Monday through Wednesday and the second crew is proposed to work Thursday through Saturday. By implementing two crews during the week it effectively eliminates overtime from their portion of work as well as keeps productivity for the crane higher than if working a 6 day 10 hour week which has a productivity of .87 percent after 4 weeks.

5 Day 8 Hour Work Schedule		
Steel Erecting Crew	**Hr.**	**Daily**
1 Structural Steel Foreman	$ 85.95	$ 687.60
4 Structural Steel Workers	$ 82.45	$ 2,638.40
1 Crane Operator	$ 66.45	$ 531.60
1 Equipment Operator	$ 57.35	$ 458.80
1 lattice Boom Crane		$ 1,767.70
56 L.H. Daily Totals		$ 6,084.10
Week		$ 30,420.50
5 Weeks		**$ 152,102.50**

Table 21: Normal 5 Day-8 Hour Shifts Cost Breakdown

11

4 Day 10 Hour Rolling Work Schedule		
Steel Erecting Crew	**Hr.**	**40 hrs./ Week**
2 Structural Steel Foreman	$ 85.95	$ 6,876.00
6 Structural Steel Workers	$ 82.45	$ 19,788.00
2 Crane Operator	$ 66.45	$ 3,987.00
1 Equipment Operator	$ 57.35	$ 3,441.00
Weekly Totals		$ 34,092.00
1 lattice Boom Crane		$ 8,838.50
Week		$ 42,930.50
2 Weeks 4 days		**$ 117,427.50**

Table 22: Rolling 4 Day-10 Hour Shifts Cost Breakdown

6 Day 10 Hour Work Schedule				
Steel Erecting Crew	**Hr.**	**40 hrs./ Week**	**Overtime 20 hrs.**	
1 Structural Steel Foreman	$ 85.95	$ 3,438.00	$ 128.93	$ 2,578.50
4 Structural Steel Workers	$ 82.45	$ 13,192.00	$ 123.68	$ 9,894.00
1 Crane Operator	$ 66.45	$ 2,658.00	$ 99.68	$ 1,993.50
1 Equipment Operator	$ 57.35	$ 2,294.00	$ 86.03	$ 1,720.50
Weekly Totals		$ 21,582.00		$ 16,186.50
1 lattice Boom Crane		$ 8,838.50		
Week		$ 30,420.50		**$ 46,607.00**
3 Weeks 5 days				**$ 178,334.75**

Table 22: 6 Day-10 Hour Shifts Cost Breakdown

Reviewing tables 21,22, and 23 above, the rolling four day – ten hour shifts proposed are calculated to be the most economical with the shortest duration. While labors hours are the same for the 6 day 10 hour shifts and the rolling schedule, the cost difference is approximately $ 60,000.00. Productivity can also be directly linked into the cost difference between the two different schedules. The rolling schedule which finishes 1 week and 1 day earlier saves approximately $ 45,000.00. When comparing the base line schedule of the 5 day 8 hour work week which had a cost of $152,102.50, the rolling 4 day 10 hour schedule which had a saving of approximately $ 34,500.00.

In order for the rolling 4 day 10 hour schedule to be implemented on the project locations factors have to be considered. Given that the Biological Research Laboratory is in the middle of State College finding enough manpower might prove to be challenging. Also due to the size of the project, the new implemented schedule is only 3 weeks instead of the original 5 week duration. Proposing this change in the schedule for a small steel subcontractor in the State College area could be difficult because of the availability of workers and resources.

Additional Trades

In order to make up the proposed time, an additional three weeks needs to be rescheduled to return the Biological Research Laboratory to its original schedule. The placement of concrete on the steel decking is another trade which can be accelerated because it is a critical path activity. The original trade is scheduled to take around 3 weeks to complete pouring the concrete on the main floor, penthouse, and mechanical mezzanine. Calculating effective hours for three weeks of a normally scheduled work period give a total of 117.6 hrs. which can be seen in table 17, above. Implementing the rolling 4 day 10 hour shift allows for the concrete to be poured within 2 weeks or 1 week and four days to be more precise. This allows for an additional week to be recovered in comparison to the original schedule. One last trade which can be accelerate using the rolling 4 day hour schedule is the exterior wall framing and masonry which has a total duration of 5 weeks. Again exploiting the effective hours of this trade yields a for a traditional work schedule 194.8 effective hours but using the rolling 4 day 10 hour schedule imposes a shortened duration of approximately 195.6 effective working hours. . On completing the structure of the exterior a savings of 2 weeks can be acquired with the implementation of the rolling schedule.

$$5\ day - 8\ hour\ weeks\ =\ 194.8\ eff\ wrk.hrs.\ < 4\ day - 10\ hour\ rolling\ 195.6\ \ eff\ wrk.hrs.$$

Recommendations and Conclusion

The research on productivity and the comparison between the regular work hours, an overtime schedule of 6-10 hour days, and the rolling 4 day 10 hour work period showed an obvious benefit in the rolling schedule. Implementing the rolling schedule on the steel trade shortens the original duration from approximately 5 weeks down to 2 week and 4 days. This saving in time is based the productivity charts above, the conception for having three days off during the week and the ability to have more effective hours by eliminating the fifth working day. Examining cost also showed a savings of approximately $34,500 in the labor and equipment costs. One major reason for the savings is the ability to remove the crane two weeks earlier from the site. To recover the additional weeks needed effective hour calculations were performed on the placing of concrete on each of the floors as well as the exterior wall framing and masonry. The saving in time from these two scenarios yielded one week for concrete and 2 weeks for the exterior wall. Given the availability of labor resources, implementing the rolling 4 day 10 hour work week would not only yield a cost savings in labor but give the ability to make up lost time due to permitting.

MAE Requirements

The integrated BAE/MAE requirement for this thesis was fulfilled by incorporating a multitude of areas from education while enrolled in AE Graduate-Level courses. The knowledge gained was spread throughout the third and fourth analyses.

AE 897 A: Solar Project Development

In this class sizing photovoltaic systems was carried out using PVwatts as well as the Solar Advisory Model or (SAM). These programs used solar power and array sizes to calculate the power generated. SAM was used partially to calculated LCOEs and Payback periods. Technically aspects were also discussed in class including the panel tilt, spacing, orientation and government incentives.

AE 597 F: Virtual Facility Prototyping

Virtual Facility Prototyping used a variety of programs such as 3D studio Max, Revit Architecture and most importantly Unity, an interactive gaming engine. Knowledge gained in these programs help create the model which was then brought to the user for approval. Transferring between programs as well as lighting and textures were made possible because information learned in the class. Lack of knowledge in these programs and processes would have made creating a virtual mockup of this caliper impossible.

Final Recommendations and Conclusions

Much time was spent throughout the year on the Biological Research Laboratory. Complicated building systems over the course of the first semester were analyzed and studied. The following semester four analyses were proposed to improve the overall project from a Design and Construction standpoint. These four analyses affect all aspects from the design of the labs to the actual construction process and work flow. These studied topics are listed below:

- Modularization of Laboratory Spaces
- BIM Implementation (Virtual Mockups)
- Sustainability
- Scheduled Acceleration (Overtime Productivity)

Analysis #I: Modularization of Laboratory Spaces

The implementation of modular units on the Biological Research Laboratory has many benefits. The ability to be constructed in a controlled environment not only delivers a better overall product but it also requires fewer workers present. Quality control checks also can be performed before at different phases of construction and right before each laboratory spaces leaves the warehouse. The modular units also have a large impact on the schedule of the project. Fabricating these units in a warehouse and shipping them to the site saves approximately 6 months on the overall schedule. A cost breakdown was also preformed of just the laboratory spaces which amounted to a total saving of $ 83,500.00. This cost saving incorporated a 25% reduction in labor as well as a 5% reduction in the materials used to make each laboratory module Modularization of the laboratory spaces will ultimately provide a better product by being constructed within a warehouse along with both cutting the overall project schedule and cost for the interior partitions.

Analysis #II: BIM Implementation (Virtual Mockups)

The Virtual Mockup on the Biological Research Laboratory was designed in Revit Architecture and brought into a gaming engine called Unity 3D. One of the goals which was accomplished in the walkthrough with the user was coming across a red flag which wouldn't be noticed on another project till it was too late to change. The problem dealt with the procedure rooms and the ability to fit certain equipment next to the airlock doors. Examining the cost aspect, if the model could directly replace a field mockup approximately $ 110,000.00 could be saved in material and labor. Waste could also be reduced on site by eliminating field mockup which could potentially affect the LEED rating. Virtual mockups should be implemented on the Biological Research Laboratory because these mockups are able to provide the user with an earlier finished product as well as offer potentially large cost savings for the University.

Analysis #III: Sustainability

Installing a Photovoltaic array on the Biological Research Laboratory has many benefits other than just generating power for the facility. The array utilizes multiple components including solar powered car canopies and properly sized inverters to generate around 3% percent or 77,700 kWh of energy. An electrical breadth was also performed where wire sizing and panel boards were determined in order to power the lights in the facility at 277V. The implications of LEED are also impacted with the addition of solar panels on the project. With the addition of not only solar panels on the roof but solar parking canopies, a LEED rating of Gold can be obtained over the original LEED silver rating. One problem with installing the system on university property is calculating a feasible payback period. A PPA agreement allows the University takes advantage of tax incentives as well as offers a positive net present value for the voltaic system.

Analysis #IV: Scheduled Acceleration (Overtime Productivity)

The research on productivity and the comparison between the regular work hours, an overtime schedule of 6-10 hour days, and the rolling 4 day 10 hour work period showed an obvious benefit in the rolling schedule. Implementing the rolling schedule on the steel trade shortens the original duration from approximately 5 weeks down to 2 week and 4 days. Examining cost also showed a savings of approximately $34,500 in the labor and equipment costs. One major reason for the savings is the ability to remove the crane two weeks earlier from the site. Given the availability of labor resources, implementing the rolling 4 day 10 hour work week would not only yield a cost savings in labor but give the ability to make up lost time due to permitting.

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[APPENDIX A]

OVERALL SITE PLAN AND EXISTING CONDITIONS

BIOLOGICAL RESEARCH LABORATORY
UNIVERSITY PARK, PA.

EXISTING CONDITIONS SITE PLAN

MICHAEL CARBONARA

SEPTEMBER 20, 2011

SYMBOLS	
CONSTRUCTION AREA	
BUILDINGS	
ASPHAULT	
GRASS	
GRAVEL ROAD	
TREES	
VEHICLE TRAFFIC	
CONSTRUCTION FENSE	

EXISTING UTILITIES	
RED LINE Sanitary Waste Line	
BLUE LINE Water Line	
PURPLE LINE Telecommunications	
YELLOW LINE Electrical Services	
YELLOW DIAMONDS Electrical Transformers	
RED SQUARES Fire hydrants	

[APPENDIX A-1]

OVERALL SITE PLAN AND EXCAVATION PLAN

BIOLOGICAL RESEARCH LABORATORY UNIVERSITY PARK, PA.

EXCAVATION SITE PLAN

MICHAEL CARBONARA

SEPTEMBER 20, 2011

SYMBOLS	
CONSTRUCTION AREA	
BUILDINGS	
ASPHAULT	
GRASS	
GRAVEL ROAD	
TREES	
VEHICLE TRAFFIC	
CONSTRUCTION FENSE	
EXCAVATION PHASE	
Temp Utilities to Trailer	
Excavator	
Dumptruck	
Bull Dozer	
Material Storage trailers	
Portable Toilet	
RED—Fire hydrants Yellow – Transformers	

[APPENDIX A-2]

OVERALL SITE PLAN AND SUPERSTRUCTURE PLAN

BIOLOGICAL RESEARCH LABORATORY
UNIVERSITY PARK, PA.

SUPERSTRUCTURE SITE PLAN

MICHAEL CARBONARA

SEPTEMBER 20, 2011

SYMBOLS	
CONSTRUCTION AREA	
BUILDINGS	
ASPHAULT	
GRASS	
GRAVEL ROAD	
TREES	
VEHICLE TRAFFIC	
CONSTRUCTION FENSE	
EXCAVATION PHASE	
Temp Utilities to Trailer	
Crane	
Dumpsters	
Bull Dozer	
Material Storage trailers	
Portable Toilet	
RED—Fire hydrants Yellow – Transformers	

[APPENDIX A-3]

OVERALL SITE PLAN AND FINISHES PLAN

BIOLOGICAL RESEARCH LABORATORY
UNIVERSITY PARK, PA.

FINISHES SITE PLAN

MICHAEL CARBONARA

SEPTEMBER 20, 2011

SYMBOLS	
CONSTRUCTION AREA	
BUILDINGS	
ASPHAULT	
GRASS	
CONCRETE PAD/ WALKWAYS	
GRAVEL ROAD	
TREES	
VEHICLE TRAFFIC	
CONSTRUCTION FENSE	

FINISHES PHASE	
Temp Utilities to Trailer	
Concrete Trucks	
Dumpsters	
Bull Dozer	
Material Storage trailers	
Portable Toilet	
RED—Fire hydrants Yellow – Transformers	

[APPENDIX B]

GENERAL CONDITIONS ESTIMATE

General Conditions Estimate

Line Number	Description	Unit	Crew	Daily Output	Labor Hours	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O&P	COST	Cost/ Category
Personal												**$ 413,400.61**
13113200200	Project Manager Average	Per hour		2591			$ 51.88		$ 51.88	$ 79.38	$ 205,660.63	
13113200240	Superintendant Average	Per hour		121.11			$ 48.13		$ 48.13	$ 73.75	$ 8,931.86	
	Project Executive	Per hour		272			$ 55.00		$ 55.00	$ 84.38	$ 22,950.00	
	Commsioning Manager	Per hour		216			$ 48.13		$ 48.13	$ 73.75	$ 15,930.00	
	Field Engineer	Per hour		2591			$ 31.63		$ 31.63	$ 48.75	$ 126,311.25	
	Bim Coordinator	Per hour		471			$ 36.25		$ 36.25	$ 55.63	$ 26,199.38	
	Site Safety Manager	Per hour		136			$ 31.63		$ 31.63	$ 48.75	$ 6,630.00	
13113200020	Clerk	Per hour		50			$ 10.25		$ 10.25	$ 15.75	$ 787.50	
Issurance and Permitting												**$ 308,297.03**
13113300020	Builders Risk insurance standard	Job								0.24%	$ 55,200.00	
13113300400	contractor's equipment	Value								0.50%	$ 97.03	
14126500010	Permits	Job								0.50%	$ 115,000.00	
13113900020	Performance Bond buildings	Job								0.60%	$ 138,000.00	
Temporary Utilities	Utilities											**$ 129,814.17**
15113800100	Heat incl. fuel and operation 12hr/day	CSF Flr	1 Skwk	100	0.08	$ 27.53	$ 3.35		$ 30.88	$ 35.67	$ 24,172.37	
15113800350	Lighting incl. service lamps, wiring and outlets	CSF Flr	1 elec	34	0.235	$ 2.73	$ 11.17		$ 13.90	$ 19.55	$ 13,248.38	
15113800400	Power for Temporary Lighting 11.8 cents/kwh	CSF Flr							$ 0.90	$ 0.98	$ 664.11	
15113800600	Power for Job duration in	CSF Flr							$ 107.25	$ 117.98	$ 79,951.11	
15433406410	Toilet	Ea/ month					$ 15.25	$ 211.69	$ 226.94		$ 11,778.19	
Office and storage Trailer												**$ 17,507.95**
15213200550	50'X12' rent	Month		17.3		$ 401.90			$ 401.90	$ 440.95	$ 7,628.44	
15213400100	Office Equipment Rental	Month		17.3		$ 200.20			$ 200.20	$ 220.22	$ 3,809.81	
15213400120	Office Supplies Average	Month		17.3		$ 86.09			$ 86.09	$ 94.59	$ 1,636.41	
15213400140	Telephone bill avg.	Month		17.3		$ 81.08			$ 81.08	$ 89.09	$ 1,541.26	
15213400160	Lights and HVAC	Month		17.3		$ 152.15			$ 152.15	$ 167.17	$ 2,892.04	
Miscellaneous / Additional												**$ 143,360.12**
Vehicular Access and Parking												
15523500100	8" gravel depth	S.Y.	B14	615	0.078	$ 8.01	$ 2.67	$ 0.62	$ 11.30	$ 13.55	$ 2,439.00	
Temporary Fensing												
15626500100	6' High Chain Link Fense	L.F.	2 Clab	300	0.053	$ 5.31	$ 1.73		$ 7.04	$ 8.51	$ 9,667.36	
Project identification												
15813500020	High intensity reflectorized signs	S.F.				$ 26.53			$ 26.53	$ 29.53	$ 14,765.00	
Cleaning and Waste Management												
17413200050	Cleanup of floor are, continuous during constr. p	M.S.F.	A5	24	0.75	$ 1.70	$ 24.05	$ 2.14	$ 27.89	$ 41.48	$ 57,258.99	
17413200100	Final by GC at end of constr.	M.S.F.	A5	11.5	1.565	$ 2.71	$ 50.45	$ 4.46	$ 57.62	$ 85.21	$ 1,729.76	
Building Commissioning												
19113500100	Basic building commissioning	%								0.0025	$ 57,500.00	
TOTAL												**$ 1,012,379.87**

[APPENDIX C]

LEED for New Constrution v2.2
Checklist

LEED for New Construction v2.2
Registered Project Checklist

Project Name:
Project Address:

Yes	?	No			
4	6	4	**Sustainable Sites**		**14** Points
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
		1	Credit 1	**Site Selection**	1
		1	Credit 2	**Development Density & Community Connectivity**	1
		1	Credit 3	**Brownfield Redevelopment**	1
		1	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
	1		Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
	1		Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel-Efficient Vehicles	1
	1		Credit 4.4	**Alternative Transportation**, Parking Capacity	1
	1		Credit 5.1	**Site Development,** Protect or Restore Habitat	1
1			Credit 5.2	**Site Development,** Maximize Open Space	1
1			Credit 6.1	**Stormwater Design,** Quantity Control	1
1			Credit 6.2	**Stormwater Design,** Quality Control	1
	1		Credit 7.1	**Heat Island Effect,** Non-Roof	1
1			Credit 7.2	**Heat Island Effect,** Roof	1
	1		Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
3	1	1	**Water Efficiency**		**5** Points
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
		1	Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
	1		Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No				
10		7	**Energy & Atmosphere**			**17** Points
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**		Required
Y			Prereq 2	**Minimum Energy Performance**		Required
Y			Prereq 3	**Fundamental Refrigerant Management**		Required

*Note for EAc1: All LEED for New Construction projects registered after June 26th, 2007 are required to achieve at least two (2) points under EAc1.

Yes	?	No				
7		3	Credit 1	**Optimize Energy Performance**		1 to 10
					10.5% New Buildings or 3.5% Existing Building Renovations	1
					14% New Buildings or 7% Existing Building Renovations	2
					17.5% New Buildings or 10.5% Existing Building Renovations	3
					21% New Buildings or 14% Existing Building Renovations	4
					24.5% New Buildings or 17.5% Existing Building Renovations	5
					28% New Buildings or 21% Existing Building Renovations	6
				7	31.5% New Buildings or 24.5% Existing Building Renovations	7
					35% New Buildings or 28% Existing Building Renovations	8
					38.5% New Buildings or 31.5% Existing Building Renovations	9
					42% New Buildings or 35% Existing Building Renovations	10
		3	Credit 2	**On-Site Renewable Energy**		1 to 3
					2.5% Renewable Energy	1
					7.5% Renewable Energy	2
					12.5% Renewable Energy	3
1			Credit 3	**Enhanced Commissioning**		1
1			Credit 4	**Enhanced Refrigerant Management**		1
1			Credit 5	**Measurement & Verification**		1
		1	Credit 6	**Green Power**		1

continued...

Yes	?	No				
7		6		**Materials & Resources**		13 Points
Y			Prereq 1	**Storage & Collection of Recyclables**		Required
		1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof		1
		1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof		1
		1	Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements		1
1			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal		1
1			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal		1
		1	Credit 3.1	**Materials Reuse**, 5%		1
		1	Credit 3.2	**Materials Reuse**,10%		1
1			Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)		1
1			Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)		1
1			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regio		1
1			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regio		1
		1	Credit 6	**Rapidly Renewable Materials**		1
1			Credit 7	**Certified Wood**		1
Yes	?	No				
11	3	1		**Indoor Environmental Quality**		15 Points
Y			Prereq 1	**Minimum IAQ Performance**		Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**		Required
1			Credit 1	**Outdoor Air Delivery Monitoring**		1
1			Credit 2	**Increased Ventilation**		1
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction		1
1			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy		1
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants		1
1			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings		1
		1	Credit 4.3	**Low-Emitting Materials**, Carpet Systems		1
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products		1
1			Credit 5	**Indoor Chemical & Pollutant Source Control**		1
	1		Credit 6.1	**Controllability of Systems**, Lighting		1
	1		Credit 6.2	**Controllability of Systems**, Thermal Comfort		1
1			Credit 7.1	**Thermal Comfort**, Design		1
1			Credit 7.2	**Thermal Comfort**, Verification		1
1			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces		1
	1		Credit 8.2	**Daylight & Views**, Views for 90% of Spaces		1
Yes	?	No				
3		2		**Innovation & Design Process**		5 Points
1			Credit 1.1	**Innovation in Design**: Low-Energy Headhouse (Zoning)		1
1			Credit 1.2	**Innovation in Design**: Site Excavation Strategy		1
		1	Credit 1.3	**Innovation in Design**: Provide Specific Title		1
		1	Credit 1.4	**Innovation in Design**: Provide Specific Title		1
1			Credit 2	**LEED® Accredited Professional**		1
Yes	?	No				
38	10	21		**Project Totals** (pre-certification estimates)		69 Points

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 pc

[APPENDIX D]

LEED for New Constrution v2009
Checklist

LEED 2009 for New Construction and Major Renovations

Project Checklist

Y	?	N				Possible Points
4	9	13			**Sustainable Sites**	Possible Points: **26**
Y	?	N	d/C			
Y			C	Prereq 1	Construction Activity Pollution Prevention	
		1	d	Credit 1	Site Selection	1
		5	d	Credit 2	Development Density and Community Connectivity	5
		1	d	Credit 3	Brownfield Redevelopment	1
		6	d	Credit 4.1	Alternative Transportation—Public Transportation Access	6
	1		d	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
	3		d	Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
	2		d	Credit 4.4	Alternative Transportation—Parking Capacity	2
	1		C	Credit 5.1	Site Development—Protect or Restore Habitat	1
1			d	Credit 5.2	Site Development—Maximize Open Space	1
1			d	Credit 6.1	Stormwater Design—Quantity Control	1
1			d	Credit 6.2	Stormwater Design—Quality Control	1
	1		C	Credit 7.1	Heat Island Effect—Non-roof	1
1			d	Credit 7.2	Heat Island Effect—Roof	1
	1		d	Credit 8	Light Pollution Reduction	1

Y	?	N				Possible Points
6	1	3			**Water Efficiency**	Possible Points: **10**
Y	?	N				
Y			d	Prereq 1	Water Use Reduction—20% Reduction	
4		0	d	Credit 1	Water Efficient Landscaping	2 to 4
				x	Reduce by 50%	2
				x	No Potable Water Use or Irrigation	4
0		2	d	Credit 2	Innovative Wastewater Technologies	2
2	1	1	d	Credit 3	Water Use Reduction	2 to 4
				x	Reduce by 30%	2
					Reduce by 35%	3
					Reduce by 40%	4

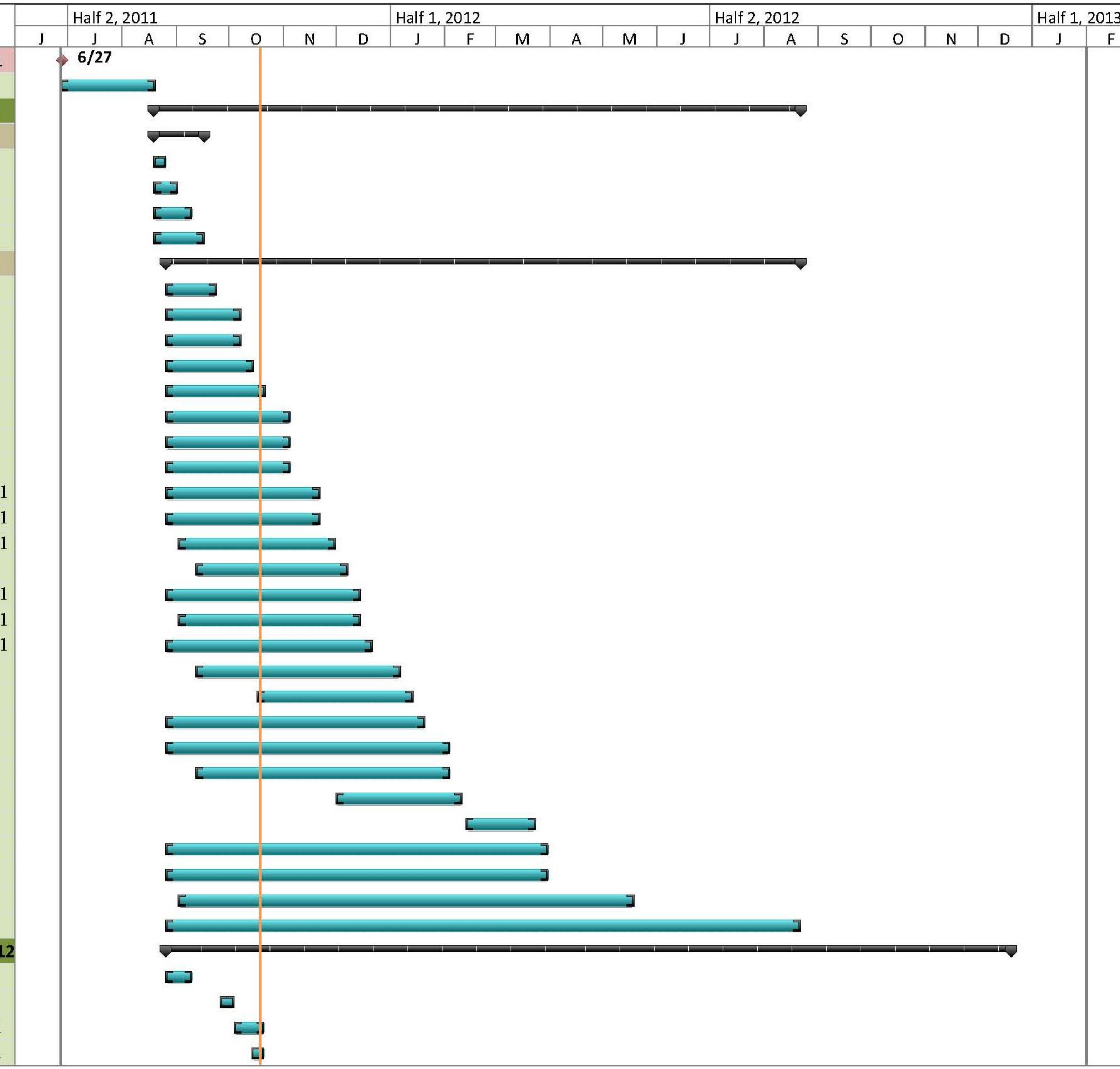
Y	?	N					Points
14	0	16				**Energy and Atmosphere**	Possible Points: **35**
Y			c	Prereq 1		Fundamental Commissioning of Building Energy Systems	
Y			d	Prereq 2		Minimum Energy Performance	
Y			d	Prereq 3		Fundamental Refrigerant Management	
11		8	d	Credit 1		Optimize Energy Performance	1 to 19
						Improve by 12% for New Buildings or 8% for Existing Building Renovations	1
						Improve by 14% for New Buildings or 10% for Existing Building Renovations	2
						Improve by 16% for New Buildings or 12% for Existing Building Renovations	3
						Improve by 18% for New Buildings or 14% for Existing Building Renovations	4
						Improve by 20% for New Buildings or 16% for Existing Building Renovations	5
						Improve by 22% for New Buildings or 18% for Existing Building Renovations	6
						Improve by 24% for New Buildings or 20% for Existing Building Renovations	7
						Improve by 26% for New Buildings or 22% for Existing Building Renovations	8
						Improve by 28% for New Buildings or 24% for Existing Building Renovations	9
						Improve by 30% for New Buildings or 26% for Existing Building Renovations	10
					X	Improve by 32% for New Buildings or 28% for Existing Building Renovations	11
						Improve by 34% for New Buildings or 30% for Existing Building Renovations	12
						Improve by 36% for New Buildings or 32% for Existing Building Renovations	13
						Improve by 38% for New Buildings or 34% for Existing Building Renovations	14
						Improve by 40% for New Buildings or 36% for Existing Building Renovations	15
						Improve by 42% for New Buildings or 38% for Existing Building Renovations	16
						Improve by 44% for New Buildings or 40% for Existing Building Renovations	17
						Improve by 46% for New Buildings or 42% for Existing Building Renovations	18
						Improve by 48%+ for New Buildings or 44%+ for Existing Building Renovations	19
0		7	d	Credit 2		On-Site Renewable Energy	1 to 7
						1% Renewable Energy	1
						3% Renewable Energy	2
						5% Renewable Energy	3
						7% Renewable Energy	4
						9% Renewable Energy	5
						11% Renewable Energy	6
						13% Renewable Energy	7
1			c	Credit 3		Enhanced Commissioning	2
1			d	Credit 4		Enhanced Refrigerant Management	2
1			c	Credit 5		Measurement and Verification	3
		1	c	Credit 6		Green Power	2

Y	?	N				Materials and Resources — Possible Points: 14
7	0	7				
Y			d	Prereq 1	Storage and Collection of Recyclables	
0		3	C	Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
				[ ]	Reuse 55%	1
				[ ]	Reuse 75%	2
				[ ]	Reuse 95%	3
0		1	C	Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
2		0	C	Credit 2	Construction Waste Management	1 to 2
				x	50% Recycled or Salvaged	1
				x	75% Recycled or Salvaged	2
0		2	C	Credit 3	Materials Reuse	1 to 2
				[ ]	Reuse 5%	1
				[ ]	Reuse 10%	2
2		0	C	Credit 4	Recycled Content	1 to 2
				x	10% of Content	1
				x	20% of Content	2
2		0	C	Credit 5	Regional Materials	1 to 2
				x	10% of Materials	1
				x	20% of Materials	2
0		1	C	Credit 6	Rapidly Renewable Materials	1
1		0	C	Credit 7	Certified Wood	1

[APPENDIX E]

PROJECT DETAILED SCHEDULE

ID	Task Name	Duration	Start	Finish
1	**CM Mobilize**	0 days	Mon 6/27/11	Mon 6/27/11
2	Notice to Proceed	40 days	Mon 6/27/11	Fri 8/19/11
3	**PROCUREMENT**	**263 days**	**Fri 8/19/11**	**Tue 8/21/12**
4	**Contract Purchasing**	**21 days**	**Fri 8/19/11**	**Fri 9/16/11**
5	Contract Award (1.01-1.09,1.11,1.14,1.25)	5 days	Fri 8/19/11	Thu 8/25/11
6	Contract Award 2 (1.07,1.12,1.13,1.15,1.22)	10 days	Fri 8/19/11	Thu 9/1/11
7	Contract Award 3 (1.10, 1.20, 1.21)	16 days	Fri 8/19/11	Fri 9/9/11
8	Contract Award 4 (1.23-1.24)	21 days	Fri 8/19/11	Fri 9/16/11
9	**Submittal and Review**	**258 days**	**Fri 8/26/11**	**Tue 8/21/12**
10	Division 31 -Earthwork	21 days	Fri 8/26/11	Fri 9/23/11
11	Division 6 -Wood, Plastics, and Composites	31 days	Fri 8/26/11	Fri 10/7/11
12	Division 33 -Utilities	31 days	Fri 8/26/11	Fri 10/7/11
13	Division 3 -Concrete	36 days	Fri 8/26/11	Fri 10/14/11
14	Division 4 -Masonry	41 days	Fri 8/26/11	Fri 10/21/11
15	Division 7 -Thermal and Moisture Protection	51 days	Fri 8/26/11	Fri 11/4/11
16	Division 27 -Communications	51 days	Fri 8/26/11	Fri 11/4/11
17	Division 28 -Electronic Safety and Security	51 days	Fri 8/26/11	Fri 11/4/11
18	Division 22 -Plumbing	62 days	Fri 8/26/11	Mon 11/21/11
19	Division 24 -Electrical	62 days	Fri 8/26/11	Mon 11/21/11
20	Division 21 -Fire Suppression	64 days	Fri 9/2/11	Wed 11/30/11
21	Division 23 -HVAC	63 days	Mon 9/12/11	Wed 12/7/11
22	Division 5 -Metals	79 days	Fri 8/26/11	Wed 12/14/11
23	Division 8 -Openings	74 days	Fri 9/2/11	Wed 12/14/11
24	Division 7 -{Metal Roof & Wall Panels}	84 days	Fri 8/26/11	Wed 12/21/11
25	Division 12 -Furnishings	85 days	Mon 9/12/11	Fri 1/6/12
26	Division 10 -Specialtieis	65 days	Mon 10/17/11	Fri 1/13/12
27	Division 24 -{Main Transformer}	106 days	Fri 8/26/11	Fri 1/20/12
28	Division 24 -{Electrical Gear}	116 days	Fri 8/26/11	Fri 2/3/12
29	Division 11 -Equipment	105 days	Mon 9/12/11	Fri 2/3/12
30	Division 9 -Finishes	52 days	Thu 12/1/11	Fri 2/10/12
31	Division 32 -Exterior Improvements	30 days	Mon 2/13/12	Fri 3/23/12
32	Division 23 -{AHU's}	156 days	Fri 8/26/11	Fri 3/30/12
33	Division 23 -{Chillers}	156 days	Fri 8/26/11	Fri 3/30/12
34	Division 22 -{EDS}	186 days	Fri 9/2/11	Fri 5/18/12
35	Division 24 -{Generator}	258 days	Fri 8/26/11	Tue 8/21/12
36	**CONSTRUCTION**	**344 days**	**Fri 8/26/11**	**Wed 12/19/12**
37	Erosion Controls	11 days	Fri 8/26/11	Fri 9/9/11
38	Strip Topsoil to Stockpile	6 days	Mon 9/26/11	Mon 10/3/11
39	Site Storm Sewerage	13 days	Tue 10/4/11	Thu 10/20/11
40	Bulk Excavation	5 days	Fri 10/14/11	Thu 10/20/11



Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
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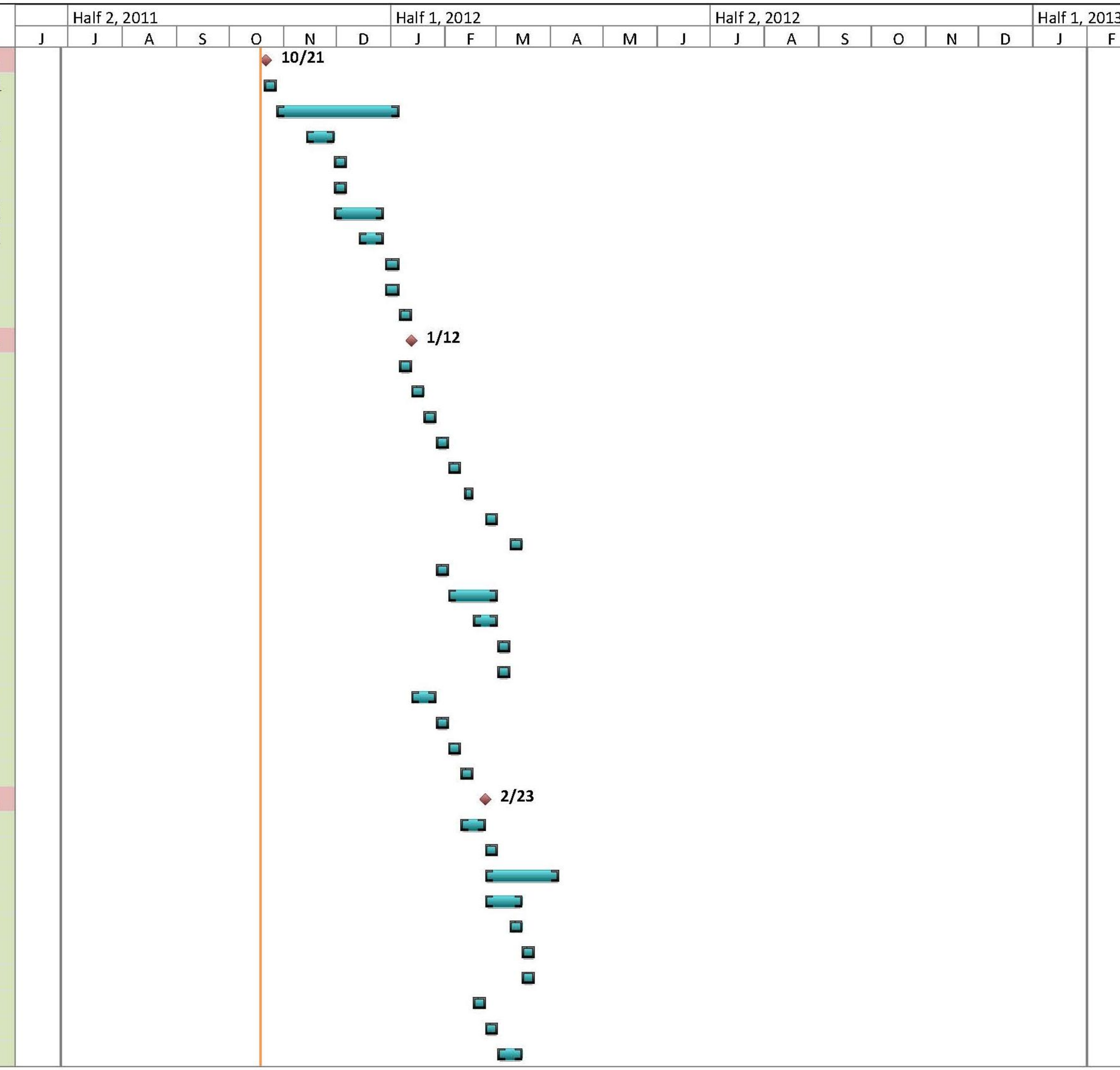
ID		Task Name	Duration	Start	Finish
41		**Foundations Commence**	0 days	Fri 10/21/11	Fri 10/21/11
42		Excavate Foundations [BL]	5 days	Fri 10/21/11	Thu 10/27/11
43		FRP Foundations (West & South) [BL]	50 days	Fri 10/28/11	Thu 1/5/12
44		FRP Foundation Walls (West & South)	12 days	Mon 11/14/11	Tue 11/29/11
45		Shore Foundation Walls	5 days	Wed 11/30/11	Tue 12/6/11
46		Excavate Foundations [FF]	5 days	Wed 11/30/11	Tue 12/6/11
47		FRP Foundation Walls (North & East)	20 days	Wed 11/30/11	Tue 12/27/11
48		Foundation Waterproofing	10 days	Wed 12/14/11	Tue 12/27/11
49		FRP Equipment Pads	6 days	Thu 12/29/11	Thu 1/5/12
50		Backfill Foundations for SOG [BL]	6 days	Thu 12/29/11	Thu 1/5/12
51		Backfill Foundation for SOG [FF]	5 days	Fri 1/6/12	Thu 1/12/12
52		**Substructure Complete**	0 days	Thu 1/12/12	Thu 1/12/12
53		FRP Loading Dock Foundations	5 days	Fri 1/6/12	Thu 1/12/12
54		FRP Loading Dock Walls	5 days	Fri 1/13/12	Thu 1/19/12
55		FRP Loading Dock SOG	5 days	Fri 1/20/12	Thu 1/26/12
56		FRP East Stairs	5 days	Fri 1/27/12	Thu 2/2/12
57		FRP Hardscape Foundations	5 days	Fri 2/3/12	Thu 2/9/12
58		FRP Hardscape Walls	5 days	Sun 2/12/12	Thu 2/16/12
59		Rub/Finish Foundation Walls	5 days	Fri 2/24/12	Thu 3/1/12
60		Under Slab Waterproofing/Insulation	5 days	Fri 3/9/12	Thu 3/15/12
61		Backfill Exterior Foundation	5 days	Fri 1/27/12	Thu 2/2/12
62		Site Duct Banks	20 days	Fri 2/3/12	Thu 3/1/12
63		Rough Grade Site	10 days	Fri 2/17/12	Thu 3/1/12
64		Site Gas	5 days	Fri 3/2/12	Thu 3/8/12
65		Site Lighting	5 days	Fri 3/2/12	Thu 3/8/12
66		Structural Steel Framing	10 days	Fri 1/13/12	Thu 1/26/12
67		First Floor Steel Deck	5 days	Fri 1/27/12	Thu 2/2/12
68		Penthouse Steel Deck	5 days	Fri 2/3/12	Thu 2/9/12
69		Steel Decking	5 days	Fri 2/10/12	Thu 2/16/12
70		**Superstructure Complete**	0 days	Thu 2/23/12	Thu 2/23/12
71		FRP Elevated Deck	10 days	Fri 2/10/12	Thu 2/23/12
72		FRP SOG	5 days	Fri 2/24/12	Thu 3/1/12
73		FRP Equipment Pads	30 days	Fri 2/24/12	Thu 4/5/12
74		Metal Stairs & Railings (Basement to Mezzanine)	15 days	Fri 2/24/12	Thu 3/15/12
75		Infill at Metal Stairs	5 days	Fri 3/9/12	Thu 3/15/12
76		FRP SOG	5 days	Fri 3/16/12	Thu 3/22/12
77		Ships Ladders	5 days	Fri 3/16/12	Thu 3/22/12
78		Roof Sheathing	5 days	Fri 2/17/12	Thu 2/23/12
79		Exterior Wall Framing/Sheathing	5 days	Fri 2/24/12	Thu 3/1/12
80		Exterior Wall Masonry/Insulation	10 days	Fri 3/2/12	Thu 3/15/12



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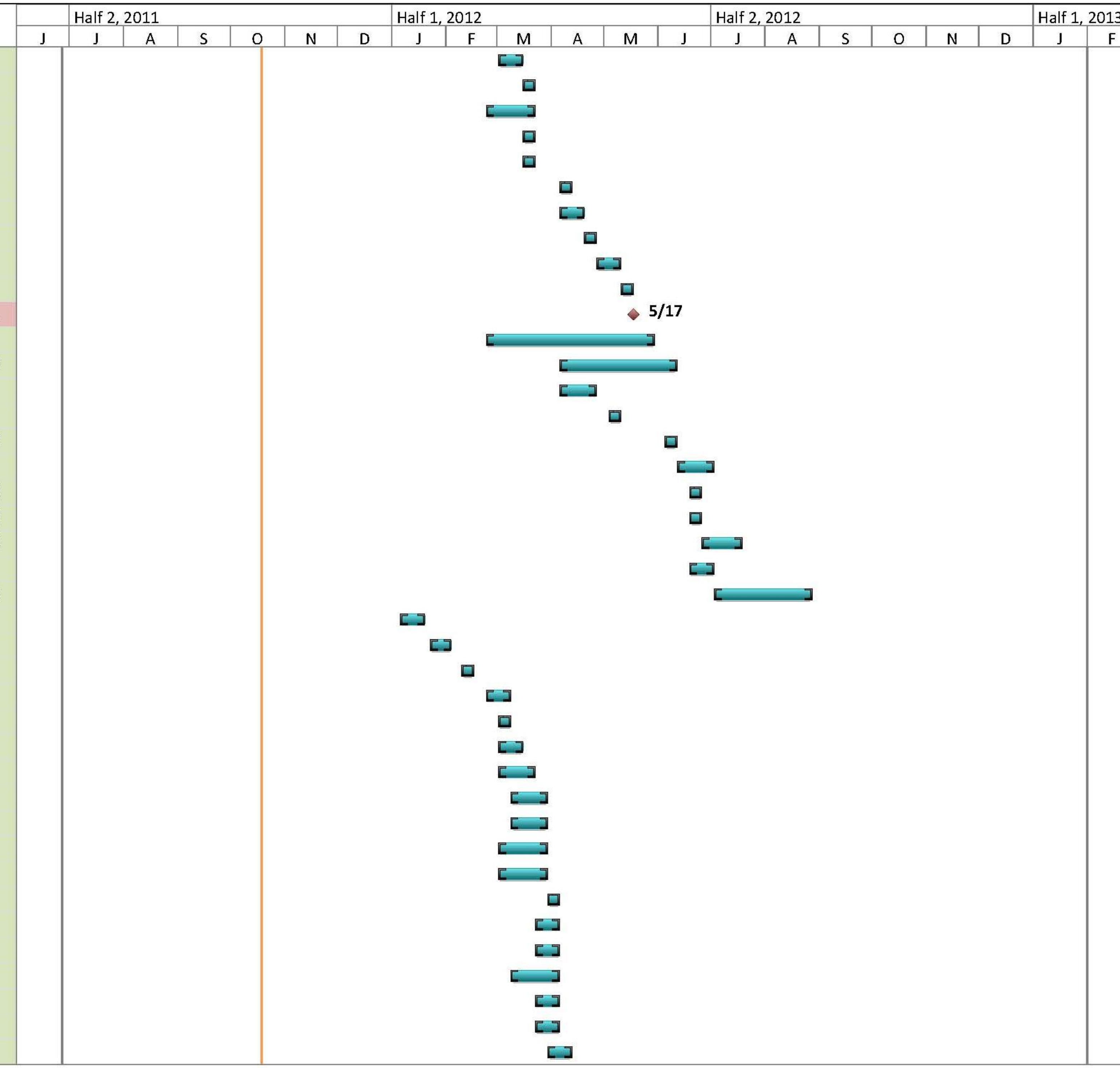
ID	Task Name	Duration	Start	Finish
81	Exterior Wall Framing/Sheathing/Insulation	10 days	Fri 3/2/12	Thu 3/15/12
82	Exterior Overhead Doors	5 days	Fri 3/16/12	Thu 3/22/12
83	Standing Seam Metal Roofing	20 days	Fri 2/24/12	Thu 3/22/12
84	EPDM Roofing Exterior Wall Metal Panels/Soffits	5 days	Fri 3/16/12	Thu 3/22/12
85	Wall Metal Panels/Soffits	5 days	Fri 3/16/12	Thu 3/22/12
86	Exterior Metal Doors & Frames	5 days	Fri 4/6/12	Thu 4/12/12
87	Aluminum Framing Storefronts/Curtainwalls	10 days	Fri 4/6/12	Thu 4/19/12
88	Glazing Storefronts/Curtainwalls	5 days	Fri 4/20/12	Thu 4/26/12
89	Louvers	10 days	Fri 4/27/12	Thu 5/10/12
90	Exterior Caulking and Sealants	5 days	Fri 5/11/12	Thu 5/17/12
91	**Building Envelope Complete**	0 days	Thu 5/17/12	Thu 5/17/12
92	Partition Layout & Top Track	68 days	Fri 2/24/12	Tue 5/29/12
93	Partition Framing	47 days	Fri 4/6/12	Mon 6/11/12
94	HM Door Frames	15 days	Fri 4/6/12	Thu 4/26/12
95	Partition Grouting	5 days	Fri 5/4/12	Thu 5/10/12
96	HM Door Frames	5 days	Tue 6/5/12	Mon 6/11/12
97	Partition GWB	15 days	Tue 6/12/12	Mon 7/2/12
98	Ceiling Framing	5 days	Tue 6/19/12	Mon 6/25/12
99	Roll-up Doors	5 days	Tue 6/19/12	Mon 6/25/12
100	Ceiling GWB	17 days	Tue 6/26/12	Wed 7/18/12
101	Ceiling Framing	10 days	Tue 6/19/12	Mon 7/2/12
102	Tape & Finish	40 days	Tue 7/3/12	Mon 8/27/12
103	Basement Under Slab Duct Banks	10 days	Fri 1/6/12	Thu 1/19/12
104	Set/Connect Transformer [UY]	10 days	Mon 1/23/12	Fri 2/3/12
105	Under Slab Sanitary Piping [FF]	5 days	Fri 2/10/12	Thu 2/16/12
106	Under Slab Utilities	10 days	Fri 2/24/12	Thu 3/8/12
107	Vent RI [PH]	5 days	Fri 3/2/12	Thu 3/8/12
108	Storm Sewerage RI [PH]	10 days	Fri 3/2/12	Thu 3/15/12
109	Plumbing RI [PH]	15 days	Fri 3/2/12	Thu 3/22/12
110	MPS/R RI [FF]	15 days	Fri 3/9/12	Thu 3/29/12
111	HWS/R RI [FF]	15 days	Fri 3/9/12	Thu 3/29/12
112	HWS/R RI [PH]	20 days	Fri 3/2/12	Thu 3/29/12
113	CHWS/R RI [PH]	20 days	Fri 3/2/12	Thu 3/29/12
114	Gas RI [BL]	5 days	Fri 3/30/12	Thu 4/5/12
115	Set/Connect ACF's [BL]	10 days	Fri 3/23/12	Thu 4/5/12
116	Plumbing Insulation [PH]	10 days	Fri 3/23/12	Thu 4/5/12
117	Ductwork [FF]	20 days	Fri 3/9/12	Thu 4/5/12
118	Set/Connect STS Generators [PH]	10 days	Fri 3/23/12	Thu 4/5/12
119	Set/Connect ACF's [PH]	10 days	Fri 3/23/12	Thu 4/5/12
120	Domestic Water RI [BL]	10 days	Fri 3/30/12	Thu 4/12/12



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Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress

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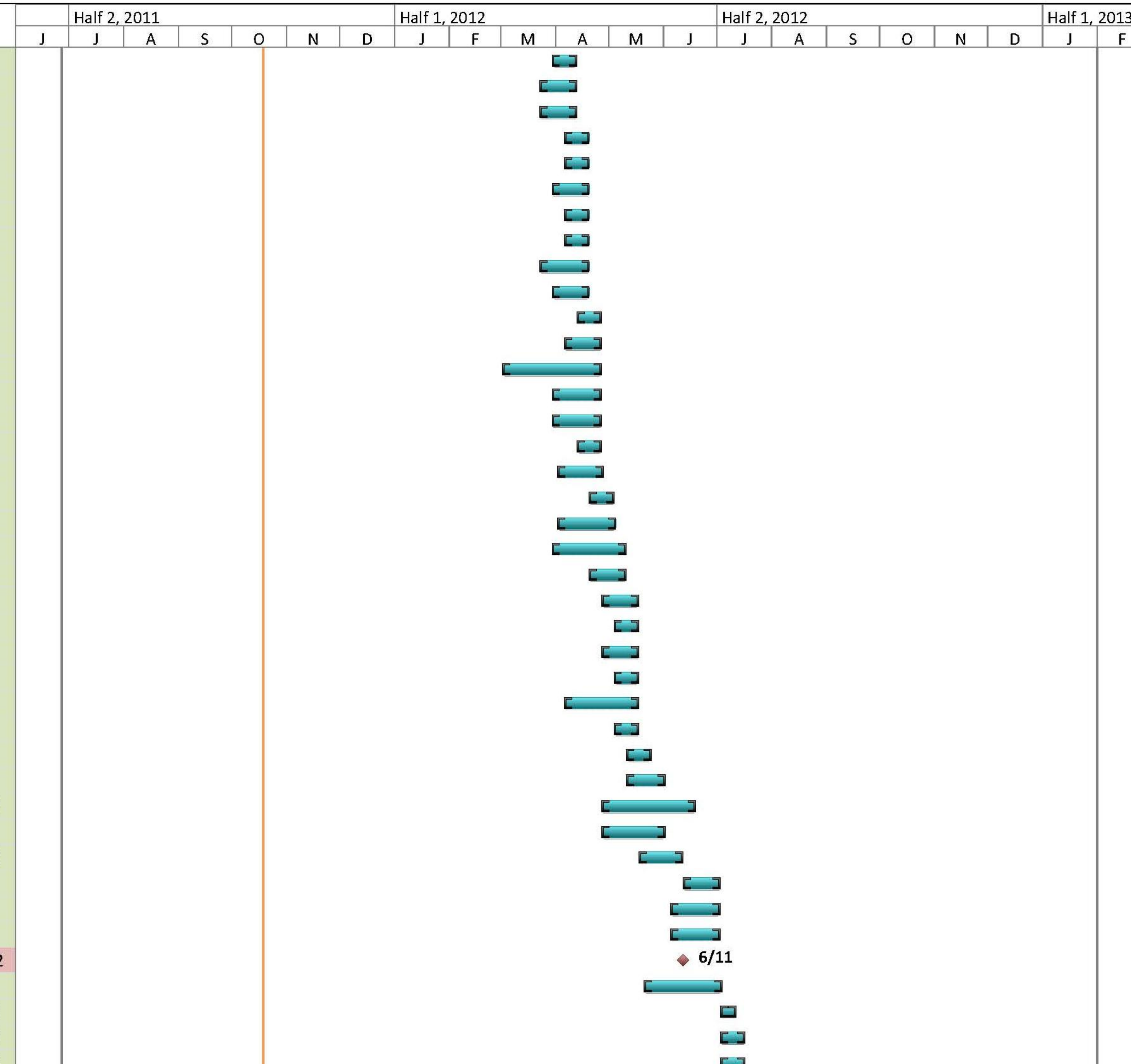
ID	Task Name	Duration	Start	Finish
121	MPS/R HWS/R Insulation	10 days	Fri 3/30/12	Thu 4/12/12
122	Set/Connect Heat Recovery Equipment	15 days	Fri 3/23/12	Thu 4/12/12
123	Roof Set/Connect Exhaust Fans	15 days	Fri 3/23/12	Thu 4/12/12
124	Set/Connect Steam Equipment [BL]	10 days	Fri 4/6/12	Thu 4/19/12
125	Set/Connect Heating Hot Water Equip	10 days	Fri 4/6/12	Thu 4/19/12
126	Boiler Stack [BL]	15 days	Fri 3/30/12	Thu 4/19/12
127	Plumbing Above Ceiling RI [FF]	10 days	Fri 4/6/12	Thu 4/19/12
128	HWS/R Insulation [PH]	10 days	Fri 4/6/12	Thu 4/19/12
129	Set/Connect In-Line Fans [PH]	20 days	Fri 3/23/12	Thu 4/19/12
130	CHWS/R Insulation [PH]	15 days	Fri 3/30/12	Thu 4/19/12
131	Compressed Air RI [BL]	10 days	Fri 4/13/12	Thu 4/26/12
132	Set/Connect Water Softener Equipment	15 days	Fri 4/6/12	Thu 4/26/12
133	Ductwork RI [PH]	40 days	Fri 3/2/12	Thu 4/26/12
134	LPS/R RI [PH]	20 days	Fri 3/30/12	Thu 4/26/12
135	ERS/R RI [PH]	20 days	Fri 3/30/12	Thu 4/26/12
136	Ductwork Insulation [FF]	10 days	Fri 4/13/12	Thu 4/26/12
137	Set/Connect Chillers [UY]	20 days	Mon 4/2/12	Fri 4/27/12
138	Set/Connect Chilled Water Equipment	10 days	Fri 4/20/12	Thu 5/3/12
139	Set/Connect AHU's [PH]	25 days	Mon 4/2/12	Fri 5/4/12
140	HPS/R HWS/R CHWS/R RI	30 days	Fri 3/30/12	Thu 5/10/12
141	EDS Exhaust Ductwork	15 days	Fri 4/20/12	Thu 5/10/12
142	Set/Connect Domestic Water Heater	15 days	Fri 4/27/12	Thu 5/17/12
143	Humidification Piping Insulation [PH]	10 days	Fri 5/4/12	Thu 5/17/12
144	LPS/R ERS/R Insulation	15 days	Fri 4/27/12	Thu 5/17/12
145	Roof Snow-Melt Mats	10 days	Fri 5/4/12	Thu 5/17/12
146	BAS Raceways	30 days	Fri 4/6/12	Thu 5/17/12
147	Plumbing Insulation	10 days	Fri 5/4/12	Thu 5/17/12
148	HPS/R HWS/R CHWS/R Insulation	10 days	Fri 5/11/12	Thu 5/24/12
149	Ductwork	16 days	Fri 5/11/12	Fri 6/1/12
150	Ductwork Insulation	37 days	Fri 4/27/12	Mon 6/18/12
151	BAS Raceways	26 days	Fri 4/27/12	Fri 6/1/12
152	Set/Connect Compressed Air Equipment	17 days	Fri 5/18/12	Mon 6/11/12
153	Set/Connect Water Booster Pumps	15 days	Tue 6/12/12	Mon 7/2/12
154	Sprinkler Mains & Branches RI	20 days	Tue 6/5/12	Mon 7/2/12
155	BAS Raceways [BL] Set/Connect EDS	20 days	Tue 6/5/12	Mon 7/2/12
156	**Permanent Power**	0 days	Mon 6/11/12	Mon 6/11/12
157	Set/Connect EDS	32 days	Mon 5/21/12	Tue 7/3/12
158	Terminal Units [FF]	7 days	Tue 7/3/12	Wed 7/11/12
159	Domestic Water Insulation [BL]	10 days	Tue 7/3/12	Mon 7/16/12
160	Sprinkler Drops/Heads [BL]	10 days	Tue 7/3/12	Mon 7/16/12



Project: Project1
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Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress

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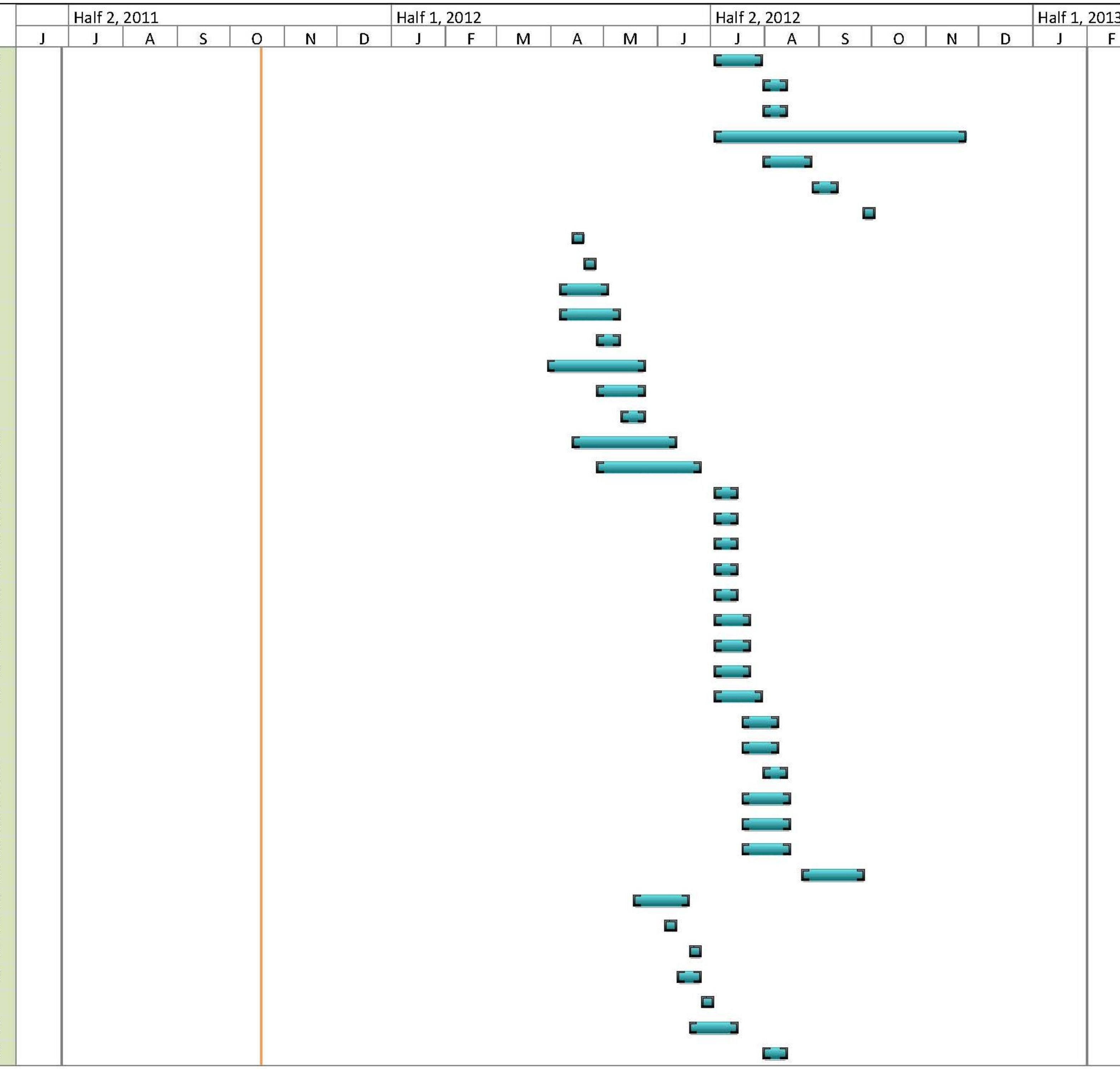
ID	Task Name	Duration	Start	Finish
161	Sprinkler Mains & Branches RI [FF]	20 days	Tue 7/3/12	Mon 7/30/12
162	Plumbing Fixtures [BL]	10 days	Tue 7/31/12	Mon 8/13/12
163	Sprinkler Drops [FF]	10 days	Tue 7/31/12	Mon 8/13/12
164	BAS Wiring & Devices [BL]	104 days	Tue 7/3/12	Fri 11/23/12
165	Sprinkler Mains & Branches RI [PH]	20 days	Tue 7/31/12	Mon 8/27/12
166	Sprinkler Drops/Heads [PH]	11 days	Tue 8/28/12	Tue 9/11/12
167	Plumbing Fixtures [FF]	5 days	Wed 9/26/12	Tue 10/2/12
168	Roof Set/Connect Disconnects	5 days	Fri 4/13/12	Thu 4/19/12
169	Roof Raceways	5 days	Fri 4/20/12	Thu 4/26/12
170	Set/Connect Panels & Disconnects [BL]	20 days	Fri 4/6/12	Thu 5/3/12
171	Set/Connect Main Switchgear [BL]	25 days	Fri 4/6/12	Thu 5/10/12
172	Roof Power Wiring and Devices	10 days	Fri 4/27/12	Thu 5/10/12
173	Raceways [BL]	40 days	Fri 3/30/12	Thu 5/24/12
174	Set/Connect Panels & Disconnects	20 days	Fri 4/27/12	Thu 5/24/12
175	Roof Lighting Wiring and Devices	10 days	Fri 5/11/12	Thu 5/24/12
176	Raceways [FF]	42 days	Fri 4/13/12	Mon 6/11/12
177	Raceways [PH]	42 days	Fri 4/27/12	Mon 6/25/12
178	Tel/Com Wiring and Devices [BL]	10 days	Tue 7/3/12	Mon 7/16/12
179	Fire Alarm Wiring and Devices [BL]	10 days	Tue 7/3/12	Mon 7/16/12
180	CCTV/AC Wiring and Devices [BL]	10 days	Tue 7/3/12	Mon 7/16/12
181	Fire Alarm Wiring and Devices [PH]	10 days	Tue 7/3/12	Mon 7/16/12
182	CCTV/AC Wiring and Devices [PH]	10 days	Tue 7/3/12	Mon 7/16/12
183	Lighting Wiring and Devices [BL]	15 days	Tue 7/3/12	Mon 7/23/12
184	Power Wiring and Devices [BL]	15 days	Tue 7/3/12	Mon 7/23/12
185	Lighting Wiring and Devices [PH]	15 days	Tue 7/3/12	Mon 7/23/12
186	Power Wiring and Devices [PH]	20 days	Tue 7/3/12	Mon 7/30/12
187	Tel/Com Wiring and Devices [FF]	15 days	Thu 7/19/12	Wed 8/8/12
188	Fire Alarm Wiring and Devices [FF]	15 days	Thu 7/19/12	Wed 8/8/12
189	Tel/Com Wiring and Devices [PH]	10 days	Tue 7/31/12	Mon 8/13/12
190	Lighting Wiring and Devices [FF]	20 days	Thu 7/19/12	Wed 8/15/12
191	Power Wiring and Devices [FF]	20 days	Thu 7/19/12	Wed 8/15/12
192	CCTV/AC Wiring and Devices [FF]	20 days	Thu 7/19/12	Wed 8/15/12
193	Set/Connect Generator [UY]	26 days	Wed 8/22/12	Wed 9/26/12
194	Road Work / Paving	22 days	Fri 5/18/12	Mon 6/18/12
195	FRP Sidewalks	5 days	Tue 6/5/12	Mon 6/11/12
196	Gravel Shoulders	5 days	Tue 6/19/12	Mon 6/25/12
197	Exterior Stair Railings	10 days	Tue 6/12/12	Mon 6/25/12
198	Parking Striping, Stops, Signage	5 days	Tue 6/26/12	Mon 7/2/12
199	Security Fencing	20 days	Tue 6/19/12	Mon 7/16/12
200	Spread Topsoil Stockpile	10 days	Tue 7/31/12	Mon 8/13/12



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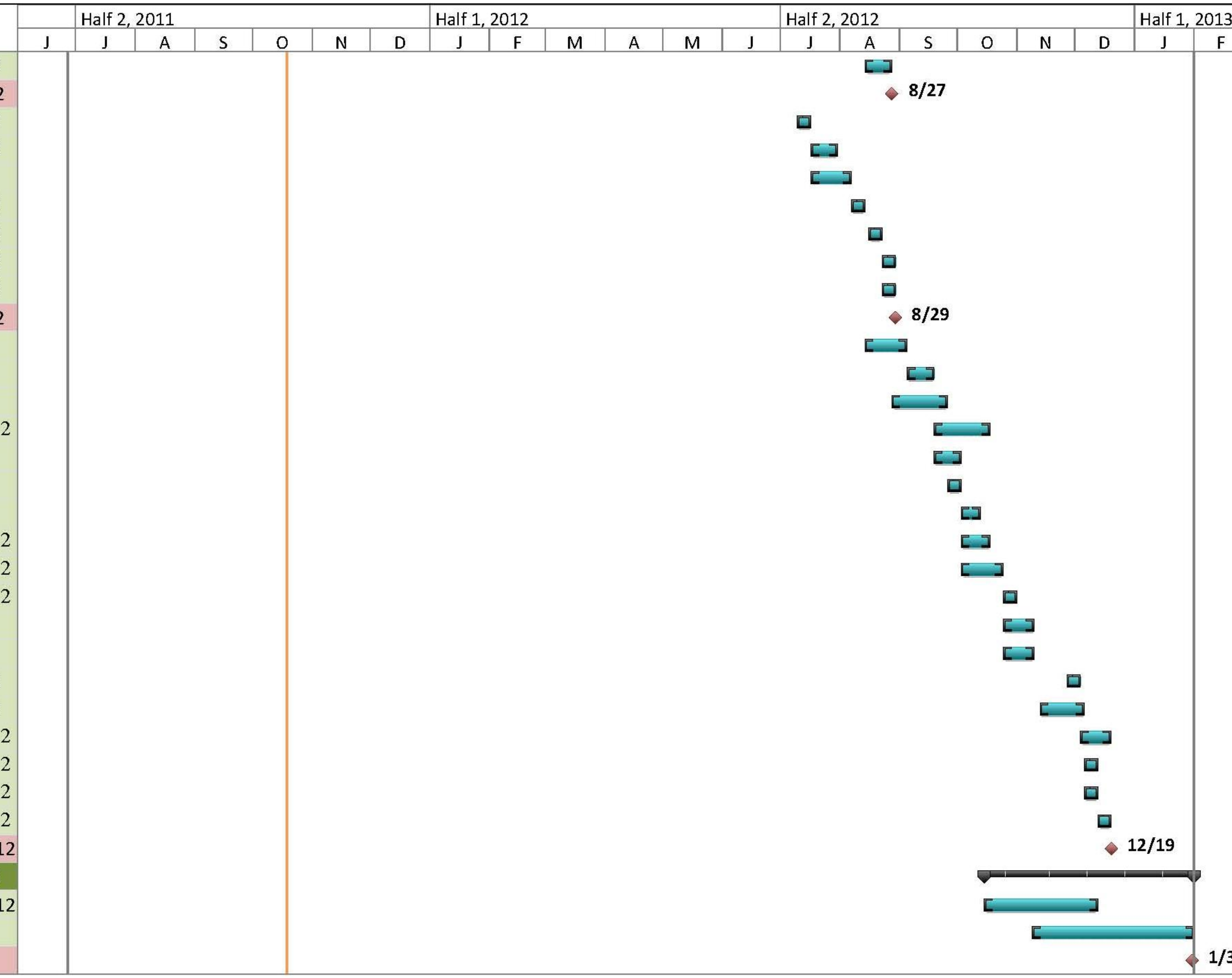
ID		Task Name	Duration	Start	Finish
201		Landscaping	10 days	Tue 8/14/12	Mon 8/27/12
202		**Sitework Complete**	0 days	Mon 8/27/12	Mon 8/27/12
203		Prime Paint & Coat [PH]	5 days	Tue 7/10/12	Mon 7/16/12
204		Prime Paint & 1st Coat [BL]	10 days	Tue 7/17/12	Mon 7/30/12
205		Resinous Flooring [PH]	15 days	Tue 7/17/12	Mon 8/6/12
206		Doors & Hardware [PH]	5 days	Tue 8/7/12	Mon 8/13/12
207		Prime Paint & First Coat [FF]	5 days	Thu 8/16/12	Wed 8/22/12
208		Ceramic Tile [FF]	5 days	Thu 8/23/12	Wed 8/29/12
209		Polished Floors [FF]	5 days	Thu 8/23/12	Wed 8/29/12
210		**Interior Compartments Complete**	0 days	Wed 8/29/12	Wed 8/29/12
211		Seal Concrete Floors [BL]	16 days	Tue 8/14/12	Tue 9/4/12
212		Doors & Hardware [BL]	10 days	Wed 9/5/12	Tue 9/18/12
213		Wall Coatings Prime & Intermediate Coating	21 days	Tue 8/28/12	Tue 9/25/12
214		Set/Connect Lab Equipement	21 days	Wed 9/19/12	Wed 10/17/12
215		Touch Up & Finish Paint [BL]	10 days	Wed 9/19/12	Tue 10/2/12
216		Entrance Mat [FF]	5 days	Wed 9/26/12	Tue 10/2/12
217		Touch-up and Finish Paint [FF]	8 days	Wed 10/3/12	Fri 10/12/12
218		Misc. Trim-out [BL]	11 days	Wed 10/3/12	Wed 10/17/12
219		Resinous Flooring [FF]	16 days	Wed 10/3/12	Wed 10/24/12
220		Fiberglass Grating [FF]	5 days	Thu 10/25/12	Wed 10/31/12
221		Lab Casework [FF]	12 days	Thu 10/25/12	Fri 11/9/12
222		Doors & Hardware [FF]	12 days	Thu 10/25/12	Fri 11/9/12
223		Touch Up & Finish Paint [PH]	5 days	Tue 11/27/12	Mon 12/3/12
224		Wall Coatings Topcoat [FF]	17 days	Tue 11/13/12	Wed 12/5/12
225		Misc. Trim-out [PH]	12 days	Tue 12/4/12	Wed 12/19/12
226		Hepa Filters [FF]	5 days	Thu 12/6/12	Wed 12/12/12
227		Wall Protection [FF]	5 days	Thu 12/6/12	Wed 12/12/12
228		Joint Sealants [FF]	5 days	Thu 12/13/12	Wed 12/19/12
229		**Substancial Completion**	0 days	Wed 12/19/12	Wed 12/19/12
230		**PROJECT CLOSEOUT**	**79 days**	**Mon 10/15/12**	**Thu 1/31/13**
231		Start-Up & Testing	43 days	Mon 10/15/12	Wed 12/12/12
232		Commisioning	60 days	Fri 11/9/12	Thu 1/31/13
233		**Commisioning Complete**	0 days	Thu 1/31/13	Thu 1/31/13



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[APPENDIX F]

ANIMAL HOLDING ROOM TAKEOFF

ROOM 119 Animal Holding Room	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment/ Unit Used	Total	Total Incl O&P	Units	Price
Material											
3 5/8" Metal Stud	2 Carp	76	0.211	L.F.	9.1	8.75	53	17.85	23.5	53	$ 1,245.50
6" Metal Stud	2 Carp	73	0.219	L.F.	12.05	9.1	11	21.15	27.5	11	$ 302.50
5/8" GWB on Wall	2 Carp	700	0.023	S.F.	0.86	0.95	576	1.81	2.4	576	$ 1,382.40
5/8" GWB on Ceiling	2 Carp	550	0.029	S.F.	0.86	1.21	231	2.07	2.8	231	$ 646.80
R13 11" wide	1 Carp	1350	0.006	S.F.	0.33	0.25	477	0.58	0.74	477	$ 352.98
R19 6" wide	1 Carp	1350	0.006	S.F.	0.43	0.25	99	0.68	0.85	99	$ 84.15
Vinyl Sheets .125 thick	1 Tilf	200	0.04	S.F.	6.1	1.57	231	7.67	9	231	$ 2,079.00
Steel Plate 1/4"	E-4			S.F.	11.2		231	11.2	12.35	231	$ 2,852.85
16 Ga x 2.5" 12 O.C.	1 Carp	115	0.07	Ea.	1.03	2.89	22	3.92	5.6	22	$ 123.20
LAB CABINTRY											
Cage Racks							3	2500	2500		$ 7,500.00
Bio Safety Cabinets								15440.63	15440.63		$ 15,440.63
PLUMBING											
Instant Hot Water Commerical 100 cup	1 plum	14	0.571	Ea.	400	29.5	1	429.5	485		$ 485.00
Satinless Steel, Self Rimming 22"x25"	Q-1	5.6	2.875	Ea.	615	134	1	749	880		$ 880.00
Area Drain	Q-1	9	1.778	Ea.	2400	62.5	1	2462.5	2480.49		$ 2,480.49
ELECTRICAL											
1W x 4W three 40 watt	1 Elec	6.7	1.194	Ea.	76.5	58.5	7	135	171		$ 1,197.00
Flush Switch	1 Elec	40	0.2	Ea.	14.75	9.8	1	24.55	31		$ 31.00
Switch Plate	1 Elec	80	0.1	Ea.	3.6	4.9	1	8.5	11.25		$ 11.25
#12 3 wire	1 Elec	2.2	3.63	Ea.	122	178	1	300	400		$ 400.00
pressed steel octagon box 4"	1 Elec	20	0.4	Ea.	3.36	1960	7	22.96	32.5		$ 227.50
Extension Rings	1 Elec	40	0.2	Ea.	5.6	9.8		15.4	20.5		
Square 4"	1 Elec	20	0.4	Ea.	2.38	19.6	6	21.98	31.5		$ 189.00
Plaster Rings	1 Elec	64	0.125	Ea.	3.09	6.15	6	9.24	12.5		$ 75.00
20 Amp recpt. #12/2	1 Elec	12.31	0.65	Ea.	31	36.5	6	67.5	88.5		$ 531.00
HVAC											
Diffuser 18 x 18	1 Sheet	9	0.889	Ea.	128	43.5	2	171.5	207		$ 414.00
Cabintry											
Metal Shelf 4 level 20" x 4'	1 Clab	6	1.333	Ea.	1325	44	1	1369	1525		$ 1,525.00
Base cabinets stainless steel	2 Carp	10	1.6	L.F	455	66.5		521.5	600		
cabinents for all drawers											
TOTAL											**$ 40,456.25**

[APPENDIX G]

PROCEDURE ROOM TAKEOFF

ROOM 119 Procedure	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment/ Unit Used	Total	Total Incl O&P	Units	Price
3 5/8" Metal Stud	2 Carp	76	0.211	L.F.	9.1	8.75	41	17.85	23.5	41	$ 963.50
6" Metal Stud	2 Carp	73	0.219	L.F.	12.05	9.1	11	21.15	27.5	11	$ 302.50
5/8" GWB on Wall	2 Carp	700	0.023	S.F.	0.86	0.95	468	1.81	2.4	468	$ 1,123.20
5/8" GWB on Ceiling	2 Carp	550	0.029	S.F.	0.86	1.21	165	2.07	2.8	165	$ 462.00
R13 11" wide	1 Carp	1350	0.006	S.F.	0.33	0.25	396	0.58	0.74	396	$ 293.04
R19 6" wide	1 Carp	1350	0.006	S.F.	0.43	0.25	99	0.68	0.85	99	$ 84.15
Vinyl Sheets .125 thick	1 Tilf	200	0.04	S.F.	6.1	1.57	165	7.67	9	165	$ 1,485.00
Steel Plate 1/4"	E-4			S.F.	11.2		165	11.2	12.35	165	$ 2,037.75
16 Ga x 2.5" 12 O.C.	1 Carp	115	0.07	Ea.	1.03	2.89	15	3.92	5.6	15	$ 84.00
LAB CABINTRY											
Pass Through Cabinent							2	13500	13500		$ 27,000.00
Bio Safety Cabinets							1	15440.63	15440.63		$ 15,440.63
Procedure Light							1	2500	2500		$ 2,500.00
Refridgerator 68 C.F.	Q-1	3	5.333	Ea.	3650	250	1	3900	4375		$ 4,375.00
PLUMBING											
Instant Hot Water Commerical 100 cup	1 plum	14	0.571	Ea.	400	29.5	1	429.5	485		$ 485.00
Satinless Steel, Self Rimming 22"x25"	Q-1	5.6	2.875	Ea.	615	134	1	749	880		$ 880.00
ELECTRICAL											
2W x 4W three 40 watt	1 elec	5.7	1.404	Ea.	92	69		161	203		
1W x 4W three 40 watt	1 Elec	6.7	1.194	Ea.	76.5	58.5	4	135	171		$ 684.00
Flush Switch	1 Elec	40	0.2	Ea.	14.75	9.8	1	24.55	31		$ 31.00
Switch Plate	1 Elec	80	0.1	Ea.	3.6	4.9	1	8.5	11.25		$ 11.25
#12 3 wire	1 Elec	2.2	3.63	Ea.	122	178	2	300	400		$ 800.00
pressed steel octagon box 4"	1 Elec	20	0.4	Ea.	3.36	1960	4	22.96	32.5		$ 130.00
Extension Rings	1 Elec	40	0.2	Ea.	5.6	9.8		15.4	20.5		
Square 4"	1 Elec	20	0.4	Ea.	2.38	19.6	13	21.98	31.5		$ 409.50
Plaster Rings	1 Elec	64	0.125	Ea.	3.09	6.15	13	9.24	12.5		$ 162.50
20 Amp recpt. #12/2	1 Elec	12.31	0.65	Ea.	31	36.5	13	67.5	88.5		$ 1,150.50
HVAC											
Diffuser 18 x 18	1 Sheet	9	0.889	Ea.	128	43.5	2	171.5	207		$ 414.00
Cabintry											
Stainless Steel Countertop	2 Carp	40	0.4	L.F.	138	16.6	10	154.4	177		$ 1,770.00
Metal Shelf 4 level 20" x 4'	1 Clab	6	1.333	Ea.	1325	44	2	1369	1525		$ 3,050.00
Base cabinets stainless steel	2 Carp	10	1.6	L.F	455	66.5	2	521.5	600		$ 1,200.00
cabinents for all drawers	2 Carp	10	1.6	L.F	481	66.5	2	521.5	600		$ 1,200.00
Doors 5 X 7 thick 2"	2 Carp	1.9	8.42	Ea.	5225	350	1	5575	6300		$ 6,300.00
Total											**$ 74,828.52**

[APPENDIX H]

GOWNING ROOM TAKEOFF

ROOM 119 Gowning	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment/ Unit Used	Total	Total Incl O&P		Price
3 5/8" Metal Stud	2 Carp	76	0.211	L.F.	9.1	8.75	33	17.85	23.5	33	$ 775.50
6" Metal Stud	2 Carp	73	0.219	L.F.	12.05	9.1		21.15	27.5		
5/8" GWB on Wall	2 Carp	700	0.023	S.F.	0.86	0.95	297	1.81	2.4	297	$ 712.80
5/8" GWB on Ceiling	2 Carp	550	0.029	S.F.	0.86	1.21	66	2.07	2.8	66	$ 184.80
R13 11" wide	1 Carp	1350	0.006	S.F.	0.33	0.25	297	0.58	0.74	297	$ 219.78
R19 6" wide	1 Carp	1350	0.006	S.F.	0.43	0.25		0.68	0.85		
Vinyl Sheets .125 thick	1 Tilf	200	0.04	S.F.	6.1	1.57	66	7.67	9	66	$ 594.00
Steel Plate 1/4"	E-4			S.F.	11.2		66	11.2	12.35	66	$ 815.10
16 Ga x 2.5" 12 O.C.	1 Carp	115	0.07	Ea.	1.03	2.89	6	3.92	5.6	6	$ 33.60
LAB CABINTRY											
Pass Through Cabinent								13500	13500		
Cage Racks								2500	2500		
Bio Safety Cabinets								15440.63	15440.63		
PLUMBING											
Instant Hot Water Commerical 100 cup	1 plum	14	0.571	Ea.	400	29.5	1	429.5	485		$ 485.00
Satinless Steel, Self Rimming 22"x25"	Q-1	5.6	2.875	Ea.	615	134	1	749	880		$ 880.00
Area Drain	Q-1	9	1.778	Ea.	2400	62.5	0	2462.5	2480.49		
ELECTRICAL											
2W x 4W three 40 watt	1 elec	5.7	1.404	Ea.	92	69	1	161	203		$ 203.00
1W x 4W three 40 watt	1 Elec	6.7	1.194	Ea.	76.5	58.5		135	171		
Flush Switch	1 Elec	40	0.2	Ea.	14.75	9.8	3	24.55	31		$ 93.00
Switch Plate	1 Elec	80	0.1	Ea.	3.6	4.9	3	8.5	11.25		$ 33.75
#12 3 wire	1 Elec	2.2	3.63	Ea.	122	178	1	300	400		$ 400.00
pressed steel octagon box 4"	1 Elec	20	0.4	Ea.	3.36	1960	1	22.96	32.5		$ 32.50
Extension Rings	1 Elec	40	0.2	Ea.	5.6	9.8		15.4	20.5		
Square 4"	1 Elec	20	0.4	Ea.	2.38	19.6	3	21.98	31.5		$ 94.50
Plaster Rings	1 Elec	64	0.125	Ea.	3.09	6.15	3	9.24	12.5		$ 37.50
20 Amp recpt. #12/2	1 Elec	12.31	0.65	Ea.	31	36.5	3	67.5	88.5		$ 265.50
HVAC											
Diffuser 18 x 18	1 Sheet	9	0.889	Ea.	128	43.5	2	171.5	207		$ 414.00
Cabintry											
Metal Shelf 4 level 20" x 4'	1 Clab	6	1.333	Ea.	1325	44	1	1369	1525		$ 1,525.00
Doors 5 X 7 thick 2"	2 Carp	1.9	8.42	Ea.	5225	350	3	5575	6300		$ 18,900.00
Total											$ 26,699.33

[APPENDIX I]

BSL2/3 TAKEOFF

BSL 2&3	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment/ Unit Used	Total	Total Incl O&P	Unit	Price
3 5/8" Metal Stud	2 Carp	76	0.211	L.F.	9.1	8.75	64	17.85	23.5	64	$ 1,504.00
6" Metal Stud	2 Carp	73	0.219	L.F.	12.05	9.1	0	21.15	27.5	0	$ -
5/8" GWB on Wall	2 Carp	700	0.023	S.F.	0.86	0.95	576	1.81	2.4	576	$ 1,382.40
5/8" GWB on Ceiling	2 Carp	550	0.029	S.F.	0.86	1.21	231	2.07	2.8	231	$ 646.80
R13 11" wide	1 Carp	1350	0.006	S.F.	0.33	0.25	576	0.58	0.74	576	$ 426.24
R19 6" wide	1 Carp	1350	0.006	S.F.	0.43	0.25	0	0.68	0.85	0	$ -
Vinyl Sheets .125 thick	1 Tilf	200	0.04	S.F.	6.1	1.57	231	7.67	9	231	$ 2,079.00
Steel Plate 1/4"	E-4			S.F.	11.2		231	11.2	12.35	231	$ 2,852.85
16 Ga x 2.5" 12 O.C.	1 Carp	115	0.07	Ea.	1.03	2.89	22	3.92	5.6	22	$ 123.20
LAB CABINTRY											
Pass Through Cabinent							0	13500	13500		$ -
Bio Safety Cabinets							2	15440.6	15440.63		$ 30,881.26
Procedure Light							1	2500	2500		$ 2,500.00
Refridgerator 68 C.F.	Q-1	3	5.333	Ea.	3650	250	1	3900	4375		$ 4,375.00
PLUMBING											
Instant Hot Water Commerical 100 cup	1 plum	14	0.571	Ea.	400	29.5	1	429.5	485		$ 485.00
Satinless Steel, Self Rimming 22"x25"	Q-1	5.6	2.875	Ea.	615	134	1	749	880		$ 880.00
ELECTRICAL											
2W x 4W three 40 watt	1 elec	5.7	1.404	Ea.	92	69		161	203		
1W x 4W three 40 watt	1 Elec	6.7	1.194	Ea.	76.5	58.5	6	135	171		$ 1,026.00
Flush Switch	1 Elec	40	0.2	Ea.	14.75	9.8	1	24.55	31		$ 31.00
Switch Plate	1 Elec	80	0.1	Ea.	3.6	4.9	1	8.5	11.25		$ 11.25
#12 3 wire	1 Elec	2.2	3.63	Ea.	122	178	6	300	400		$ 2,400.00
pressed steel octagon box 4"	1 Elec	20	0.4	Ea.	3.36	1960	6	22.96	32.5		$ 195.00
Extension Rings	1 Elec	40	0.2	Ea.	5.6	9.8		15.4	20.5		
Square 4"	1 Elec	20	0.4	Ea.	2.38	19.6	22	21.98	31.5		$ 693.00
Plaster Rings	1 Elec	64	0.125	Ea.	3.09	6.15	22	9.24	12.5		$ 275.00
20 Amp recpt. #12/2	1 Elec	12.31	0.65	Ea.	31	36.5	22	67.5	88.5		$ 1,947.00
HVAC											
Diffuser 18 x 18	1 Sheet	9	0.889	Ea.	128	43.5	2	171.5	207		$ 414.00
Cabintry											
Stainless Steel Countertop	2 Carp	40	0.4	L.F.	138	16.6	15	154.4	177		$ 2,655.00
Metal Shelf 4 level 20" x 4'	1 Clab	6	1.333	Ea.	1325	44	3	1369	1525		$ 4,575.00
Base cabinets stainless steel	2 Carp	10	1.6	L.F	455	66.5	4	521.5	600		$ 2,400.00
Wall Cabinents	2 Carp	15	15	L.F.	481	44.5	12	525.5	599		$ 7,188.00
cabinents for all drawers	2 Carp	10	1.6	L.F	481	66.5	2	521.5	600		$ 1,200.00
Doors 5 X 7 thick 2"	2 Carp	1.9	8.42	Ea.	5225	350	1	5575	6300		$ 6,300.00
Total											**$ 79,446.00**

[APPENDIX J]

Structural Breadth Calculations

Steel Breadth – Modularization of laboratory spaces

Calculating Span of 20ft

$$1.2D + 1.6L = Tl$$

$$1.2(20) + 1.6(100) = \frac{184lbs}{sf} x\ 11' = 2024\frac{lbs}{ft} = 2.02\frac{kips}{ft} = (\ tributary\ area)$$

WL^2/8 = M_{max}= ((2.02 kips/ft)*20^2)/8 = 101.0 K-ft

WL^2/2 = V_{max}= ((2.02 kips/ft)*20)/2 = 20.2 K-ft-

Using an un-braced length of zero from the steel manual values are derived from Table 3-2

Try beam 14 x30 with a moment under LRFD of 205 ft-K and 120.0 K for Shear

$$1728\ is\ the\ conversion\ fro\ mft^3\ to\ in^3$$

$$I\ is\ from\ table\ 3-3$$

$$Wide\ Flange\ Beam - 14x30 = 340in^4$$

$$E = 29{,}000\ KSI$$

$$\Delta L = \frac{5WL^4}{384EI} * 1728 = \frac{5(1.76K-Ft)20^4}{384(29000KSI)(340in^4)} * 1728 = .6425$$

$$\Delta TL = \frac{5WL^4}{384EI} * 1728 = \frac{5(2.02K-Ft)20^4}{384(29000KSI)(340in^4)} * 1728 = .7375$$

$$\Delta L < \frac{L}{360} = 20 * \frac{12}{360} = .6425'' < .667''$$

$$\Delta TL < \frac{L}{240} = 20 * \frac{12}{240} = .7375'' < 1.00''$$

Assuming that Vibrations are not an Issue

Calculating Span of 8ft

$$1.2D + 1.6L = Tl$$

$$1.2(20) + 1.6(100) = \frac{184lbs}{sf} x\ 11' = 2024\frac{lbs}{ft} = 2.02\frac{kips}{ft} = (\ tributary\ area)$$

WL^2/8 = M_{max}= ((2.02 kips/ft)*8^2)/8 = 16.16 K-ft

WL^2/2 = V_{max}= ((2.02 kips/ft)*8)/2 = 8.08 K-ft

Using an un-braced length of zero from the steel manual values are derived from Table 3-2

Try beam 8 X10 with a moment under LRFD of 32.9 ft-K and 40.2 K for Shear

$$1728\ is\ the\ conversion\ fro\ mft^3\ to\ in^3$$

$$I\ is\ from\ table\ 3-3$$

$$Wide\ Flange\ Beam - 8\ X\ 10 = 30.8in^4$$

$$E = 29{,}000\ KSI$$

$$\Delta L = \frac{5WL^4}{384EI} * 1728 = \frac{5(1.76K - Ft)8^4}{384(29000KSI)(30.8in^4)} * 1728 = .182$$

$$\Delta TL = \frac{5WL^4}{384EI} * 1728 = \frac{5(2.02K - Ft)8^4}{384(29000KSI)(30.8in^4)} * 1728 = .208$$

$$\Delta L < \frac{L}{360} = 20 * \frac{12}{360} = .182" < .667"$$

$$\Delta TL < \frac{L}{240} = 20 * \frac{12}{240} = .208" < 1.00"$$

Girder Sizing

Try beam 16 X45 with a moment under LRFD of 309 ft-K and 167 K for Shear

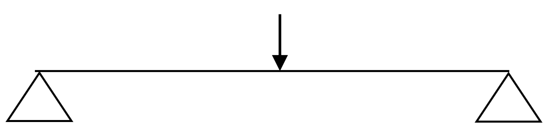
$$1728\ is\ the\ conversion\ fro\ mft^3\ to\ in^3$$

$$I\ is\ from\ table\ 3-3$$

$$Wide\ Flange\ Beam - 16\ X\ 45 = 586\ in^4$$

$$E = 29{,}000\ KSI$$

$$\boldsymbol{Vmax^1 + Vmax^2 = Ptl}$$



$$2.02\frac{kips}{ft}\ x\ 10 + 2.02\frac{kips}{ft}\ x\ 4 = 28.28\ K$$

$$\boldsymbol{Mmax = \frac{PL}{4} = \frac{28.28\ K\ x\ 22ft}{4} = 155.54\ K - ft}$$

$$\boldsymbol{Vmax = \frac{P}{2} = 14.14\ K}$$

$$\boldsymbol{Vl = \frac{WL}{2} = \frac{1.76 * 20}{2} = 17.6\ K}$$

$$\boldsymbol{Vl2 = \frac{WL}{2} = \frac{1.76 * 8}{2} = 7.04\ K}$$

$$\boldsymbol{Pl = 17.6 + 7.04 = 24.64\ K}$$

$$\boldsymbol{Tl = \frac{WL}{2} = \frac{2.02 * 20}{2} = 20.2\ K}$$

$$\boldsymbol{Tl2 = \frac{WL}{2} = \frac{2.02 * 20}{2} = 8.08\ K}$$

$$\boldsymbol{Ptl = 20.2 + 8.08 = 28.28\ K}$$

$$\Delta \mathrm{LL} = \frac{PlL^3}{48EI} * 1728 = \frac{24.64K * 22^3}{48(29000KSI)(586in^4)} * 1728 = .556"$$

$$\Delta \mathrm{TL} = \frac{PlL^3}{48EI} * 1728 = \frac{28.28K * 22^3}{48(29000KSI)(586in^4)} * 1728 = .638"$$

$$\Delta L < \frac{L}{360} = 20 * \frac{12}{360} = .556" < .667"$$

$$\Delta TL < \frac{L}{240} = 20 * \frac{12}{240} = .638" < 1.00"$$

Column Resizing

$$\boldsymbol{TA = Area\ of\ col = 4x11 + 11x20 = 264\ square\ feet}$$

$$1.2D + 1.6L = Tl$$

$$1.2(20) + 1.6(100) = \frac{184lbs}{sf} x\ 264\ sf = 48576\ lbs\ x\ \frac{kip}{1000lbs} = 48.576\ kips$$

[APPENDIX K]

TYPICAL BAY TAKEOFF

Structural Breakdown Cost	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment	Total	Total Incl O&P	Cost
Material										
2" deep steel decking Ga. 19	E-4	3490	0.009	S.F.	1.53	0.44	0.04	2.01	2.41	$ 1,484.56
3" deep steel decking Ga. 19	E-4	2925	0.011	S.F.	1.65	0.52	0.05	2.22	2.66	$ 1,638.56
										$ (154.00)
Structural Steel										
8X10	E-2	600	0.093	L.F.	12.1	4.26	2.68	19.04	23.5	$ (188.00)
14X30	E-2	900	0.062	L.F.	36.5	2.84	1.79	41.13	47	$ (940.00)
16X45	E-2	800	0.07	L.F.	54.5	3.19	2.01	59.7	71.64	$ (1,576.08)
12X19	E-2	880	0.064	L.F.	32.6	2.9	1.83	37.33	44.796	$ 1,791.84
8X13	E-2	600	0.093	L.F.	15.21	4.26	2.68	22.15	26.58	$ 425.28
14X22	E-2	990	0.057	L.F.	31.5	2.58	1.62	35.7	42.84	$ 942.48
Concrete 6"slab	C-8	2585	0.022	S.F.	1.96	0.76	0.29	3.04	3.67	$ 1,541.40
										$ 1,027.60
Fireproofing										
1 inch thick	G-2	2400	0.01	S.F.	0.53	0.35	0.06	0.94	1.16	$ (510.40)
Total Savings										**$ 818.72**
										Per Typical Bay

[APPENDIX L]

ELECTRICAL BREADTH CALCULATIONS

Parking Canopies (7.5-1)

Electrical Calculations DC Side

- Isc= 9.16 A
- 25% Safety Factor and another 25% for wire and fuses
- Add 2 strings in parallel the amps multiply by 2
- Max Wire Amp for 2 strings= Isc*1.25*1.25*2= 9.16*1.25*1.25*2=28.62
- Max wire amp for 1 string= Isc*1.25*1.25=9.16*1.25*1.25=14.31 A
- The minimum current carrying capacity of the wires between the combiner box and the inverter is 28.62 Amp
- Conduit 1" above the roof add 22°C
- Max Temp= 38°C
- Ambient Temp= 38+22= 60°C
- Correction factor for 60°C= .71 outside on roof
- #12 AWG @ 90°C= 30A* .71= 21.3A > 14.31 A ok to uses for connecting string to combiner box
- #8 AWG @ 90°C= 50A * .71= 35.5 A> 28.62 (Max wire Amp), so wire is OK to use between the combiner box and inverter

Electrical Calculations AC Side

- Inverter Max AC Output 27.1A to connect to panelboard
- Use 1.25 times inverter max output then round to the nearest breaker size for
- 27.1*1.25=33.875 Amp
- #10 AWG @ 90°C= 40A > 33.875 (Max wire Amp), so wire is OK to use between A/C disconnect and underground splice box
- 33.875*4=135.5 Amps wire sizing from parking canopy to electrical box inside building
    - 135.5 A < 150 A so #1 AWG in a 2" rigid PVC pipe
- Next breaker size 150Amp
- Assumed THWN 90°C from table 310.16
- #1 Wire 135.5 Amps = 150 A Breaker size so OK to use
- When connecting to an electrical panel a 150 A breaker is to be used to sufficiently take the load.

Large Roof (10.1-1)

Electrical Calculations DC Side

- Isc= 9.16 A
- 25% Safety Factor and another 25% for wire and fuses
- Add 3 strings in parallel the amps multiply by 3
- Max Wire Amp for 3 strings= Isc*1.25*1.25*2= 9.16*1.25*1.25*3=42.9375
- Max wire amp for 1 string= Isc*1.25*1.25=9.16*1.25*1.25=14.31 A
- The minimum current carrying capacity of the wires between the combiner box and the inverter is 42.9375Amp
- Conduit 1" above the roof add 22°C
- Max Temp= 38°C
- Ambient Temp= 38+22= 60°C
- Correction factor for 60°C= .71 outside on roof
- #12 AWG @ 90°C= 30A* .71= 21.3 A > 14.31 A ok to uses for connecting string to combiner box
- #6 AWG @ 90°C= 75A * .71= 53.25 A> 42.9375 (Max wire Amp), so wire is OK to use between the combiner box and inverter

Electrical Calculations AC Side

- Inverter Max AC Output 36.1 A to connect to panelboard
- Use 1.25 times inverter max output then round to the nearest breaker size for
- 36.1*1.25=45.125 Amp
- #8 AWG @ 90°C= 55 A > 45.125 A (Max wire Amp), so wire is OK to use between A/C disconnect and splice box
- 45.125*4=180.50 Amps wire sizing from parking canopy to electrical box inside building
    - 180.5 A < 195 A so 2/0 AWG in a 2.5" rigid PVC pipe
- Next breaker size 200 Amp
- Assumed THWN 90°C from table 310.16
- 2/0 Wire 180.5 Amps = to Breaker size so OK to use
- When connecting to an electrical panel a 200 A breaker is to be used to sufficiently take the load.

Small Roof (10.1-1)

Electrical Calculations DC Side

- Isc= 9.16 A
- 25% Safety Factor and another 25% for wire and fuses
- Add 3 strings in parallel the amps multiply by 3
- Max Wire Amp for 3 strings= Isc*1.25*1.25*2= 9.16*1.25*1.25*3=42.9375
- Max wire amp for 1 string= Isc*1.25*1.25=9.16*1.25*1.25=14.31 A
- The minimum current carrying capacity of the wires between the combiner box and the inverter is 42.9375Amp
- Conduit 1" above the roof add 22°C
- Max Temp= 38°C
- Ambient Temp= 38+22= 60°C
- Correction factor for 60°C= .71 outside on roof
- #12 AWG @ 90°C= 30A* .71= 21.3 A > 14.31 A ok to uses for connecting string to combiner box
- #6 AWG @ 90°C= 75A * .71= 53.25 A> 42.9375 (Max wire Amp), so wire is OK to use between the combiner box and inverter

Electrical Calculations AC Side

- Inverter Max AC Output 36.1 A to connect to panelboard
- Use 1.25 times inverter max output then round to the nearest breaker size for
- 36.1*1.25=45.125 Amp
- #8 AWG @ 90°C= 55 A > 45.125 A (Max wire Amp), so wire is OK to use between A/C disconnect and splice box
- 45.125=Amps wire sizing from parking canopy to electrical box inside building
    - 45.125 A < 50 A so #8 AWG in a 1" rigid PVC pipe
- Next breaker size 50 Amp
- Assumed THWN 90°C from table 310.16
- #8 Wire 50 Amps = to Breaker size so OK to use
- When connecting to an electrical panel a 50 A breaker is to be used to sufficiently take the load.

Parking canopy calculations and check for array size and modules

INPUTS					
Location Inputs			**Pronius IG Plus 7.5-1**		
Min Temp	-8	°C	PV Array	6350-8600	W
Max Temp	38	°C	MPPT Min Voltage	230	V
Roof	30	°C	Max Voltage	600	V
Array Size	7080	W			
Max Roof Temp	68	°C			
Astronergy CHSM6612P					
Pmax	295	W			
Vmpp	35.72	V			
Impp	8.3	A			
Voc	45.03	V			
ISC	9.16	A			
Temp Coeff	-0.332	%/°K			
OUTPUTS					
Astronergy CHSM6612P					
Modules Per String	12				
Number of Strings	2				
Number of Panles	24				
Array Rated Power	7080	W			
Max Voltage	49.963	V			
High Temp V	30.621	V			
Array Output Voltage					
Max Voltage	599.5618	OK			
High Temp V	306.2061	OK			

Small roof calculations and check for array size and modules

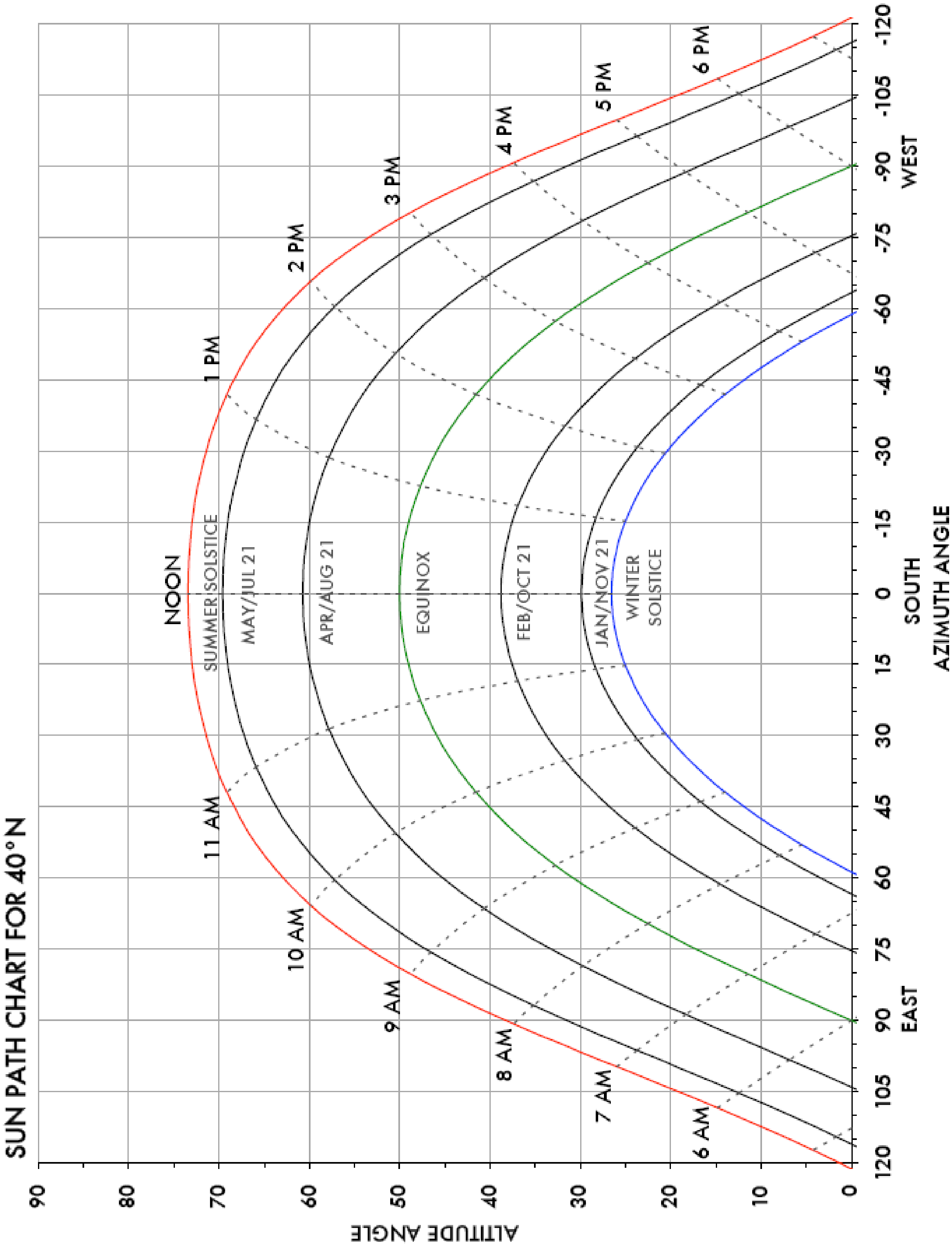
INPUTS					
Location Inputs			**Pronius IG Plus 10.0-1**		
Min Temp	-8	°C	PV Array	6350-8600	W
Max Temp	38	°C	MPPT Min Voltage	230	V
Roof	30	°C	Max Voltage	600	V
Array Size	8850	W			
Max Roof Temp	68	°C			
Astronergy CHSM6612P					
Pmax	295	W			
Vmpp	35.72	V			
Impp	8.3	A			
Voc	45.03	V			
ISC	9.16	A			
Temp Coeff	-0.332	%/°K			
OUTPUTS					
Astronergy CHSM6612P					
Modules Per String	10				
Number of Strings	3				
Number of Panles	30				
Array Rated Power	8850	W			
Max Voltage	49.963	V			
High Temp V	30.621	V			
Array Output Voltage					
Max Voltage	499.6349	OK			
High Temp V	255.1718	OK			

Large roof calculations and check for array size and modules

INPUTS						
Location Inputs				**Pronius IG Plus 10.0-1**		
Min Temp	-8	°C		PV Array	8500-11500	W
Max Temp	38	°C		MPPT Min Voltage	230	V
Roof	30	°C		Max Voltage	600	V
Array Size	35400	W				
Max Roof Temp	**68**	**°C**				
Astronergy CHSM6612P						
Pmax	295	W				
Vmpp	35.72	V				
Impp	8.3	A				
Voc	45.03	V				
ISC	9.16	A				
Temp Coeff	-0.332	%/°K				
OUTPUTS						
Astronergy CHSM6612P						
Modules Per String	10					
Number of Strings	12					
Number of Panles	120					
Array Rated Power	35400	W				
Max Voltage	49.963	V				
High Temp V	30.621	V				
Array Output Voltage						
Max Voltage	499.6349	OK				
High Temp V	255.1718	OK				

[APPENDIX M]

SUN PATH CHART


SUN PATH CHART FOR 40°N
ALTITUDE ANGLE
AZIMUTH ANGLE
EAST
SOUTH
WEST
NOON
SUMMER SOLSTICE
MAY/JUL 21
APR/AUG 21
EQUINOX
FEB/OCT 21
JAN/NOV 21
WINTER SOLSTICE
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM

[APPENDIX N]

Energy Load Analysis Calculations

Energy Load Analysis for Biological Research Facility

1. $\frac{W}{cfm}\ for\ supply\ air = 76.667\ hp * \left[\frac{746\left(\frac{W}{hp}\right)}{24228\ cfm}\right] = 2.28\ \frac{W}{cfm}$
2. $\frac{W}{cfm}\ for\ return\ air = 90.1\ hp * \left[\frac{746\left(\frac{W}{hp}\right)}{21726\ cfm}\right] = 3.09\ \frac{W}{cfm}$
3. $\frac{2.28+3.09}{2} = 2.685\ \frac{W}{cfm}$
4. $\frac{21726\ cfm\ (total\ cfm\ based\ on\ exhaust)}{20000\ sf} = 1.08\frac{cfm}{gross\ sf}$
5. **Ventilation** - $2.685\frac{W}{cfm} *\ 1.08\frac{cfm}{gross\ sf} * \left(\frac{8760\ hours}{1000}\right) = 25.40\frac{kWh}{gross\ sf}$
6. **Cooling** - $\frac{1kW}{ton} * 280\ tons * \frac{963\ hours}{20000\ gross\ sf} = 13.48\ \frac{kWh}{gross\ sf}$
7. **Lighting** - $1.0\frac{W}{gross}ft^2 * \left(\frac{4534\ hours}{1000}\right) = 4.534\frac{kWh}{gross\ sf}$ **

   **Assumes lights are on for 87.2 hours a week

8. **Process/Plug** - $5.735\ \left(\frac{W}{gross\ sf}\right) *\ 0.80 * \frac{5256\ hours}{1000} = 24.11\ \frac{kWh}{gross\ sf}$ ***

   ***Assumes that 80% of all equipment is operating 60% of the hours in a year
9. **Heating** - $44.3\ kW * \frac{5782\ hours}{20000\ sf} = 12.81\ \frac{kWh}{gross\ sf}$

   Total = (25.40+13.48+4.53+24.11+12.81) $= 80.33\frac{kWh}{gross\ sf}$

10. $107.31\frac{kWh}{gross\ sf} * 20000\ sf = 2{,}146{,}200\ kWh$/yr
11. $\frac{\mathbf{2{,}146{,}200\ kWh}}{\mathbf{yr}} * \frac{1\ yr}{12\ months} = \frac{\mathbf{178{,}850\ kWh}}{\mathbf{month}} * \frac{1\ month}{30\ days} = \frac{\mathbf{5{,}961\ kWh}}{\mathbf{day}}$

Degree Days for state College were used to determine the amount of hours that both heating and cooling used throughout the calculations.

[APPENDIX O]

Inverter Cut Sheet


http://www.wholesalesolar.com/inverters.html
Maximum energy harvest – cloudy or clear
Fronius **IG Plus** PV Inverter
The first complete solution. Reliable. Proven. Smart.
An outstanding addition to the family: The next generation Fronius IG Plus inverter builds on a successful model with multiple enhancements, including maximum power harvest, a built-in six circuit string combiner, integrated, lockable DC Disconnect, significantly improved efficiency, and unbeatable reliability. New, larger power stages expand the proven Fronius IG family from 2 to 12 kW in a single inverter.
Fronius
POWERING YOUR FUTURE

http://www.wholesalesolar.com/inverters.html

INPUT DATA — Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Recommended PV-Power (Wp)	2500-3450	3200-4400	4250-5750	5100-6900	6350-8600	8500-11500	9700-13100	9700-13100	10200-13800
MPPT-Voltage Range	230 ... 500 V								
DC Startup Voltage	245 V								
Max. Input Voltage (at 1000 W/m² 14°F (-10°C) in open circuit operation)	600 V								
Nominal Input Current	8.3 A	10.5 A	13.8 A	16.6 A	20.7 A	27.6 A	31.4 A	31.4 A	33.1 A
Max. usable Input Current	14.0 A	17.8 A	23.4 A	28.1 A	35.1 A	46.7 A	53.3 A	53.3 A	56.1 A
Admissible conductor size (DC)	No. 14 - 6 AWG								
Number of DC Input Terminals	6								
Max. Current per DC Input Terminal	20 A; Bus bar available for higher input currents								

OUTPUT DATA — Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Nominal output power ($P_{AC nom}$)	3000 W	3800 W	5000 W	6000 W	7500 W	9995 W	11400 W	11400 W	12000 W
Max. continuous output power 104°F (40°C) 208 V / 240 V / 277 V	3000 W	3800 W	5000 W	6000 W	7500 W	9995 W	11400 W	11400 W	12000 W
Nominal AC output voltage	208 V / 240 V / 277 V							208 V / 240 V	277 V
Operating AC voltage range (default) 208 V	183 - 229 V (-12 / +10 %)								
240 V	211 - 264 V (-12 / +10 %)								
277 V	244 - 305 V (-12 / +10 %)								
Max. continuous output current 208 V	14.4 A	18.3 A	24.0 A	28.8 A	36.1 A	48.1 A	54.8 A	31.6 A*	n.a.
240 V	12.5 A	15.8 A	20.8 A	25.0 A	31.3 A	41.7 A	47.5 A	27.4 A*	n.a.
277 V	10.8 A	13.7 A	18.1 A	21.7 A	27.1 A	36.1 A	41.2 A	n.a.	14.4 A*
Admissible conductor size (AC)	No. 14 - 4 AWG								
Max. continuous utility back feed current	0 A								
Nominal output frequency	60 Hz								
Operating frequency range	59.3 - 60.5 Hz								
Total harmonic distortion	< 3 %								
Power factor	1								

GENERAL DATA — Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Max. Efficiency	96.2 %								
CEC Efficiency 208 V	95.0 %	95.0 %	95.5 %	95.5 %	95.0 %	95.0 %	95.5 %	95.0 %	n.a.
240 V	95.5 %	95.5 %	95.5 %	96.0 %	95.5 %	95.5 %	96.0 %	95.5 %	n.a.
277 V	95.5 %	95.5 %	96.0 %	96.0 %	96.0 %	96.0 %	96.0 %	n.a.	96.0 %
Consumption in standby (night)	< 1 W								
Consumption during operation	8 W		15 W			22 W			
Cooling	Controlled forced ventilation, variable fan speed								
Enclosure Type	NEMA 3R								
Unit Dimensions (W x H x D)	17.1 x 24.8 x 9.6 in.		17.1 x 36.4 x 9.6 in.			17.1 x 48.1 x 9.6 in.			
Power Stack Weight	31 lbs. (14 kg)		57 lbs. (26 kg)			82 lbs. (37 kg)			
Wiring Compartment Weight	24 lbs. (11 kg)		26 lbs. (12 kg)			26 lbs. (12 kg)			
Admissible ambient operating temperature	-4 ... 122°F (-20 ... +50°C)								
Compliance	UL 1741-2005, IEEE 1547-2003, IEEE 1547.1, ANSI/IEEE C62.41, FCC Part 15 A & B, NEC Article 690, C22. 2 No. 107.1-01 (Sept. 2001)								

PROTECTION DEVICES — Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Ground fault protection	Internal GFDI (Ground Fault Detector/Interrupter); in accordance with UL 1741-2005 and NEC Art. 690								
DC reverse polarity protection	Internal diode								
Islanding protection	Internal; in accordance with UL 1741-2005, IEEE 1547-2003 and NEC								
Over temperature	Output power derating / active cooling								

* per Phase

Fronius USA LLC Solar Electronic Division
10421 Citation Drive, Suite 1100, Brighton, Michigan, 48116
E-Mail: pv-us@fronius.com

[APPENDIX P]

Solar Panel Cut Sheet

Datasheet
Crystalline PV Module CHSM6612P

265 | 270 | 275 | 280 | 285 | 290 | 295

ELECTRICAL SPECIFICATIONS

STC rated output (P_{mpp})	265 Wp	270 Wp	275 Wp	280 Wp	285 Wp	290 Wp	295 Wp
PTC rated output	238.0 Wp	242.6 Wp	247.2 Wp	251.8 Wp	256.5 Wp	261.1 Wp	265.7 Wp
Standard sorted output				(P_{mpp} + 5 Wp) > P_{flash} > P_{mpp}			
Measurement tolerance	+/- 3%	+/- 3%	+/- 3%	+/- 3%	+/- 3%	+/- 3%	+/- 3%
Warranted power output STC ($P_{mpp\ min}$)	265 Wp	270 Wp	275 Wp	280 Wp	285 Wp	290 Wp	295 Wp
Rated voltage (V_{mpp}) at STC	35.54 V	35.57 V	35.60 V	35.63 V	35.66 V	35.68 V	35.72 V
Rated current (I_{mpp}) at STC	7.48 A	7.62 A	7.76 A	7.90 A	8.04 A	8.15 A	8.30 A
Open circuit voltage (V_{oc}) at STC	44.24 V	44.38 V	44.51 V	44.64 V	44.77 V	44.90 V	45.03 V
Short circuit current (I_{sc}) at STC	8.27 A	8.42 A	8.56 A	8.71 A	8.86 A	8.94 A	9.16 A
Module efficiency	13.6%	13.9%	14.1%	14.4%	14.7%	14.9%	15.2%
Rated output (P_{mpp}) at NOCT	185.1 Wp	188.5 Wp	192.0 Wp	195.5 Wp	199.0 Wp	202.5 Wp	206.0 Wp
Rated voltage (V_{mpp}) at NOCT	32.37 V	32.38 V	32.38 V	32.38 V	32.39 V	32.51 V	32.47 V
Rated current (I_{mpp}) at NOCT	5.72 A	5.82 A	5.93 A	6.04 A	6.14 A	6.23 A	6.34 A
Open circuit voltage (V_{oc}) at NOCT	40.59 V	40.72 V	40.84 V	40.96 V	41.08 V	41.20 V	41.32 V
Short circuit current (I_{sc}) at NOCT	6.40 A	6.51 A	6.62 A	6.74 A	6.85 A	6.91 A	7.09A

Temperature coefficient α (P_{mpp})	- 0.451%/K
Temperature coefficient β (I_{sc})	+ 0.087%/K
Temperature coefficient δ (I_{mpp})	+ 0.007%/K
Temperature coefficient ε (V_{mpp})	-0.445%/K
Temperature coefficient χ (V_{oc})	- 0.332%/K
Normal operating cell temperature (NOCT)	46C

Maximum system voltage SCII	1000 Vdc
Maximum system voltage NEC	600 Vdc
Number of diodes	6
Maximum series fuse rating	15 A

A CHINT COMPANY

ASTRONERGY

ASTRONERGY

QUALIFICATION AND WARRANTIES

Product standard	IEC 61215, 61730 / UL 1703
Extended product warranty	10 years
Output warranty of 90% performance P_{mpp} (STC)	10 years
Output warranty of 80% performance P_{mpp} (STC)	25 years

CELL TECHNOLOGY

Cell type	polycrystalline
Number of cells / cell arrangement	72 / 6 x 12
Cells dimension	6"

MECHANICAL SPECIFICATIONS

Outer dimensions (L x W x H)	1956 x 994 x 50 mm 77.01 x 39.13 x 1.97 in
Frame technology	Aluminum, silver anodized
Module composition	Glass / EVA / Backsheet (white)
Weight (module only)	23.5 kg / 51.7 lbs
Front glass thickness	3.2 mm / 0.13 in
Junction box IP rating	IP 65
Cable length / diameter (UL)	1000 mm / 39.37 in / 12 AWG
Cable length / diameter (IEC)	1000 mm / 39.37 in / 4 mm²
Maximum load capacity	5400 Pa
Fire class	C
Connector type (TUV)	MC Type 4 compatible

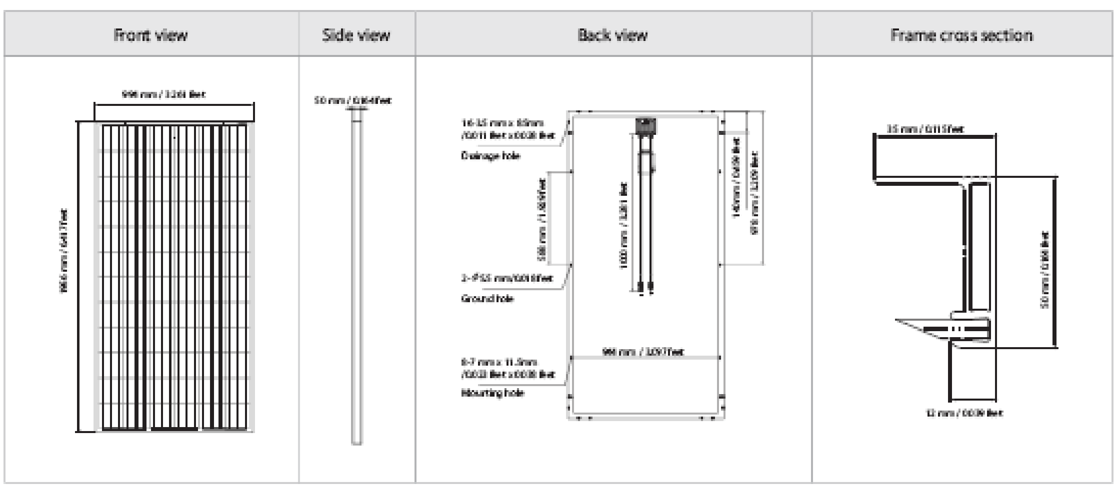
MISCELLANEOUS

Packing unit	20 modules
Weight of packing unit	528 kg / 1162 lbs

ARTICLE NUMBER (per panel)

Power class	Article No. (IEC)	Article No. (UL)
265 Wp	200030	200037
270 Wp	200031	200038
275 Wp	200032	200039
280 Wp	200033	200040
285 Wp	200034	200041
290 Wp	200035	200042
295 Wp	200036	200043

MODULE DIMENSION DETAILS



www.astronergy.com