April 3rd, 2013

SENIOR THESIS FINAL REPORT

PENN STATE SENIOR THESIS

REPLACEMENT HIGH SCHOOL

MARYLAND

BRADY SHEERIN

CONSTRUCTION MANAGEMENT
ADVISOR: CHIMAY ANUMBA

Replacement High School Project
Maryland

Brady Sheerin | Construction Management

Statistics

GSF: 254,878
Height: 3 Stories @ 70'
Project Cost: $7.25 Million
Dates Of Construction: Dec 2011—August 2013
Delivery: CM at Risk, Cost + Fee w/ GMP

Project Team

Owner: Prince George's County Public Schools
Architect: WMCRP Architects
CM: HESS Construction + Engineering Services
Civil engineer: KCI Technologies, Inc
Structural Engineer: ReSTL Designers, Inc.
Mechanical/Electrical Engineer: Allen & Schariff Corporation

Structural

The structural system is a combination of both load bearing CMU walls and structural steel. Columns consist of HSS members and wide flange beams supported by 18" by 18" concrete piers on spread footings. Floors consist of 3-1/4" light weight concrete on composite steel decking.

Mechanical

The mechanical system consists of 9 water to water heat pump modules to manage the 437 geothermal wells that provide heating and cooling for the school. Additionally there are 2 DOAS and 23 AHU's.

Electrical

Building is fed by two 2,500 KVA pad mounted transformers supplied by PEPCO. Each of which tie into their own 3,000 amp 480/277 volt switchboard

Architecture

The building exterior consists primarily of ground face CMU glazed curtain walls and several different styles of aluminum wall panels. In the heart of the building is a large rotunda and spiral stair case topped with a glazed curtain wall that creates a nice architectural feature.

Table of Contents

EXECUTIVE SUMMARY

The following report contains four in-depth analyses that focus on some of, if not all of, the following core areas of investigation: Critical Industry Issues, Value Engineering, Constructability Review, and Schedule Reduction/Acceleration. Additionally, a mechanical redesign breadth and a structural breadth were performed in an attempt to validate changing the current fully geothermal system to a hybrid system.

Analysis #1: Mechanical System

The results of this analysis and subsequent breadth validated changing the current geothermal mechanical system into a hybrid system. The results showed that with a minor structural redesign the roof of the mechanical room would be able to support a 352 ton cooling tower. Due to the cooling and heating load characteristics of the building it was found that a fully geothermal system was not the most efficient system. By using a cooling tower to supplement the peak load conditions the upfront cost of installation would be cheaper by $1,347,349.40 and it would take over 200 years for the fully geothermal system to prove more cost efficient.

Analysis #2: Solar Energy Conversion System (SECS)

The owner's goal for this project was to create a state-of-the-art educational facility, particularly in the field of science and technology. If a photovoltaic array were incorporated into the building it could possibly serve an educational function while saving money on utility bills. For this analysis a PV array was designed with an upfront cost of roughly $660,000 with a payback period just under five years. Additionally if this system were chosen to be implemented it could be installed in a timely manner and have little to no impact on the project schedule.

Analysis #3: Alternate Delivery Method

Due to several delays on the project, poor communication, and problems associated with the construction drawings the construction management agency was put under a lot of pressure. The current CM @ Risk delivery method did not provide them with much leverage when it came to dealing with subcontractors and they suffered from that as a result. This analysis compares the current delivery method against a design-build delivery system. The findings showed that a design-build approach would increase construction and delivery speeds, reduce cost and schedule growth, foster more collaboration between parties, and reduce owner risk. However it would reduce owner input as well.

Analysis #4: Façade Prefabrication

In an attempt to reduce the project schedule a prefabricated façade system was investigated. It was found that this approach added an additional 8% to the current price of the façade. With this considered, it is still suggested that a precast façade be implemented because it reduces the schedule by 6 weeks, would create a cleaner site, allow for higher quality control, and be safer among other things.

Acknowledgements

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Angie Veintimilla, AE Undergraduate

Michael Palmer, AE Undergraduate

Introduction

The original high school at this undisclosed location was completed in the early 60's and over half of it has never been renovated. Due to this, the Prince George County Public School District (PGCPS) saw a need to build a replacement school. The project consists of a 255,000 SF school, a field house, 6 tennis courts, a football field surrounded by a track, a baseball field, a softball field, and a soccer field. Hess Construction + Engineering Services has been contracted to build this $74.25 million project, which does not include the cost of demolition (See Figure 1 for a rendering of the school).

Figure 1: New Facility

The project entails the demolition of the existing school and the construction of a new state-of-the-art facility. The new school is located within close proximity of the present one so that it can be tied into the existing gymnasium which was completed in 2003. The new three story building consists of two, three story classroom wings, a connecting atrium, an auditorium, cafeteria, administrative offices, culinary labs, and auxiliary gym facilities connected to the existing gym. In the heart of the building is a large rotunda and spiral stair case topped with a curtain wall that serves as an architectural feature. Typical finishes consist of painted CMU and abuse-resistant gypsum drywall, tile, resilient flooring, and acoustical tiled ceilings.

The exterior for the building is comprised of 4 differently colored Trenwyth/Prairie Stone ground-face CMU blocks, prefabricated architectural Aluminum faced plastic core panels, Phenolic panels, corrugated steel panels, perforated aluminum panels, and translucent curtain-walls. The windows are aluminum with a low-E insulating glass. The roof is primarily built-up-roofing with a white cap sheet on top of fiber glass insulation to reduce the heat island effect.

Figure 2: Classroom Wing GF CMU Facade

The school has been designed to achieve a LEED Gold rating by acquiring no less than 39 points under the US Green Building Councils LEED® Green Building Rating System ™ for New Construction. The majority of the projects points will be coming from Sustainable Sights and Indoor Environmental Quality. Several ways this rating will be achieved is by focusing on alternative transportation, water efficiency, reducing the heat island effect of the roof, recycling/managing construction waste, and using Low-Emitting Materials. However the building falls short of capturing any points for day lighting and renewable energy.

Client Info

Prince George's County Public Schools (PGCPS) is a district located in the state of Maryland. Their mission is to "advance the achievement of its diverse student body through community, engagement, sound policy, governance, accountability, and fiscal responsibility." PGCPS oversees over 200 schools in 9 different districts.

The reason PGCPS is replacing the existing high school is because over 50 percent of the buildings are over 40 years old and haven't seen any renovations in that time. Based on academic program requirements and existing conditions of the facilities the Board and State were able to justify approving the construction of a new school. Originally the project was designed for a capacity of 2,300 students because of projected enrollment growth in the area. Unfortunately, the State did not approve the student capacity because of a surplus of seats in high schools. This caused a redesign in the building which omitted one of the three classroom wings reducing the schools capacity to 1,200; which correlates more closely with current enrollment trends.

PGCPS, more specifically the current tenants of the existing high school, have several concerns with the construction of the new school primarily stemming from the fact that the two are in such close proximity. First and foremost they are concerned for the safety of their students and staff, because construction will be taking place concurrently with the present school year. They have expressed concerns about heavy equipment, noise levels, fumes, and dust control. Due to this HESS Construction has been able to implement strategies and schedule activities to mitigate these concerns. Another hot topic has been the issue of available parking. With all of the work taking place, most of the existing parking has been taken over and torn out. To remedy this HESS has turned over a temporary parking lot to be used until the final lot is complete. Additionally any and all utility shut downs must occur during non-school hours.

The School is scheduled to be complete in August 2013 for the start of the school year. However, temporary occupancy may be granted in some areas of the building as long as it does not interfere with the completion of other construction activities. The new high school will meet the owner's needs by providing a much needed up to date, state-of-the-art facility for its students.

Project Delivery Method

The delivery method used for this project is a CM at Risk, Cost plus Fee with a GMP. This delivery system was chosen because of the economic climate and the intrinsic benefits it has for the owner. Over the years HESS Construction has been able to foster a longstanding relationship with PGCPS which has helped them secure many projects with the district. HESS prides itself on only pursing jobs in education and for this reason, claims to be able to provide a much better product than their competitors.

PGCPS holds contracts with the architect, construction manager and a third party consultant. HESS construction holds lump sum contracts with all of their subcontractors and prequalifies each one based off of relevant quantitative experience, requisite skills, project capacity and work history. All subs were required to submit a Bid Bond on AIA Document A-310 issued by a surety licensed to issue bonds in the state of Maryland with their bids. The bond capacity had to be at least 95 percent of the largest possible total of bids submitted.

If for some reason the subcontractor awarded is unable to carry out the contract they would then be responsible to pay HESS the difference in their contract, amount and the subsequently hired sub, as liquidation damages.

For a visual representation of the contracts held on this project reference figure 3.

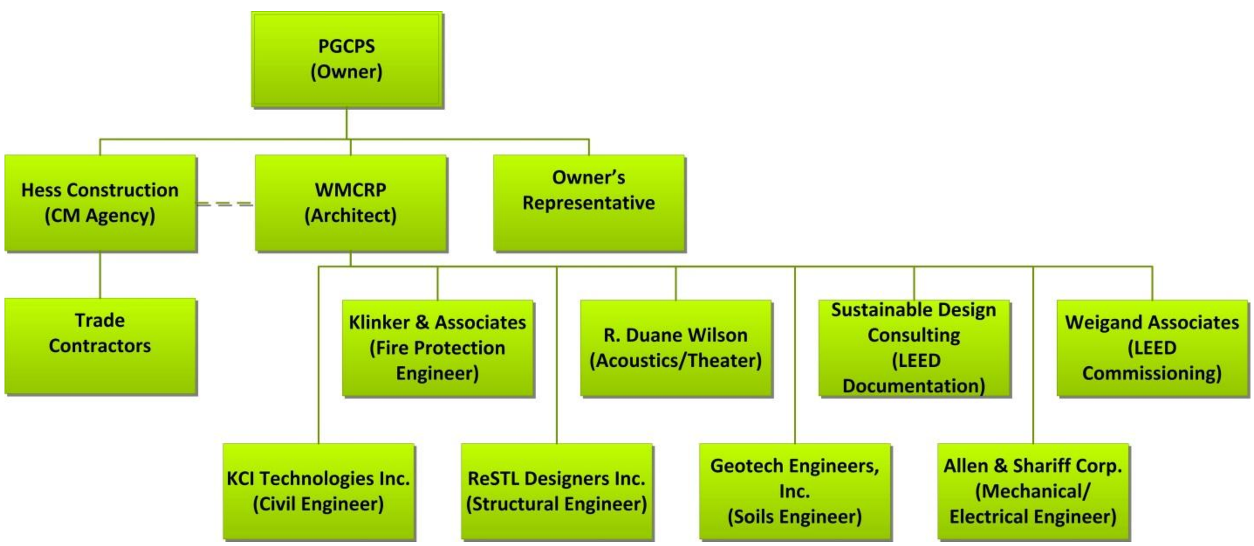


Figure 3: Project Delivery Method

Hess' Project Team

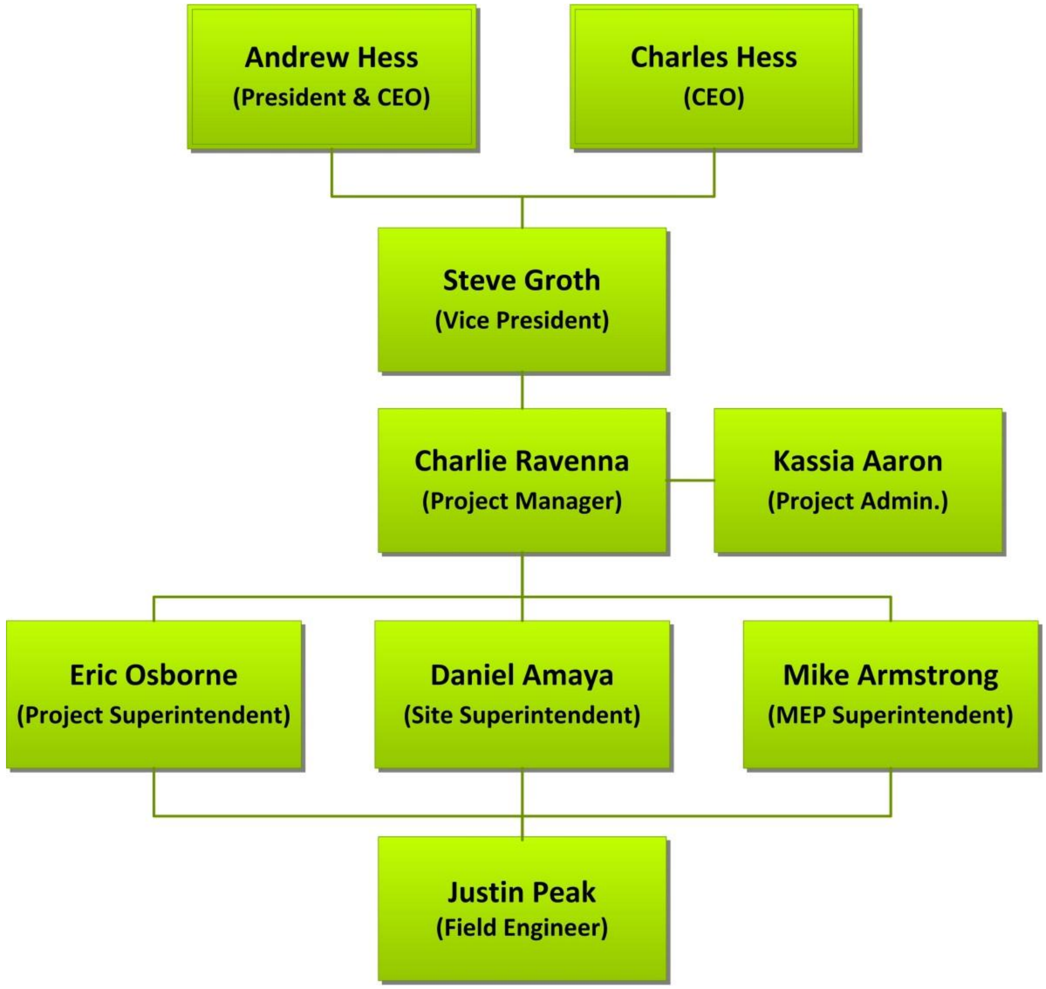


Figure 4: Hess Staffing Plan

Figure 4 depicts the staffing plan used on this project. Hess assigns their teams based on project size and complexity. Throughout the course of the project this team will be altered depending on the needs of the project. During the beginning phases of the job only the Field Engineer and Site Superintendent are on site every day. As time progresses and construction starts to pick up the rest of the project staff from the PM down move out to the field full time with the exception of the MEP Superintendent who splits his time between two different jobs. As time progresses the MEP Superintendent starts dedicating more time to the job and the Site Superintendent starts phasing out. By the time the job is about to be turned over the only two people dedicating all of their time to the job are the Project Admin and Field Engineer.

Project Schedule Summary

The project schedule on this job is of extreme importance. Although the entire job is scheduled to be completed in 3 years, Hess only has 18 months to construct a brand new school, so it is imperative that the project team not fall behind. The notice to proceed for this job was given on the 1st of December 2011, two months after it was supposed to, and the school must be complete and turned over in August for the 2013 school year.

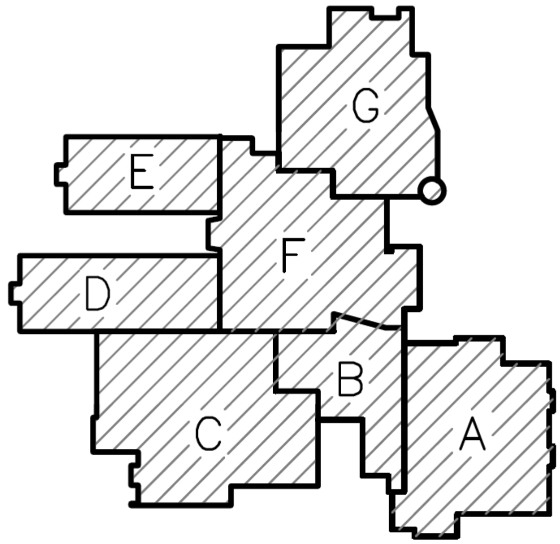


Figure 5: Building Section Breakdown

There are four major phases to this project. The first of which deals with the construction of the high schools building pad, football stadium, football field house, and tennis courts. This phase is scheduled to start at the notice to proceed and be completed in 240 days. The building pad preparation, rough grade and utilities are on the critical path and need to be completed in order to start foundations. In order to prepare the building pad the site had to be cleared of all existing features. This included the partial demolition of the existing gymnasium. Once the site was cleared, fill had to be brought on site and compacted to provide adequate bearing for the schools foundation. This whole process took approximately 65 days, at which point the foundation work began. The rest of the items mentioned in this phase are not on the critical path and therefore not as important to complete on time.

Phase 2 overlaps with phase 1 and relates to the construction of the school and the work associated with that task. In all, this phase is scheduled to take 385 days. The erection of the sub and superstructure are on the critical path followed by the enclosure, rough-ins, and finishes. Because of the size of the building there is substantial overlap between these activities so that multiple activities could occur simultaneously. The path of construction for this work went from section F to E, to D, to G, to C, to B, to A (reference Figure 5). This staggering can also be seen in the schedule for interiors; however there is much more overlap in different section of the building. Substantial completion for the new school is set for July 25th 2013, and final completion is set for September 20th 2013.

At the completion of phase 2 partial demolition of the existing school commences to make way for a new bus loop. Once this phase is complete phase 4 begins with the demolition of the rest of the building and a parking lot is placed on the footprint of the old school. When it is all said and done the whole project will be completed on July 25th 2014.

A detailed schedule of 150 line items can be seen in Appendix B. To keep the schedule concise only the most important and significant activities are listed.

Local Conditions

Soils and Subsurface Conditions

For this project GEOTECH ENGINEERS, INC. performed 37 test borings and soil laboratory tests in order to prepare a geotechnical report. It was found that the majority of the soils on-site were clays with a water table ranging from 12 to 17.7 feet below grade. Through these findings they recommended using controlled fill for the building support, compacted to at least 95 percent per ASTM D-1557. The existing grade of the proposed building footprint has an overall drop in elevation of 16 feet from elevation 185 to 169. The design elevation for the slab-on-grade is 184.4; this requires that a large quantity of fill be brought on site. All existing areas within the outline of the building foundation must be removed and replaced with suitable fill if the current grade elevation is above 176. Additionally any area where the existing soil is within five feet of the bottom of a footing it is to be undercut and replaced with control fill.

Parking

Figure 6: Arial View of Local Conditions

Figure 6 illustrates the existing conditions of the local geography of the site. To the east and south the site is bounded by residential neighborhoods. This poses a problem because the local municipality will not allow construction deliveries or parking to take place on these roads. The west provides no relief either because there is an interstate in the way. To solve the problem of access and parking to the site a new road, from the south, was installed. This road serves as both temporary parking for construction vehicles, and as the only means of access to and from the site.

Other

- To protect against frost perimeter footings should be placed at a minimum of 2.5 feet below the final exterior grade.
- Average tipping fees in Maryland run about $68/ton
- High crime rate area
    - Concerns about break ins and thefts

Site Plan for Existing Conditions

The existing conditions and site plans for this job can be seen in Appendix C. The access road to the south is the only means of transporting materials to and from the site. It also serves as parking for laborers.

The "Site Clearing and Building Pad Fill Site Plan" illustrates the initial layout of the construction fence and entrance gates. It also shows where the replacement school will be constructed and the key features of the site layout. At this point in time there are no designated vehicular paths due to the amount of site clearing that needs to be done.

The next site layout displays the plan for the foundation and SOG. At this point in the project the construction fence has been moved to create more room for construction activities. The portion of the new school that is faded illustrates the work that still needs to be completed. The area that is illuminated represents completed foundations and partial SOGs. At this point in the project access paths have been established. At the same time foundations are being installed on the west side of the site, wells are being drilled for the geothermal field in the east. It can also be seen that a portion of the existing school has been demolished and the gymnasium has been left in place so that it can be incorporated into the new school.

The final site plan shows the layout for the superstructure. It is at this time that a crawler crane is brought onto site and additional laydown areas are established. Due to a delay in the schedule a second smaller crane was brought on site to erect sections D and E. laydown areas for the cranes are placed both on the site near the building footprint and on the SOG. Because the foundations have been poured there is no longer vehicular access through the center of the building.

Building System Summary

The following information found on Table 1 describes key aspects of the design and construction of the building and its systems for this high school project.

Yes	No	Work Scope	If yes, address these questions / issues
x		Demolition	Types of materials, lead paint, or asbestos?
x		Structural Steel Framing	type of bracing, composite slab?, crane size / type / location(s)
x		Cast in Place Concrete	Horiz. and Vert. Formwork types, concrete placement methods
	x	Precast Concrete	Casting location, connection methods, crane size / type / location(s)
x		Mechanical System	Mech. Room locations, system type, types of distribution systems, types of fire suppression
x		Electrical System	size / capacity, redundancy
x		Masonry	Load bearing or veneer, connection details, scaffolding
x		Curtain wall	Materials included, construction methods, design responsibility
	x	Support of Excavation	Type of excavation support system, dewatering system, permanent vs. temporary

Table 1: Building System Summary

Demolition

There is a significant amount of demolition involved in this project, the majority of which will take place after the completion of the new school. Special considerations regarding asbestos abatement will have to be taken when demolishing the existing school structure which was erected in 1959, along with its several additions. However, the existing gymnasium which was completed in 2003 will remain and tie into the new high school.

Other Items to be demolished are the existing parking lots, football field/track, bus loop, and walkways. See highlighted items on figure 7 for visual representation of items to be demoed.

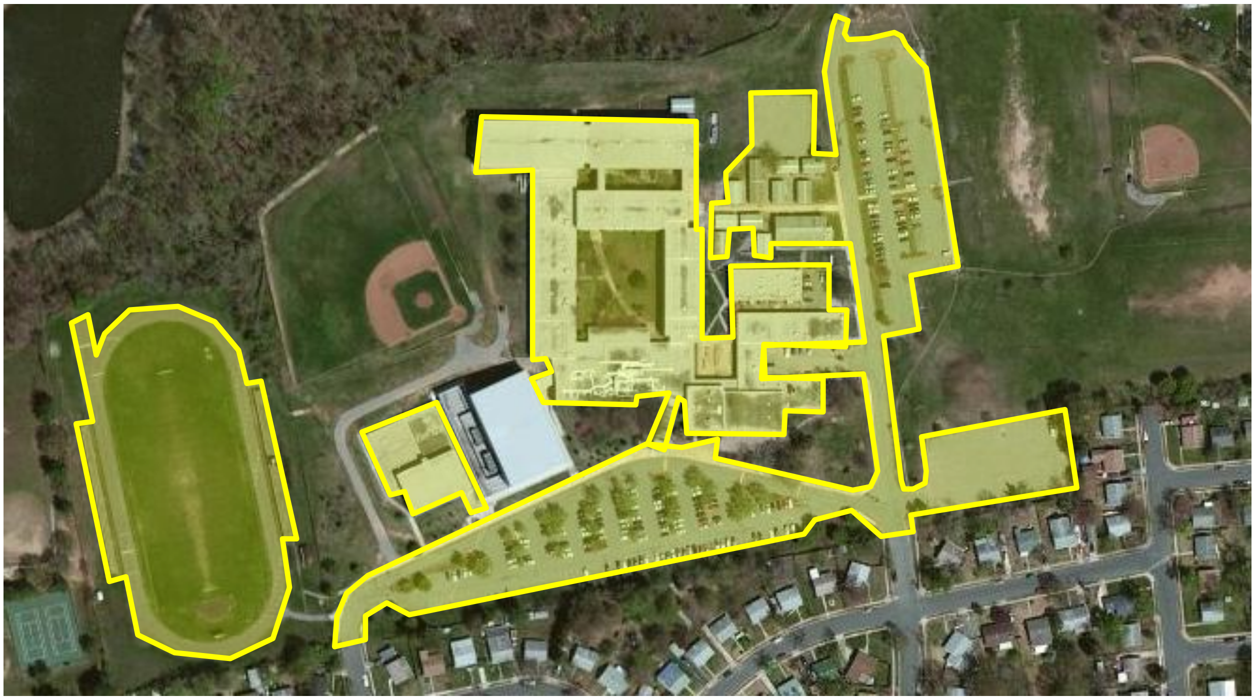


Figure 7: Demo Plan

Structural Steel Framing

The new high school is a combination of both CMU load bearing walls and structural steel. The columns for the building are hollow structural steel (HSS) members and wide flange beams supported by at least an 18" by 18" concrete pier on spread footings. Columns are spliced at the third floor level for areas D, E and F. All wide flange beams and girders conform to either ASTM A-572 or A-992 and are of grade 50 (50,000 KSI). Lateral structural steel support is accomplished through the use of cross bracing in 33 different locations and welded moment connections in four bays.

The floors-on-deck of the building are constructed of 3-1/4" light weight concrete on 2" galvanized composite steel deck with welded-wire-fabric, and shear studs. Roofs are comprised of 20 gauge 1-1/2" type B roof deck on K-Series and LH joists.

A 150 ton crawler crane was scheduled to place all structural steel for the building, but because of a loss of time in the schedule a second crane was brought on site to expedite construction. (Figure 8 depicts steel erection in section F)

Figure 8: Steel Erection in Section F

Cast in Place Concrete

All cast in place concrete used on this project is designed per ACI 318-05. Additionally all concrete is to have a compressive strength at 28 days of 4,000 psi.

On this project CIP concrete pours were achieved by direct pours and by utilizing concrete pump trucks. Normal weight concrete was used for the foundations, auditorium stage wall, and S.O.G., while light weight concrete was used for slab on deck. To form the auditorium wall interlocking panels were placed on an arced radius and temporarily braced (see Figure 9). All other formwork was site constructed out of plywood and 2x4's.

Figure 9: Auditorium Form Work @ Stage Wall

Mechanical System

The mechanical room for the high school is located on the first floor in the south west corner of the building. To ensure the building operates and performs as intended a Building Automation System (BAS) is used to observe and control the schools environment which is monitored both on and offsite. If communication with the system is ever lost the controller will revert to its inherent set points.

The mechanical room has nine 30 ton water to water heat pump modules to manage the four geothermal fields and two geothermal vaults of 437 combined wells all at a depth of 400 feet. The 12" supply and return pipes for this system travel over 1,600 feet each, from building stub up to geothermal vault. The fields encompass approximately 207,000 square feet and sit underneath the proposed football and baseball fields. In addition to the nine modules the mechanical room also houses 10 pumps, four expansion tanks, two gas-fired hot water boilers, and a slew of other equipment.

There are two Dedicated Outdoor Air Systems (DOAS) with a combined 28,170 CFM capacity that serve the north and south wings of the building. Each of these DOAS's have a heat recovery wheel and are connected to three indoor air handling units (one on each floor of the classroom wings.) In addition to this there are 17 separate rooftop air handling units, nine of which have energy recovery wheels. To ensure a healthy indoor air quality all outdoor air intakes have an airflow monitoring system to measure contaminants in the air. Air flow is distributed throughout the building in sheet metal ducts and zone controlled by VAV boxes.

Fire suppression for the school consists of an automatic sprinkler system with high temperature heads in conjunction with a heat and smoke detection system. In locations where duct penetrates fire rated walls fire-dampers are installed. The server room for the school (Rm. F-255) works on a pre-action fire protection system to make sure the system doesn't accidentally go off.

Electrical System

The main electrical room is located in the south west corner of the building and is fed from two separate 2,500 KVA pad mounted transformers supplied by PEPCO just outside the building. Each transformer ties into its own 3,000 amp 480/277 volt switchboard with ground fault protection. A backup generator is located in close proximity to the building to power emergency equipment in the event of a power outage.

Additional panelboards and step down transformers are located throughout the building to supply power to all necessary equipment.

Masonry

As was mentioned before, a large portion of this high school is constructed out of load bearing concrete masonry units (CMU's). Building sections A, B, C, and G are comprised almost entirely out of load bearing CMU walls. These walls range greatly in thickness depending on their location in the building. In some cases they serve as both structure and architectural façade. Much of the masonry units are placed off of scaffolding.

Curtain Wall

The exterior for the school is comprised primarily of ground-face CMU and several different styles of wall panels. Consideration was taken by the architect to pick materials that would complement the exterior façade of the existing gymnasium. Additionally there are a number of glazed curtain walls with different glazing provisions that relate to their orientation on the building. Due to the nature of the building façade, much of it will be installed off of scaffolding.

LEED

This project has been designed to achieve a LEED Gold rating by acquiring no less than 39 points under the US Green Building Councils LEED® Green Building Rating System ™ for New Construction. The majority of the projects points will be coming from Sustainable Sights and Indoor Environmental Quality. Several ways this rating will be achieved is by focusing on alternative transportation, water efficiency, reducing the heat island effect of the roof, recycling/managing construction waste, and using Low-Emitting Materials. One of the most significant features is the use of geothermal energy, which is the utilization of the earth's natural heat. Geothermal is an economical, pollution free and renewable source of heating and cooling. However, the building falls short of capturing any points for day lighting.

Constructability Challenges

The soil that the proposed replacement school will sit on had been found to be unsuitable material by the geotechnical engineer. The entire footprint of the building sat on moderately compressible fill that had been placed during the construction of the existing school. This meant that all of the existing soil had to be undercut and controlled fill had to be brought on site. Based on the geotechnical engineers recommendations the new fill had to be compacted to 95 percent of the maximum dry density as determined by ASTM D-1557. The way HESS overcame this was by monitoring the settlement with the use of settlement plates to insure that the soil would not settle excessively. This was a huge concern because even with the new fill, it was expected that the soil underneath it would still settle. The settlement plates were installed prior to fill placement and were monitored every day before and during fill placement and for three weeks after the completion of new fill. Foundations were not allowed to be placed during this time.

Another constructability challenge was that HESS was given a later than expected notice to proceed date. On top of that S.A. Halac the structural subcontractor showed up on site two weeks late, which further impacted the schedule. This was extremely important to overcome, because they were already working on a tight schedule, in which they had to get a 255,000 square foot high school built and occupied in 18 months. This required them to find ways to shorten the critical path because 7 months into the project they were behind schedule by a month and a half. The way they overcame this was by accelerating their steel contractor by requiring them to bring a second crane on site. This allowed for them to set steel in two different sections of the building simultaneously.

A third constructability challenge had to do with poor sequencing. When the schedule was originally created not enough consideration was taken concerning school functions and the summer school timetable. Operations such as temporary utility shut downs, road closures and specific construction activities had to be re-sequenced. The project staff overcame this by regularly meeting with the school to find times when they would be allowed to complete the necessary work outside of the original time frame.

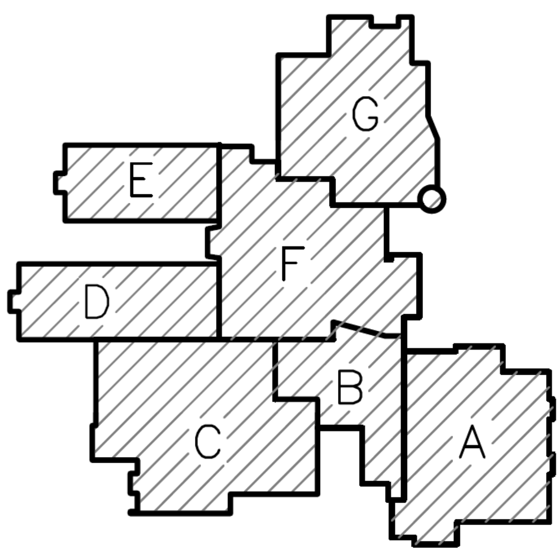


Figure 10: Building Layout

Value Engineering Topics

There were three notable instances of value engineering that were implemented on this job. They were a reduction in school size, a change in finishes, and a change to the telecom package.

The biggest and most significant VE change was the reduction in the size of the school. The school was initially designed to have three educational wings as can be seen in Figure 11, but one of the wings was omitted (reference Figure 12) so that the project could stay on budget. This seriously detracted from the goals of the owner because they wanted a school designed with population growth in mind, but it saved them $28 million. As the building stands right now, it will not be large enough to accommodate all of the students enrolled there. This means that the school will have to set up trailers to house the surplus of students. This was a large sacrifice that the owner had to make that they did not have control over.

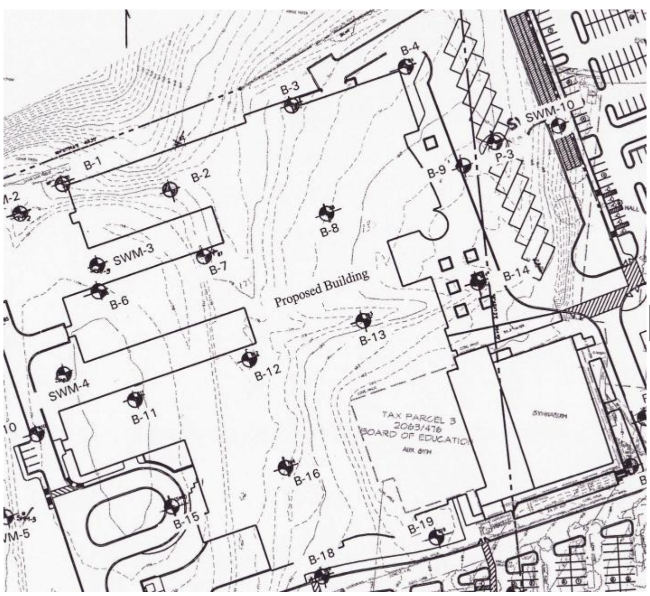


Figure 11: Original Building Footprint

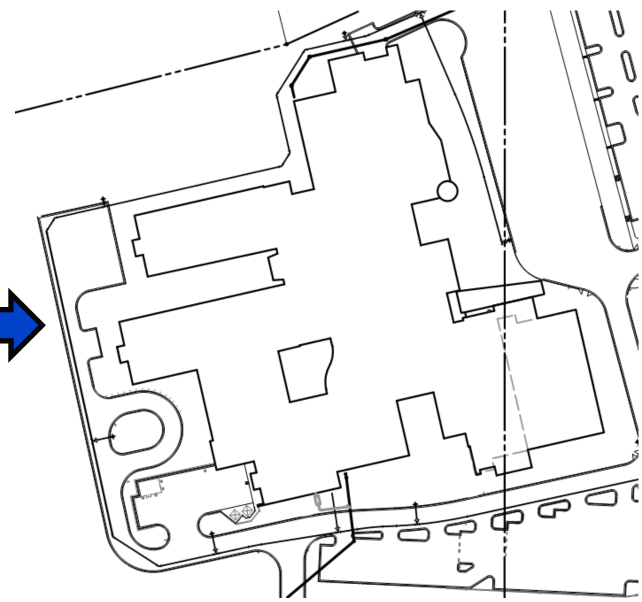


Figure 12: Revised Building Footprint

In another attempt to save money, some of the finishes were changed as well. For instance, instead of using custom casework throughout the school, the owner was forced to select casework with a more standard finish to stay on budget. This was also the case when selecting floor finishes. The owner was not very satisfied with having to make these decisions because they wanted the biggest, best, and nicest things for their school, but instead had to select a lesser product.

One more way the owner tried to reduce costs was by changing the scope of the telecom package for the building. Instead of having the contractor purchase and install all of the equipment, the school decided that they would buy their own equipment. The contractor is still responsible for roughing in all of the data wire, but not for supplying the equipment. Although this did not save the owner much it did negate the markup expense the contractor placed on the equipment.

It can be seen that adhering to the budget provided by the state caused a lot of VE implementation, all of which the owner was not very happy to have to do. The only VE change that was not accepted was the use of PVC sewer above grade in the building. The reason this was declined was because it was not code-compliant since the building has plenum ceiling spaces.

Technical Analysis #1 – Mechanical System

Problem Identification

In order to complete this project with the provided budget the owner had to value engineer out a lot of high end features and equipment that they wanted to keep. To address this I would suggest tweaking the current mechanical system because it has one of the most significant costs associated with the new high school. The current mechanical system is a geothermal system consisting of 437 wells all at a depth of 400 feet. By switching this to a hybrid geothermal system the owner will still get the benefits associated with geothermal wells, but should have money left over to add value to their building. This reduction in cost would be related to the need to drill fewer wells, which are very expensive.

Research Goal

The goal of this topic is to perform a value engineering analysis of the current mechanical system. To do this I will further investigate geothermal systems and hybrid geothermal systems. I will propose reducing the number of wells and modular geothermal heat pumps to reduce the costs of the mechanical system. To regain the loss in heating and cooling capacity that this will cause I will implement a cooling tower and boiler into the system. At this point I will determine if there are benefits associated with sizing down the geothermal fields and the implications that this would have. I will then perform life cycle cost analyses of the two systems to determine the validity of this approach. At this point, if there are any savings, I will determine what items they could be applied to that the owner had to value engineered out.

Research Steps

- Investigate the current geothermal well system
- Determine the size of cooling tower and boiler needed for a revised hybrid geothermal systems
- Redesign geothermal system by decreasing the number of wells and increasing the size of the mechanical equipment
- Contact project team for cost information
- Perform cost analysis
- Determine constructability issues and perform a payback period analysis

Resources and Tools to be used

- Hess Construction contacts
- Industry professionals
- RS Means
- Applicable literature & AE 404 notes
- Mechanical classmates
- AE department faculty

Preliminary Research

Hybrid geothermal systems are sometimes capable of providing an owner a more cost effective system than a strictly geothermal system depending on the geographical location and load requirements for a building. This is because strictly geothermal systems are most efficient when the differences between the peak cooling and heating loads are within 10% of each other. When they are not it is more practical to supplement a portion of the peak cooling or heating load with a cooling tower or boiler, depending on which one controls.

A reason that some owners may shy away from a hybrid system is because they might be worried about compromising on environmental benefits. However it is important to note that choosing a hybrid system does not sacrifice the environmental benefits of a fully geothermal system because the equipment does not operate frequently. Instead, the supplemental equipment typically only runs during rare circumstances.

Figure 14 shows three case studies in which the rate of return for hybrid geothermal systems was faster than that of fully geothermal systems. This makes sense when one considers Figure 13 which depicts the first cost of a geothermal system, hybrid system, and a conventional HVAC system. By reducing the number of wells, which are very expensive, the overall cost of the system can be dramatically reduced.

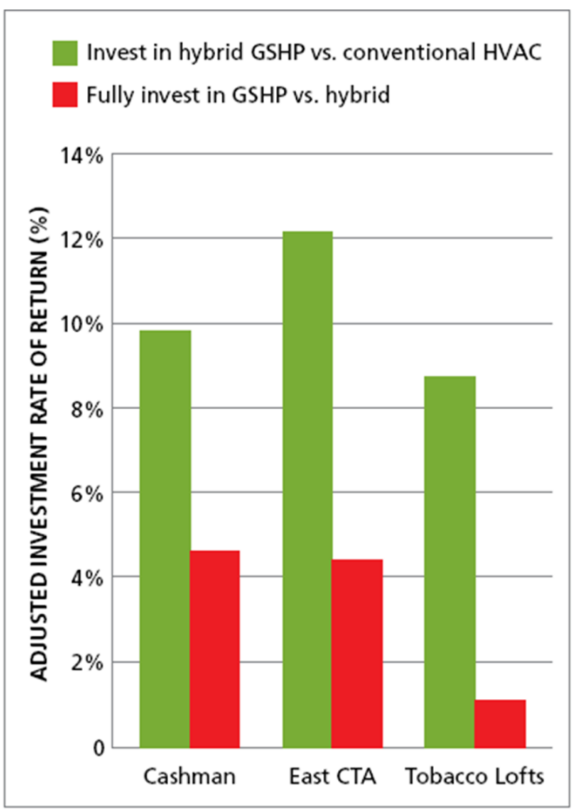


Figure 14: The Economics of Hybrid Systems

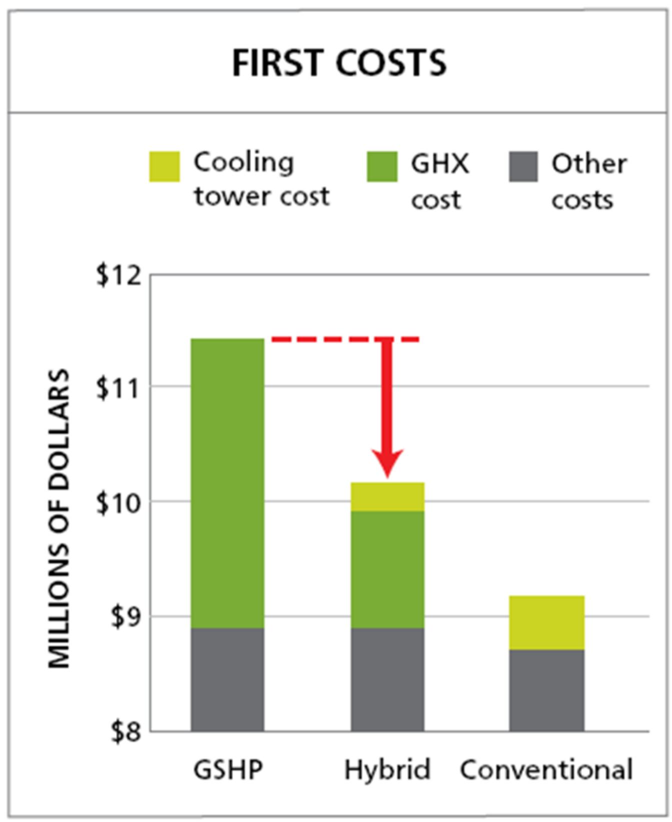


Figure 13: First Cost Comparison

Findings from Ensuing Breadths

- Cost Savings from reduction of wells: **$1,420,250**
- Cost of Cooling Tower (Including Shipping): **$68,005**
    - Running Cost for a typical year: **$5,846.70**
    - Yearly Maintenance Cost: **$823**
- Cost of Structural Redesign: **$4,896.60**
- Cooling Tower Operating Weight: **25,333 lbs.**
- Cooling Tower Shipping Weight: **11,664 lbs.**

Payback Period

Table 2 depicts the difference in cost between the two systems. Because the TRANE TRACE 700 modeling software could not model a geothermal system it was not possible to determine the difference between the yearly running and maintenance cost of the geothermal wells for the two systems. For this reason it was assumed that the costs associated with the wells would be the same. In reality it is likely that the cost of running the geothermal wells for the hybrid system would be lower because the pumps would be required to do less work, but the maintenance cost would be about the same. The hybrid geothermal system includes the cost of the structural redesign, the cooling tower and its yearly running and maintenance costs.

System	Cost of Wells	Cost of Cooling Tower	Difference in Yearly Running Costs	Difference in Maintenace Costs	Difference in Structural Cost
Fully Geothermal	$2,840,500.00	-	-	-	-
Hybrid Geothermal	$1,420,250.00	$68,005.00	$5,846.70	$823.00	$4,896.60

Table 2: Cost Difference between Systems

Based on this information the total first cost for the Fully Geothermal system is **$2,840,500**, and the first cost of the hybrid system is **$1,493,151.60** (price includes wells, cooling tower, and structural redesign). Each year the hybrid geothermal system would cost **$6,669.70** more to operate than the current system. Based on this it would take just over 202 years until the fully geothermal system would prove to be the more economical system (see figure 15).

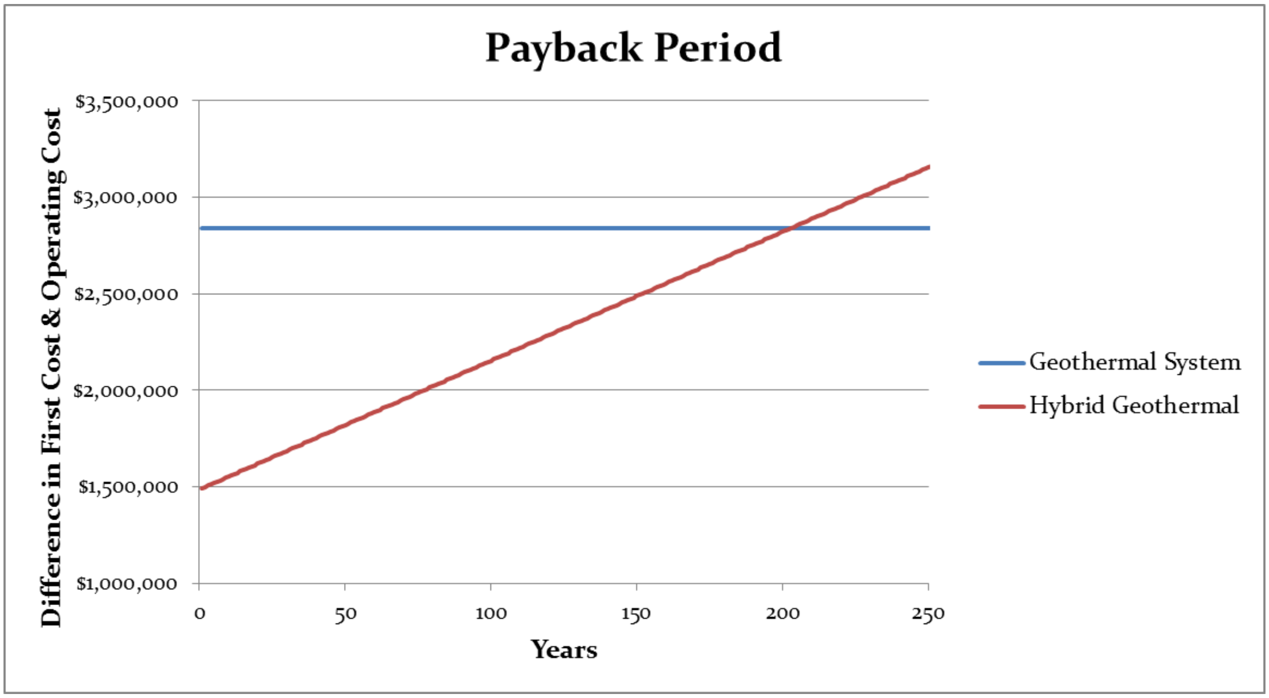


Figure 15: Hybrid vs. Geothermal Payback Period

Constructability

On the current schedule there are seven months dedicated to geothermal well drilling. By reducing the number of wells by half three months can be saved on this operation. This means that construction on the baseball, softball and football fields can start sooner. It is important to note that these items are not on the critical path so they will not affect the completion of the building. Additionally, because the fields are so far away from where the school is being constructed there would be no benefit seen from less site congestion (see Figure 16).

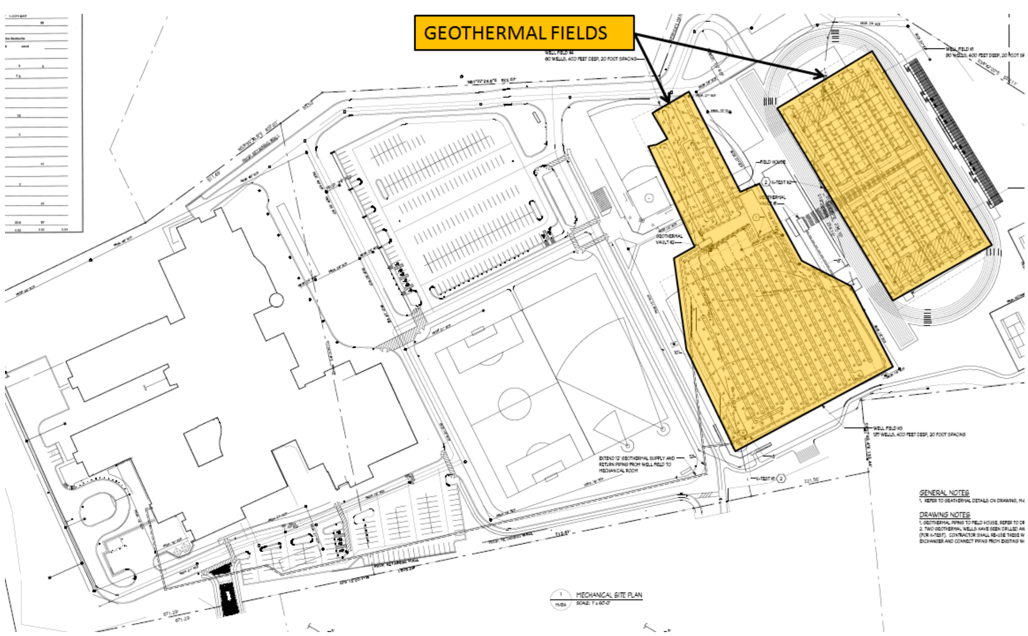


Figure 16: Current Geothermal Fields

Another concern associated with a hybrid system is the additional structural concerns associated with putting a cooling tower on the roof of the mechanical room. The actual process of placing the cooling tower does not pose a concern because the tower weighs less than 6 tons and there is a 150 ton crane already on site. Figure 17 shows the proposed location of the cooling tower. The tower is placed on the roof of the mechanical room so that it can be easily tied into the existing system.

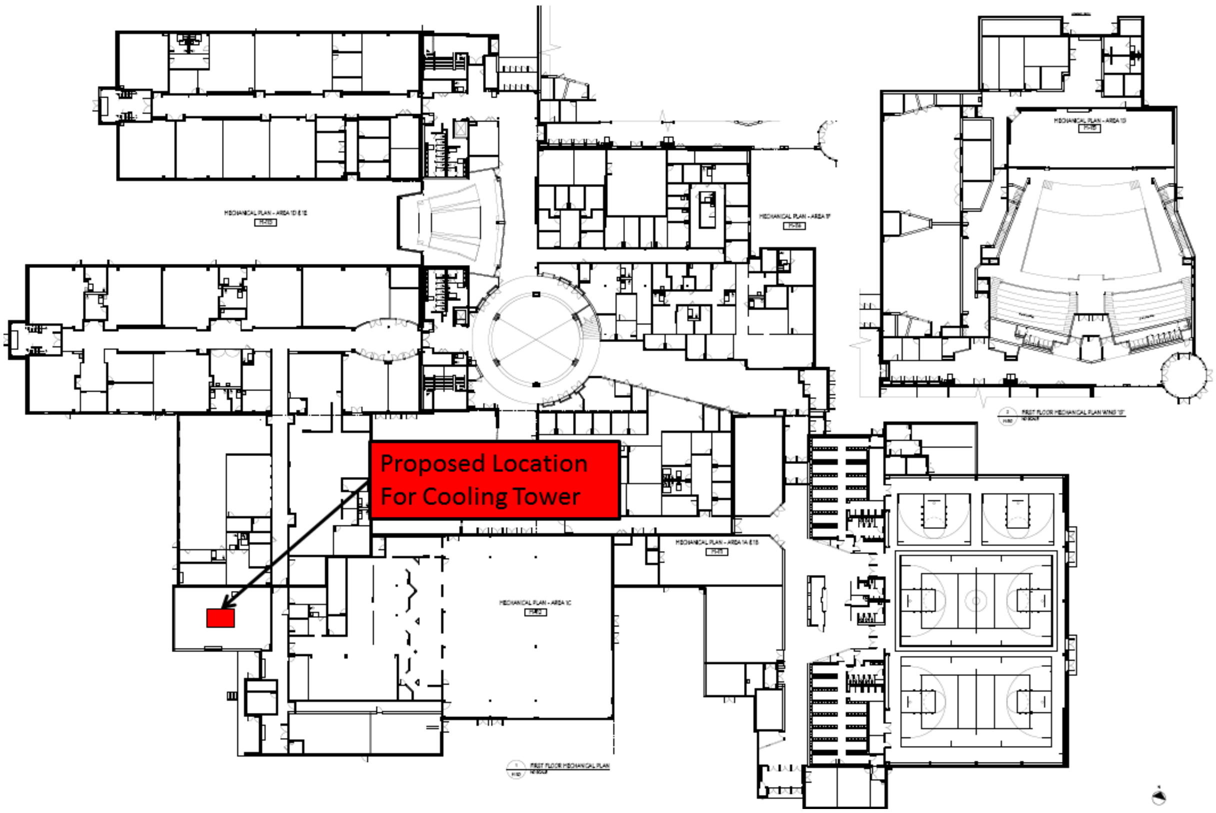


Figure 17: Proposed Location of Cooling Tower

Conclusion

Based on all of the provided information and the results found during the mechanical and structural breadth it is advised that a hybrid geothermal system be utilized on this project. PGCPS would benefit from an upfront savings of **$1,347,348.40** which they could use to invest back into the school. If they were to set aside $500,000 of this savings they would have $847,348.40 left over to spend on the telecom package, the custom casework they wanted, and nicer finishes and the hybrid system would still be more cost efficient up until 75 years.

This $847,000 could also be used to cover the cost of the artificial turf football field which was bid as an alternate and came in at $680,000.

The findings of this analysis suggest that a strictly geothermal system at this site is not the most practical design for the geographical location and that a hybrid system would be more efficient.

Mechanical Breadth

Current System Analysis

As previously mentioned the existing mechanical design for the school utilizes a vast geothermal well system. The well fields consist of 437 wells with a depth of 400 feet each with extensive lateral runs. Given that the soil conditions are sandy/silty soils, it is assumed that each well will offset a capacity of 1.6 tons of heating/cooling. Therefore, it is assumed that the well field will supplement approximately 700 tons.

With regards to mechanical equipment, the building utilizes nine 30 ton heat pump modules, which is the primary source of heating and cooling generation. Additionally there are nine exterior air handling units equipped with their own internal heat pump units to meet the varying heating and cooling requirements of their respective zones. The combination of these two heat pump configurations comprises a total of 342.2 tons of heating and cooling generation for the building. Although they do not make up any significant amount of thermal generation, it should also be noted that the building design also contains two packaged rooftop electric cooling units (12.3 tons), one small water source heat pump (3.2 tons), and one split system air-cooled computer room A/C ("CRAC") unit (3.7 tons).

To analyze the mechanical requirements of the design, an energy model was created using the Trane TRACE 700 modeling software. This was done to determine the ratio of the heating to cooling load demand. With this information it is possible to determine the practicality of implementing such an extensive and costly geothermal well field.

The following procedures and assumptions were made in the calculation of the building load and energy consumption:

1. The building was broken up into 9 large zones based on use and conditioning requirements (see Figure 18):

    101. Gym – Existing Mechanical System To Remain (not included in energy model)
    102. Cafeteria
    103. Kitchen Labs
    104. Classroom Wing 1
    105. Classroom Wing 2
    106. Lecture Hall
    107. Transition Spaces (All Corridors, Lobbies, and Open Gathering Spaces)
    108. Administration (Offices)
    109. Auditorium

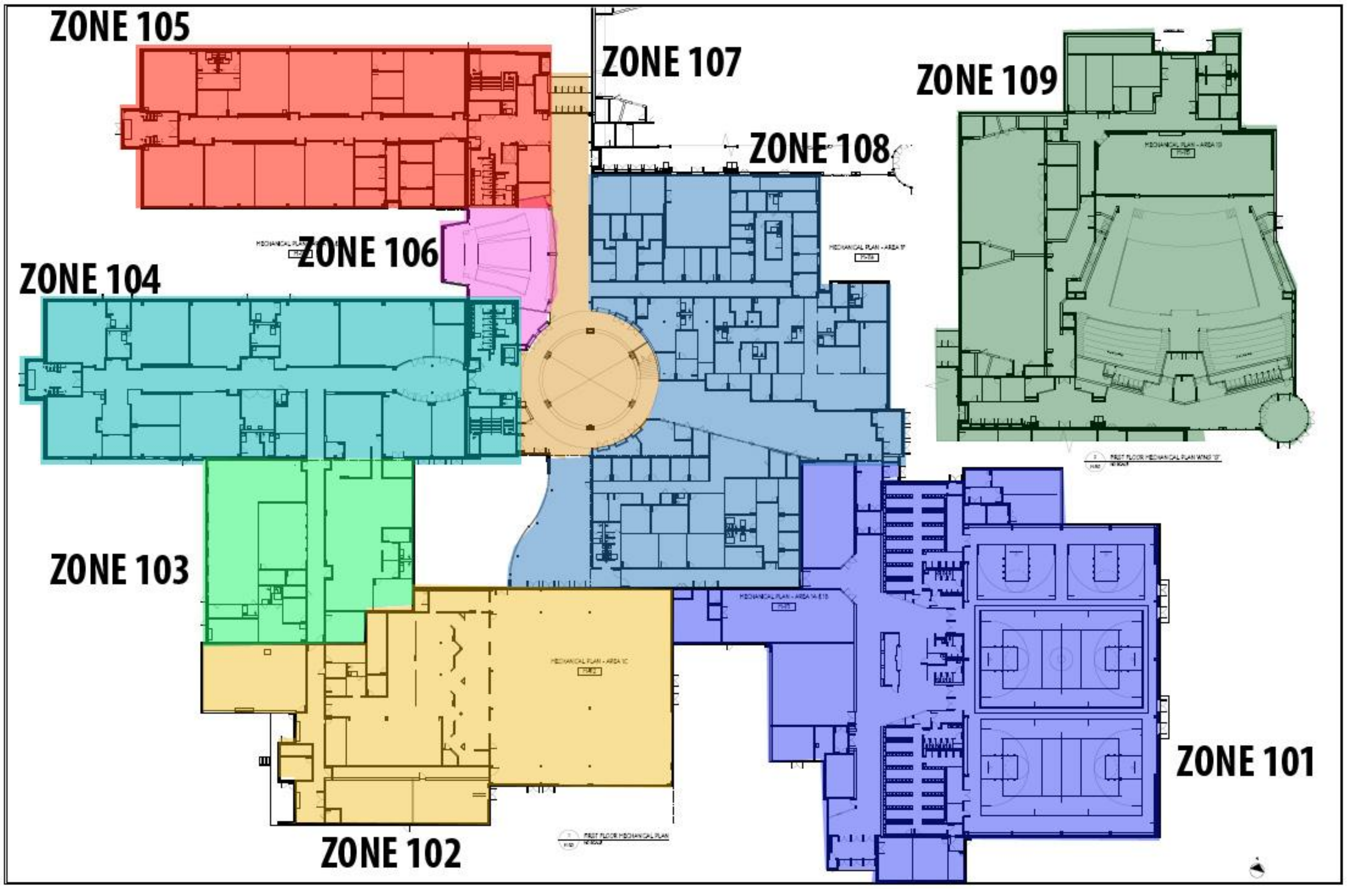


Figure 18: Building Broken Up into Zones

2. Take offs from the existing drawings were made for each of the respective zones to include:
    a. Floor Area (SF)
    b. Roof Area (SF)
    c. Wall Area (SF) and Orientation (off by a factor of 24 degrees East of South)
        i. North
        ii. South
        iii. East
        iv. West
    d. Floor Heights
    e. Occupancy density

See Table 3

Takeoffs													
#	Zone Name	Building Pieces	Floor (sf)	N	E	S	W	Flat Roof	Roof	Height	Occ	# Extra Floors	Multi Story SF
101	Gym	I-A,B	37700	4972	6537	6076	10608	20593	17033	43.4			
102	Cafeteria	II-C	19355	4973	1227	13826	1582	12590	9870	16	1397		
103	Kitchen	III-C	10343	-	5095	-	1583	10343		16	127		
104	Classrooms	III-D	20657	10455	1814	10826	3747	20657	-	45.4	1134	2	41314
105	Classrooms	IV-E	15980	9360	2514	7601	3747	15980	-	45.4	918	2	31960
106	Lecture Hall	N/A	2815	-	-	-	2064	2815		45.4	230		
107	Transition	Centrla Core & Atrium	5746	1813	-	434	1537	5746		45.4	120	2	11492
108	Admin	V-B,F	26638	3368	8973	1790	-	22048	9291	35	385		
109	Auditorium	V1-G	31176	7336	7475	-	6271	7298	7856	51	1587		

Table 3: Building Takeoffs

3. This information was then input to the Trane Trace 700 energy modeling software utilizing the weather data for Washington, DC. This was found to be the closest region with comparable weather data for the location of the facility.

4. The data was then input for the ventilation and internal load requirements specific to each room. This was done using baseline values from ASHRAE Tables 90.1 and 62.1 (see Appendix D) in conjunction with the prescribed alterations defined in the existing mechanical drawings (See Table 4).

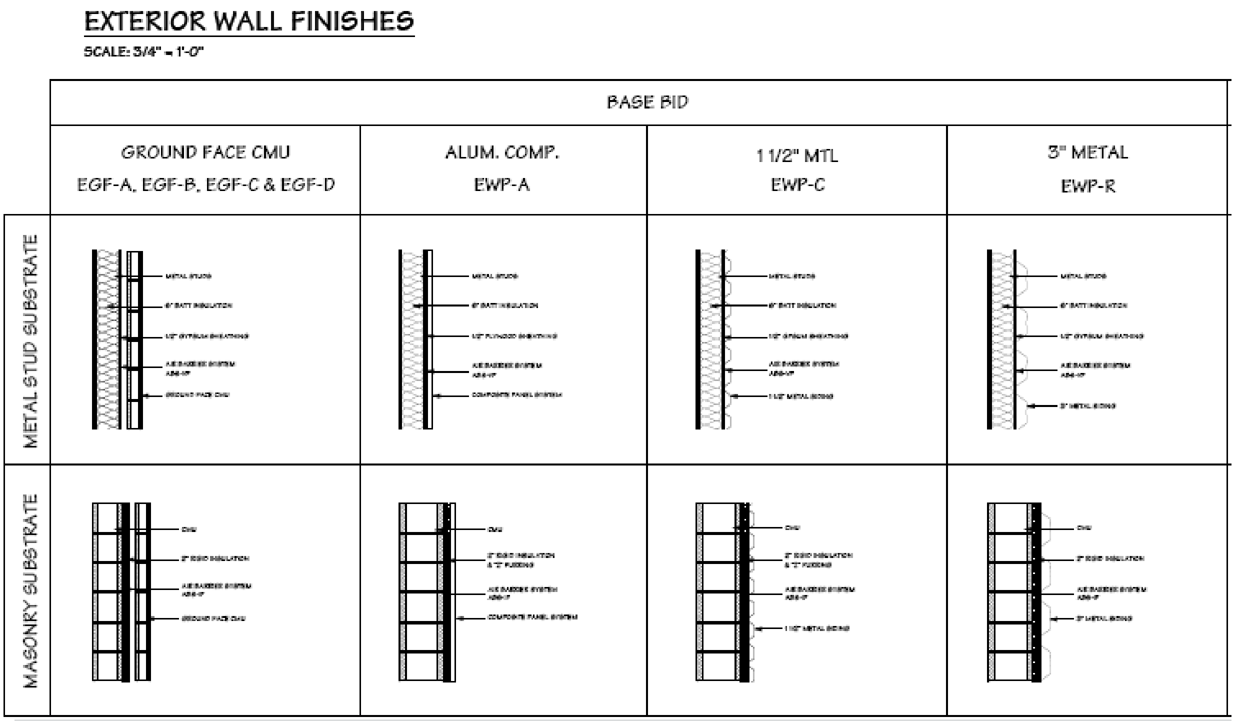
PROJECT REQUIREMENTS - HVAC AND LIGHTING LEED

ITEM	INPUT NOTES	SPATIAL TYPE OR ZON ADMIN. AREA	CLASSROOM	CAFETERIA	GYMNASIUM	AUDITORIUM	SCIENCE CLASSROOMS	KITCHEN	MULTI-PURPOSE ROOMS	TV STUDIO	COMPUTER LAB	TELECOM CLOSET	PROJECT NOTES
SPACE TEMPERATURE LOCAL STAT ADJUSTMENT SETPOINT ADJUST LIMIT	1	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 78°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 76°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 75°F Y Y +/- 2°F +/- 2°F	HTG 70°F; CLG 75°F Y Y +/- 2°F +/- 2°F	HTG 66°F; CLG 72°F Y Y +/- 2°F +/- 2°F	
SPACE HUMIDITY	2	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	50% + 10%	
PRESSURE RELATIONSHIPS	3						NEGATIVE PRESSURE	KITCHEN WILL BE EXHAUSTED	+/- 2°F +/- 2°F				
FILTRATION	4	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	NOTE 2	
OUTSIDE AIR / VENTILATION RATES	5	20 CFM PER PERSON	20 CFM PER PERSON	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	CODE OR LEED REQUIREMENTS	
SOUND AND NOISE LEVELS	6	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	NOTE 1	
OCCUPACNY SCHEDULE	7	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	NOTE 3	
OCCUPANT ACCESS TO OVERRIDE UNOCCUPIED MODE	8	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
SPECIAL HEATING / COOLING OPERATING REQUIREMENTS	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
SPECIAL EXHAUST REQUIREMENTS	10												
LIGHTING CONTROLS	11	N	OS	N/A	N/A		OS	N/A	OS	N/A	OS	N/A	

PROJECT NOTES:
1. DOCUMENT UNUSUAL NOISE AND/OR VIBRATIONS DURING PERFORMANCE VERIFICATION PHASE.
2. PROVIDE MERV 13 FILTERS FOR ALL UNITS SERVING REGULARLY OCCUPIED AREAS.
3. OCCUPANCY SCHEDULE DEPENDS ON AFTER SCHOOL ACTIVITIES. WEEKDAY AND WEEKEND SCHEDULES WILL HAVE TO BE ADJUSTED.
4. PROVIDE CONTROLS FOR AUTOMATIC TURN-OFF OF NON-EMERGENCY INTERIOR LIGHTING DURING NON-BUSINESS HOURS.

Table 4: Project Specific Ventilation Requirements

5. The envelope of the building was then translated into the energy modeling software. The existing wall types (as shown in Fig 19) were used to calculate the thermal integrity of the design.



Corresponding U Values

	Ground Face CMU	Alum. Comp.	1 1/2" MTL	3" Mtl
Metal Stud Substrate	0.04143	0.04347	0.04124	0.03985
Masonry Substrate	0.08424	0.08423	0.08123	0.07965

Figure 19: Envelope Wall Types

In comparing these values with the Minimum requirements for wall types in Zone 4 (Shown in Figure 20) it is clear to see that the existing wall types greatly surpass these minimum requirements and as such will not need to be improved.

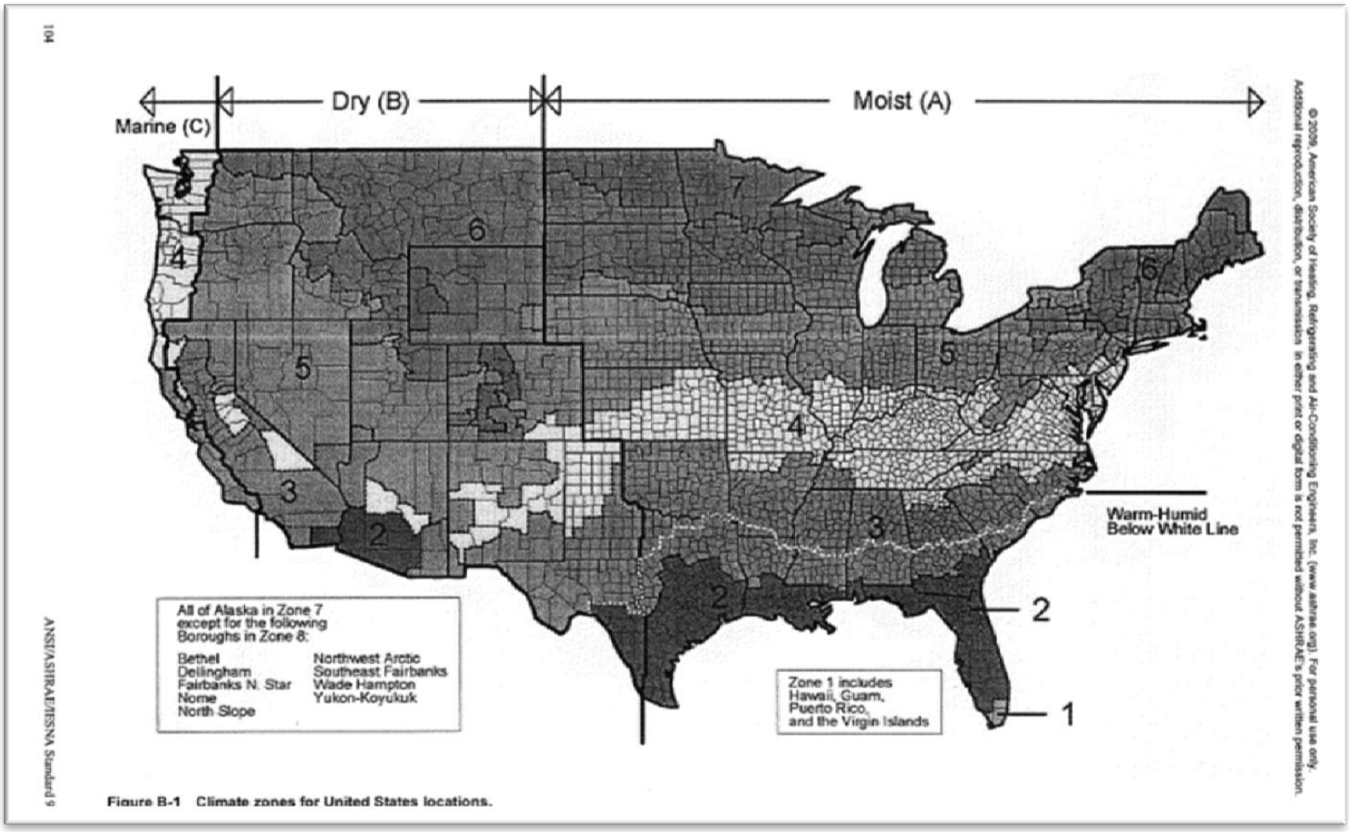


Figure 20: Zone Type by Geographic Location

6. The system of the building was then modeled to generate the basic load calculations. A system with a boiler for heating and air-water chiller for cooling was selected because Trace700 does not have any system settings for geothermal wells. It was found that the utilization of this configuration generated accurate building demand/load results. Additionally, heat recovery wheels were modeled in the air handling units to compensate for a minor reduction in building load. This was done to maintain accuracy with the existing system which has implemented a basic heat recovery wheel in each air handler.

7. The following results were generated by the model. The ratio of which can be seen by Figure 21.

   i. Total Peak Heating Load: **275 tons**
   ii. Total Peak Cooling Load: **738 tons**

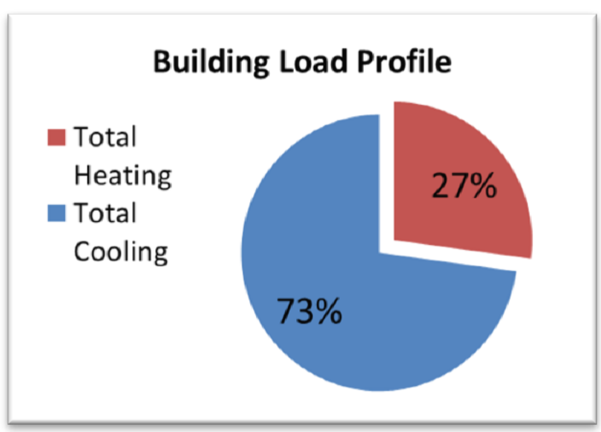


Figure 21: Building Load Profile

8. In comparing this with the installed mechanical equipment design it was found that the energy model created was within a 2-3 % error range as shown by Table 5

Total Cooling Capacity Installed(Geothermal+Equipment)	718.47
Trace700 Building Cooling Load Profile	738
% Deviation	**2.72**

Table 5: Installed vs. Modeled Cooling Deviation

9. Since the cooling demand load greatly exceeds the heating load requirements it is clear that the cooling load controlled in the design of the current geothermal system. The following breakdown of the cooling load was created to determine the amount of cooling being supplemented by the use of the 437 geothermal wells in conjunction with the installed equipment.

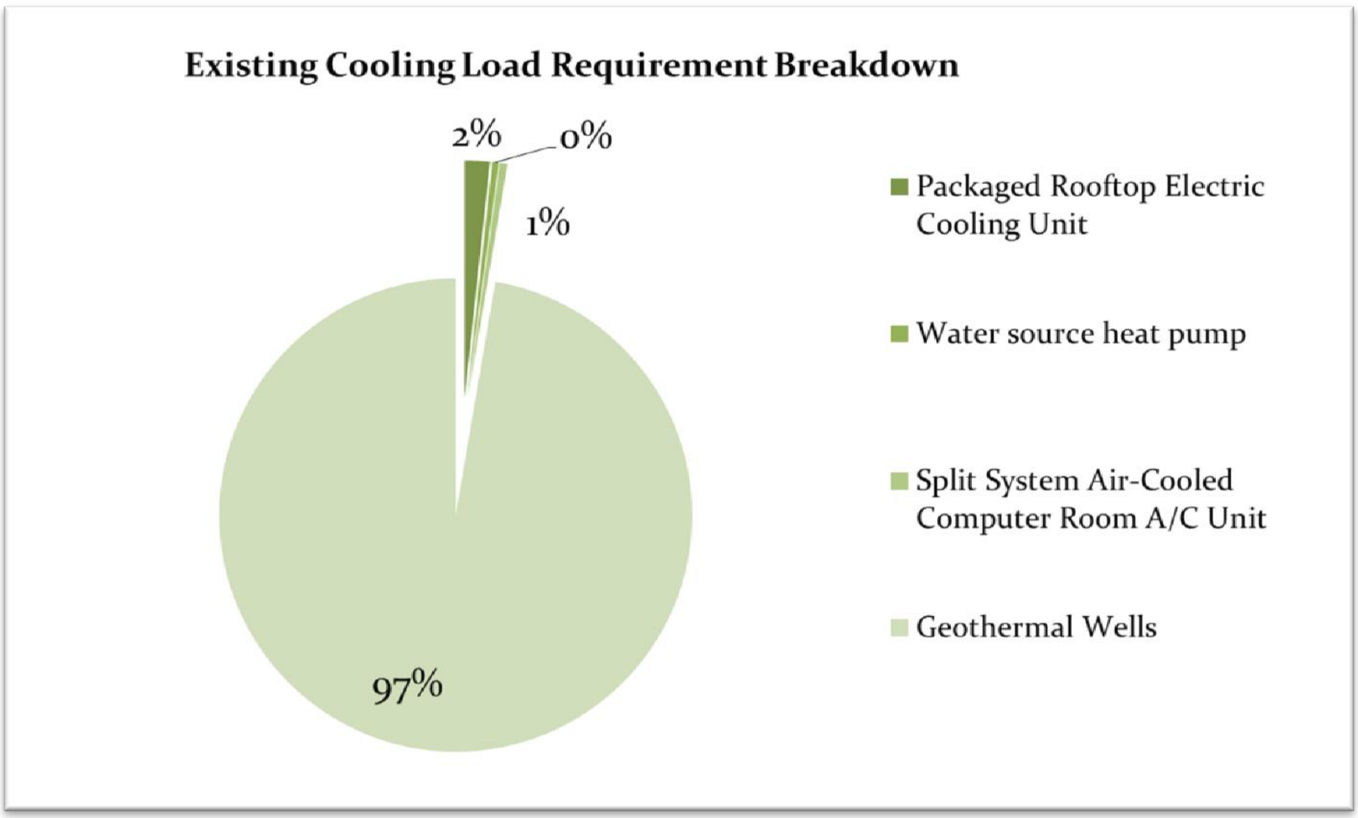


Figure 22 Existing Cooling Load Requirement Breakdown by Equipment

Mechanical Redesign

Given the data collected above, it is suggested that a reconfiguration of the mechanical system be implemented to optimize the system efficiency while controlling first cost. The designed geothermal well system contains 437 wells at an installed price of $6,500 a well, resulting in a total upfront cost of $2,840,500. To help alleviate the financial restrictions associated with the project, it is proposed that a Hybrid geothermal system be used in place of the existing system to reduce upfront cost, while still providing an efficient, environmentally friendly solution.

To achieve an appropriate redesign of this system it is recommended that the geothermal well fields be sized such that the heating and cooling loads offset by the wells are comparable. The remaining cooling load will then be supplemented by the installation of a cooling tower on the roof of the mechanical room. To determine an optimum ratio of heating to cooling the Trane Trace 700 energy model outputs were used to determine the typical weekly loads and peak load demand per month (see Figures 23 & 24) In comparing the heating and cooling load variation per month, it is determined that the new geothermal well field be sized to supplement 350 tons of cooling. This results in a 50% reduction in geothermal wells which saves approximately $1,420,250 in upfront costs. Additionally as is shown by Figure 24, this configuration will be effective for the majority of days during a typical year. It can thus be assumed, that even in a worst case scenario, that the new cooling tower will only be used during the months of May through September.

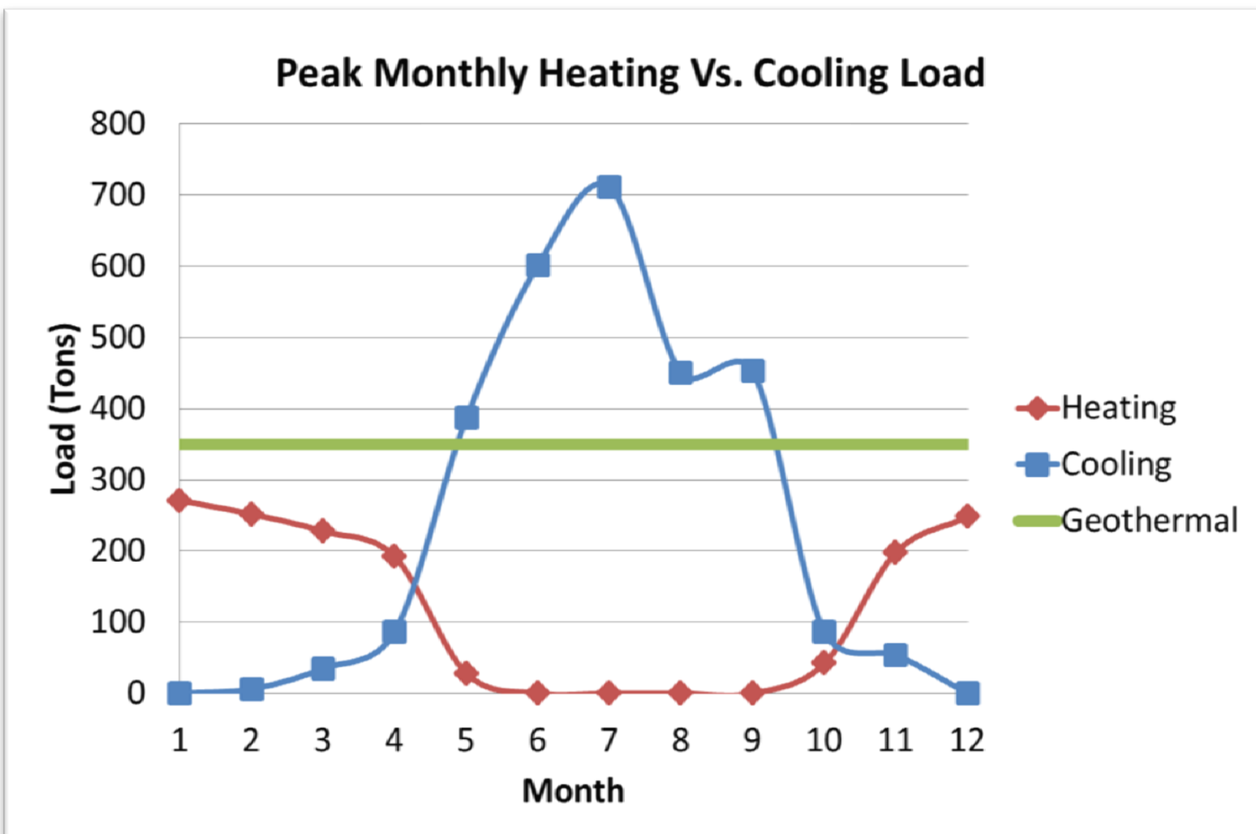


Figure 23: Peak Monthly Heating vs. Cooling Load

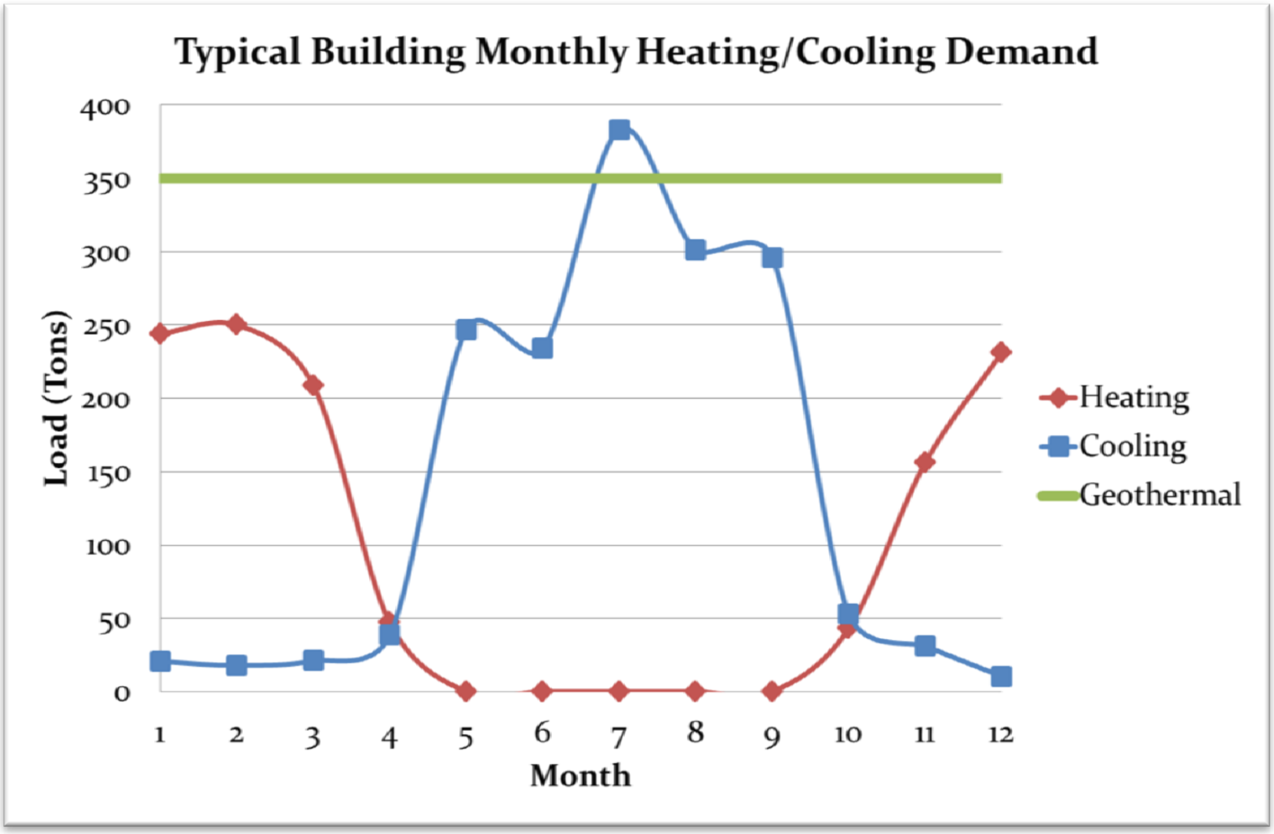


Figure 24: Typical Building Monthly Heating & Cooling Demand

This redesign results in a new building load profile that is depicted in figure 25. This design is much more efficient than the existing one because the heating and cooling loads are within the 10% range previously mentioned.

After determining the geothermal design capacity, a 352 ton cooling tower was selected to supplement the remaining cooling load. A Marley NC8407M-`1 steel cooling tower was selected to calculate the energy and payback values for the system redesign and structural breadth. (See page 34)

Based on the performance characteristics found on the spec sheet in Appendix E and the typical running expectations it was found that this cooling tower will cost $5,846.70 to run each year assuming a utility rate of 13¢/kWh and cost an additional $823/year to maintain.

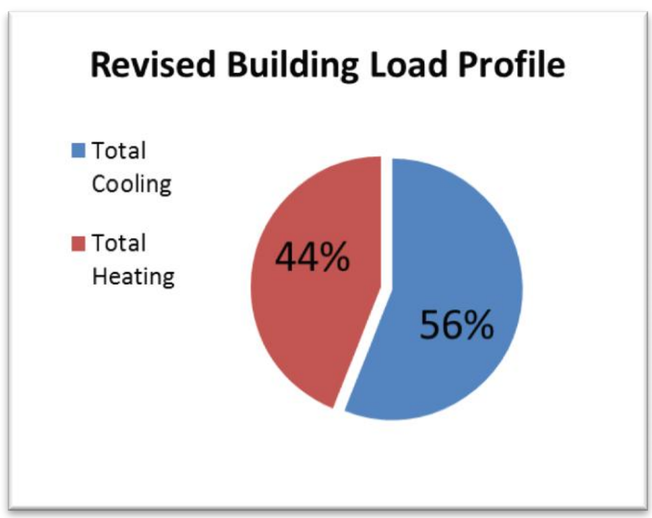


Figure 25: Revised Building Load Profile

Structural Breadth

Description/Steps Taken

The first step of this breadth was determining the existing structural layout of the roof over the mechanical room which can be seen in figure 26. The room is 36' by 54' and enclosed by 12" reinforced CMU block. The roof of the room is supported by 26K9 joists spaced at 6' o.c. with 1.5" type B, 18 gauge roof deck.

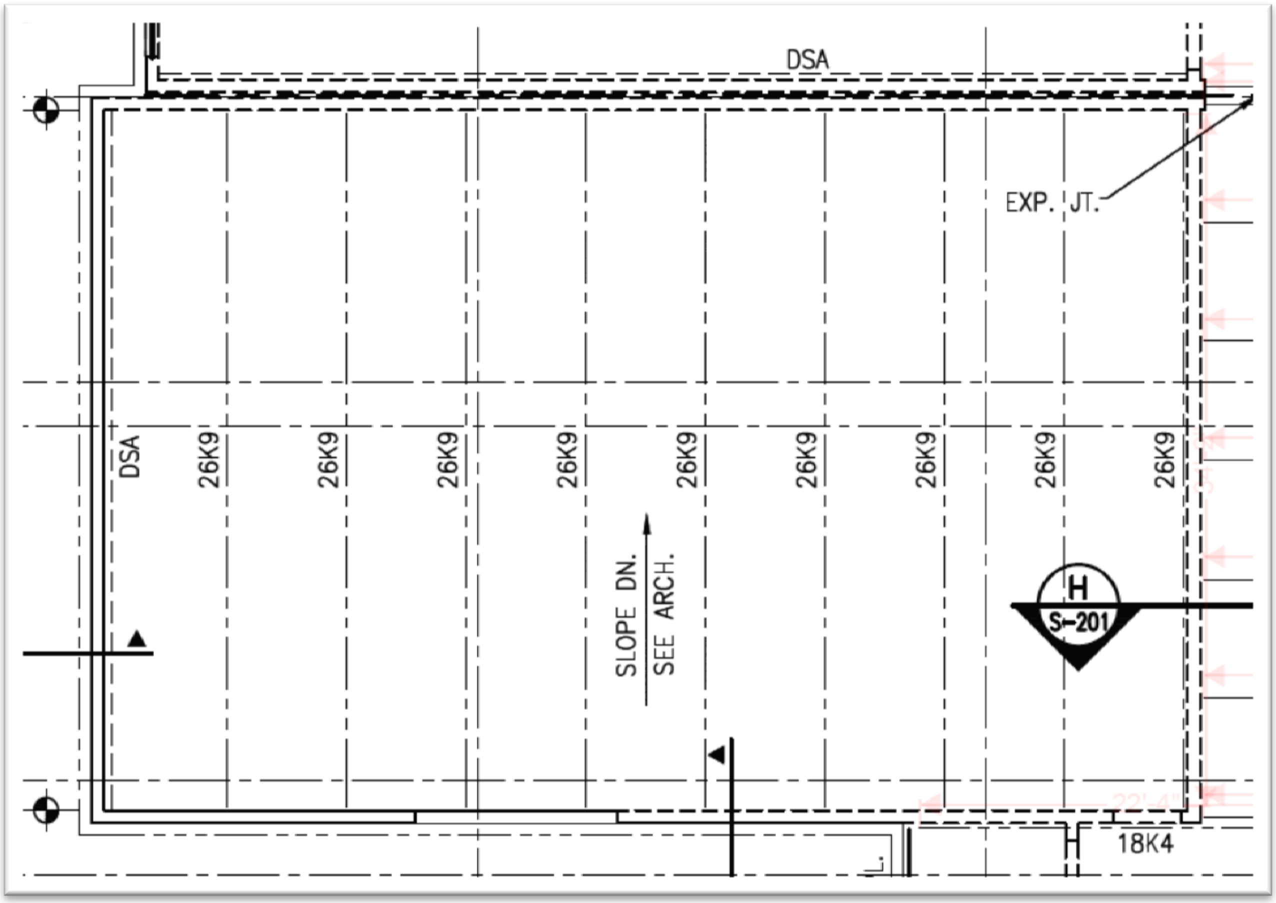


Figure 26: Existing Structural Roof Framing

The next step was determining the loads of the existing roof. It is a built-up-roof so 20 pounds per square foot was assumed for the dead load with an additional 10 pounds for miscellaneous items (i.e. ductwork, lights, plumbing, etc.). According to the structural drawings the snow load for the roof was 19.3 pounds and the roof live load was 30 lbs. This meant that the live load would control for the calculations performed on the attached pages.

After determining the size and weight of the selected cooling tower (12' x 21' and 25,333lbs) it was determined that the current structural system would not be adequate in supporting the load and several of the trusses would have to be removed and replaced with wide flange beams.

The Vulcraft Product Information from AE 404 was consulted to determine the maximum allowable spacing of the beams based off of the current roof deck. Based on the catalogs, for a three span condition, the 18 gauge Type B roof deck could hold an ultimate weight of 66 pounds at a span of 9 feet. The current ultimate roof load is 60 pounds so this span was determined to be acceptable.

At this point the roof structure was redesigned by removing four joists and replacing them with 3 girders. Calculations were run to determine the size of the girders (see calculations section). Based off of the placement of the cooling tower it was determined that (1) W16x31, (2) W14x30, and (2) W8x10 were needed to support the cooling tower. For simplicity, and because there is very little difference in cost ($2/LF) it was decided to use three W16x31 beams and eliminate the two W14x30's. A cost of the described members and subsequent redesign cost can be seen in Table 6.

Structural Redesign Cost				
Member	**Quantity**	**LF**	**Cost/LF**	**Total Cost**
W16x31	3	36	$56.50	$6,102.00
W14x30	0	36	$54.50	$0.00
W8x10	2	21	$26.50	$1,113.00
26K9	-4	36	$16.10	-$2,318.40
		Redesign Cost:		**$4,896.60**

Table 6: Structural Redesign Cost

Structural Calculations

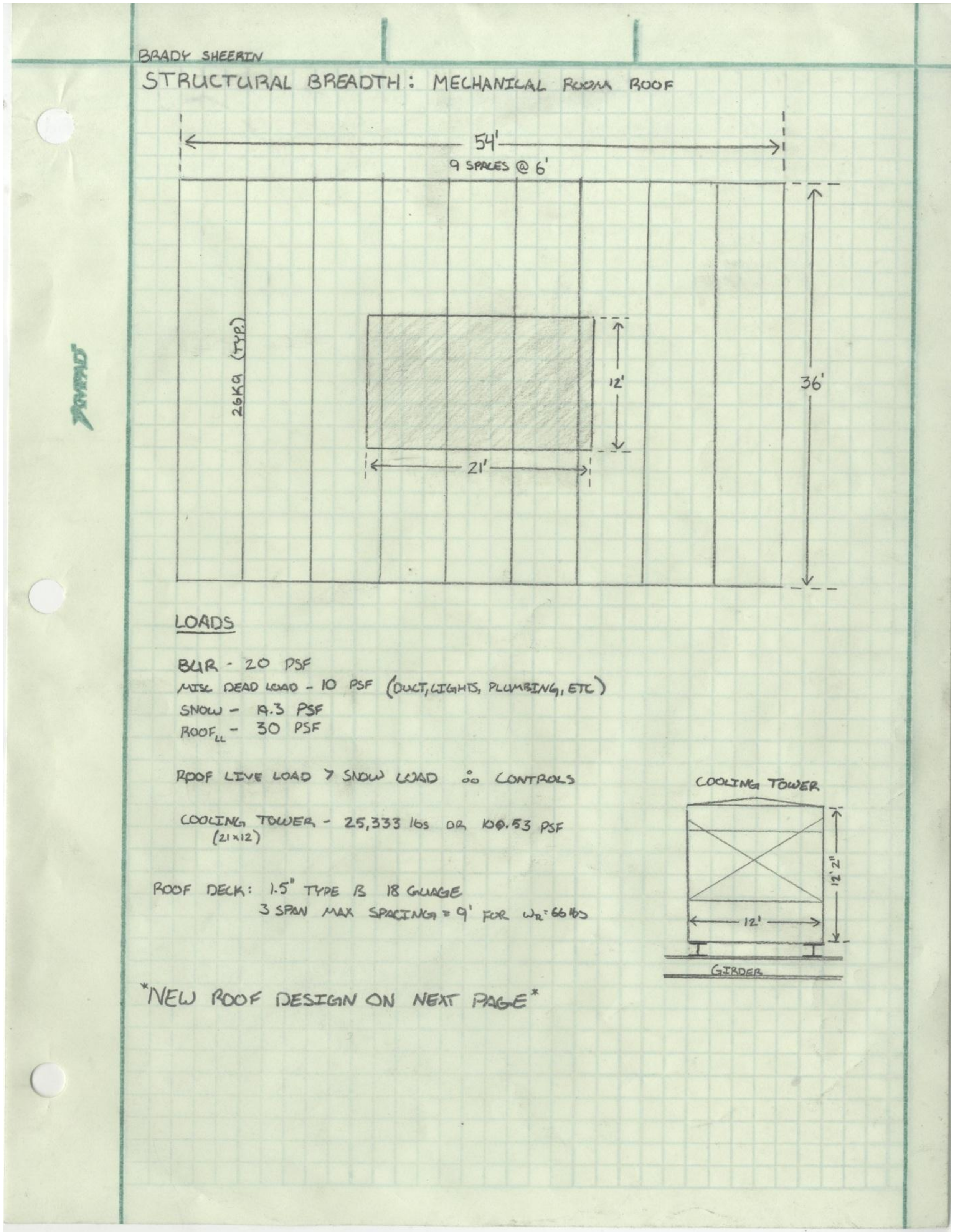


Figure 27: Structural Calculations Page 1 of 4

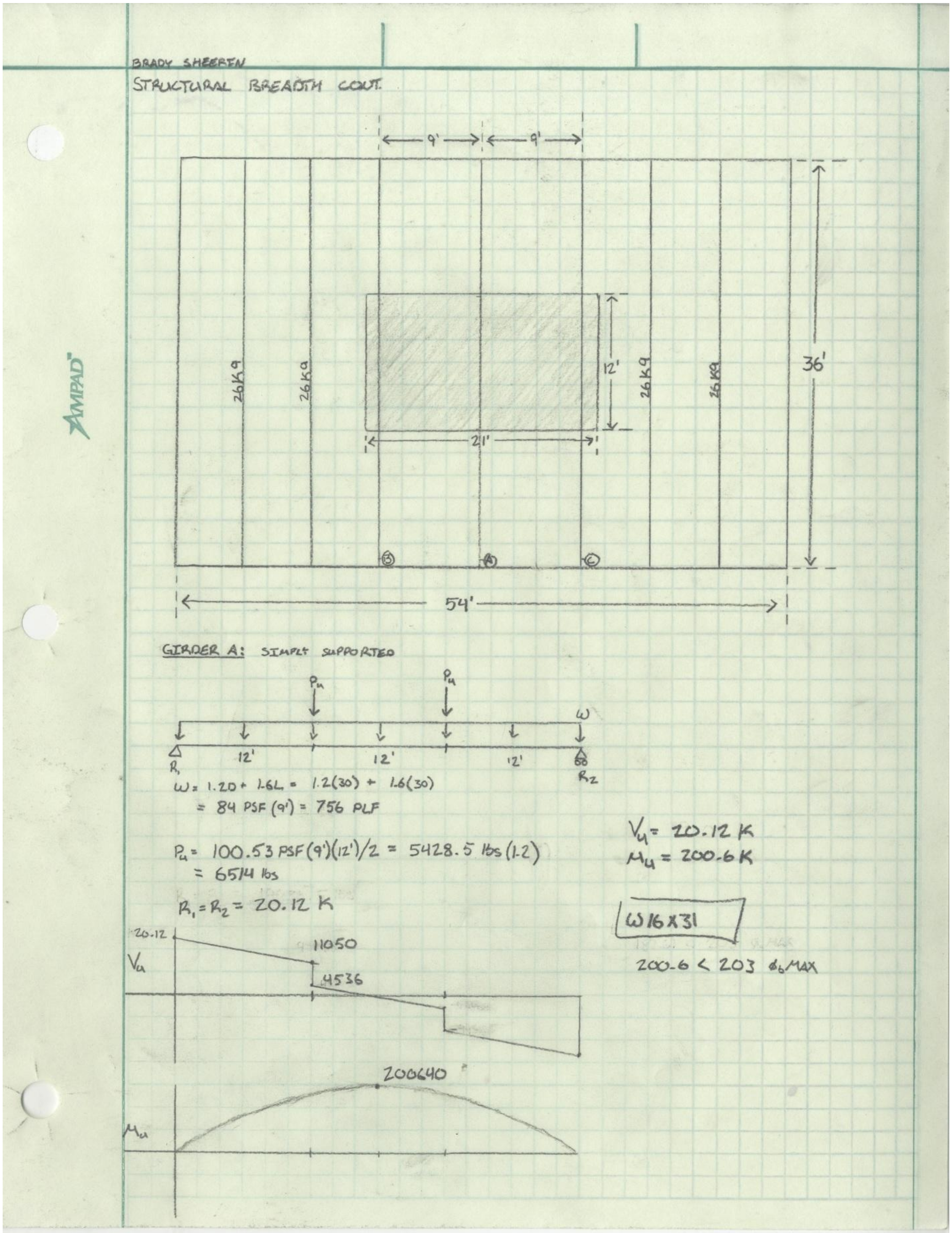
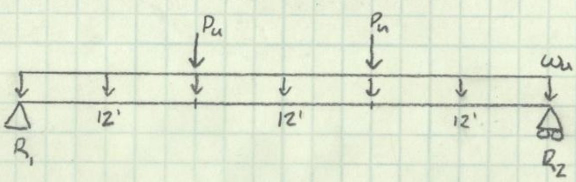


Figure 28: Structural Calculations Page 2 of 4

BRADY SHEERIN
STRUCTURAL BREADTH CONT.

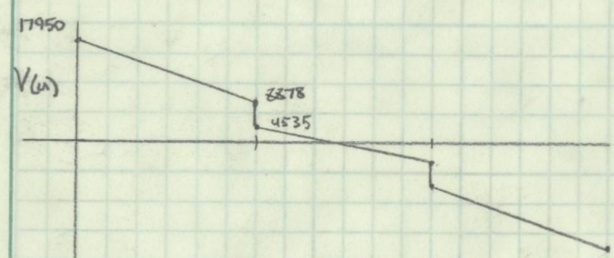
GIRDER B & C: SIMPLY SUPPORTED

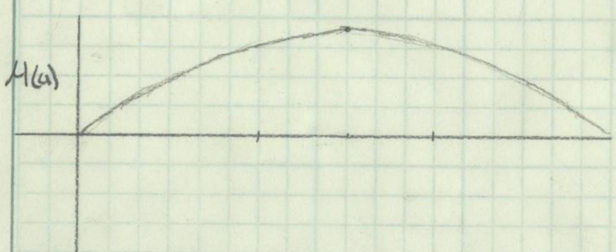


$w_u = 1.2D + 1.6L = [1.2(30) + 1.6(30)]\,9'$
$= 756$ PLF

$P_u = [100.53 \text{ PSF} (6')(12')/2](1.2)$
$= 4343$ lbs

$R_1 = R_2 = 17950$ lbs





$V_u = 17.95$ K
$M_u = 174.57$ K

W14x30

$174.57 < 177$ ϕ_b MAX

Figure 29: Structural Calculations Page 3 of 4

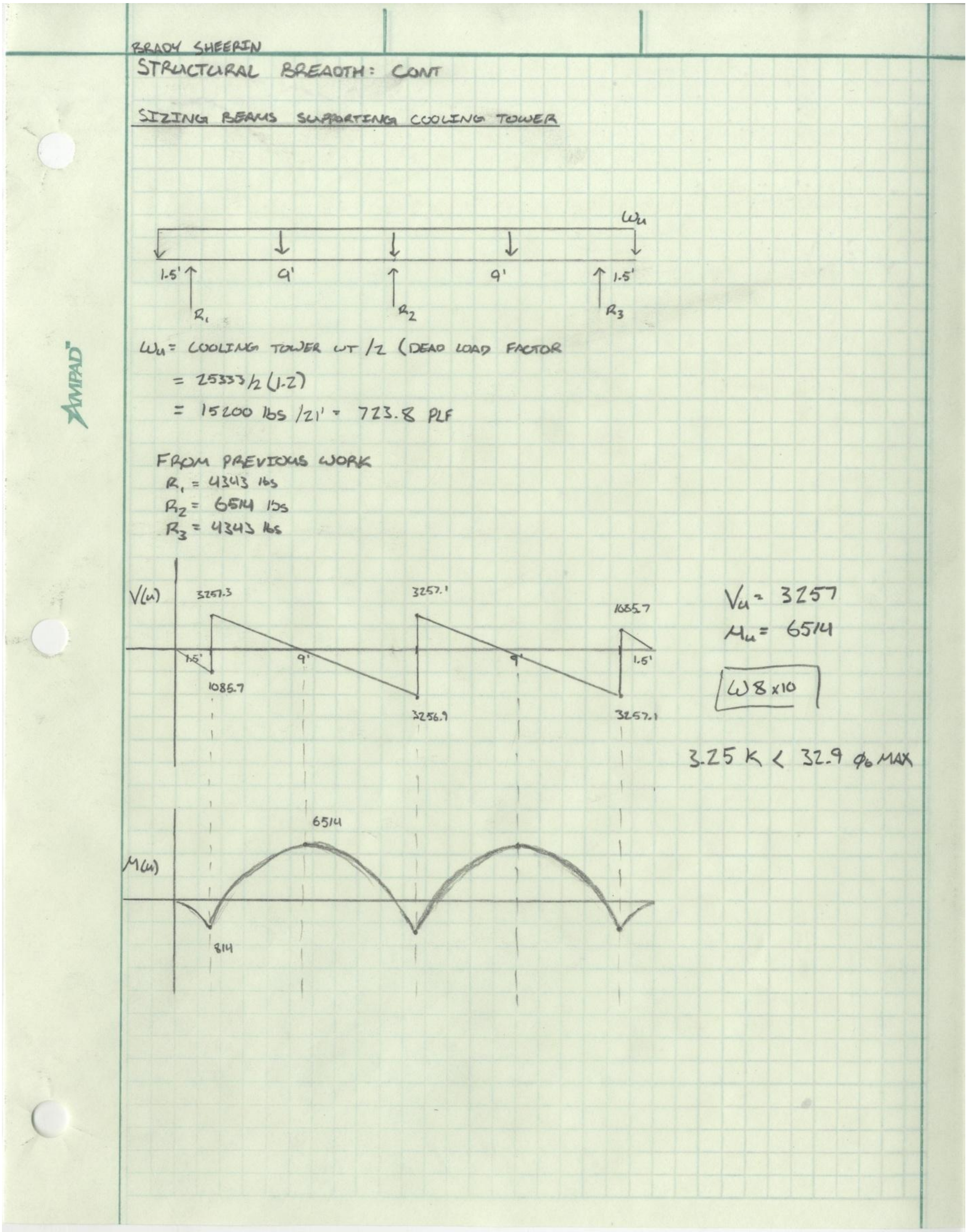


Figure 30: Structural Calculations Page 4 of 4

Technical Analysis #2 – Solar Energy Conversion System (SECS)

Problem Identification

The owner's goal for this project was to create a state-of-the-art educational facility, particularly in the field of science and technology. To do this many innovative design processes were incorporated into the plan for the school. However, little emphasis was placed on solar design. With that mind, if a photovoltaic array were incorporated into the building it could possibly serve an educational function while saving money on utility bills.

The use of a PV system for this project is ideal because the owner is a school district and they will own and operate the building for years and years to come.

Research Goal

The goal of this analysis is to see if the use of a photovoltaic array would be beneficial on this project. It will determine whether or not it is feasible, what the advantages and disadvantages associated with it are, and the associated costs of a PV array. This analysis will determine the amount of power that can be generated from the use of an array based off of a typical solar year. That information will be translated into potential monthly savings. This analysis will cover the upfront costs of the system including installation, and determine what the payback period will be. It will also determine the most viable roof locations for implementation.

The intent of this analysis is to show that a PV array would prove to be a beneficial investment for the owner. The overall goal is to find out if the long term benefits of a PV system can outweigh the upfront costs for the given local.

Research Steps

- Determine solar angles of the given local
- Pick equipment
- Evaluate optimal PV array (quantity, size, cost)
- Perform payback analysis

Tools

- EGEE 437 class material
- System Advisory Model (SAM)
- Project Team & Industry Professionals
- SECS textbook
- Faculty
- RS Means
- Google SketchUp
- University of Oregon Solar Radiation Sun Path Chart Program
- Scilab

Background Information

The use and knowledge of solar energy conversions systems (SECS) has risen and fallen through the decades, which can largely be contributed to access to fuels. In times when sources of fuel are abundant and costs are low people do not consider solar energy to be efficient. However, when fuels become scarce and their prices rise it is often followed by the exploration of alternate sources of energy. In times like this, people often look toward the sun in hopes of finding efficient ways of harnessing its power. Some methods of doing this involve solar hot water panels, solar chimneys, solar gardens, and of course photovoltaics.

Photovoltaics have come a long way in recent years and are becoming more popular still. The country of Germany is well known for its successful use of PV systems on a grand scale. They provide the perfect example for how successful these systems can be, especially when one considers that their solar utility (effective W/m^2) is less than that of America.

For these reasons photovoltaic panels are consistently being researched and reformed, which has made them more affordable and efficient. There is a much better understanding of how to optimize the performance of a SECS today than ever before. Additionally, depending on the location, the federal and state government often provides incentives to curb the high costs of implementing these systems.

Photovoltaic cells work by converting solar energy into electricity. They do this by using materials that capture photons, typically silicon, which then release electrons. These electrons then create a current that can be used to power equipment or charge a battery. An inverter is often used in a PV system to convert the current from DC to AC. Photovoltaic cells are placed together in series in a module, often referred to as a panel, which is then connected to a string. A number of strings are what is often referred to as an array.

PV arrays can be implemented into buildings in two primary ways. They can be integrated into the building or mounted on or offsite. The location of this project is in a relatively unsafe area and therefore it would not be logical to have them mounted at ground level, even though the site would be large enough to accommodate an array. To eliminate concerns of potential damage, the roof of the high school will be investigated because it provides a lot of unused real estate.

It is very important to take shading into consideration when designing a PV array. The cells of a PV module act like a bunch of batteries connected in series. If you were to take one of those batteries out then the whole system wouldn't be able to supply any electricity. The same is true for a module. If you were to cast a shadow on one of the cells of a module it would be the equivalent of removing a battery. For this reason modules now come with a number of bypass diodes which allow the module to work when part of it is shaded, although much less efficiently.

Building Analysis and Shading Concerns

To make sure that it is possible to use a PV system on this school a building and site analysis was performed. This is necessary so that it can be determined where the system has the most direct access to solar irradiance.

Figure 31: Google SketchUp Model of Building

The construction of the new high school is located at latitude 38.8° north and is oriented 24° east of south. This has the potential to cause some problems because for the given location the optimal direction to point the collector is due south. This means that instead of being able to run collectors parallel with the roof line they will have to be installed at an angle.

The design of the high school has several rooflines which vary in heights (see Figure 31). This causes considerable shading during different times of the day and year (reference Figures 32-34). The only viable option where shading is not a concern is on the roof of sections D, and E. These sections just so happen to be the tallest portions of the building and the tallest structures in the area. The only shading that will occur in these sections will be due to the parapet wall which is 1.5' tall and from the PV panels themselves.

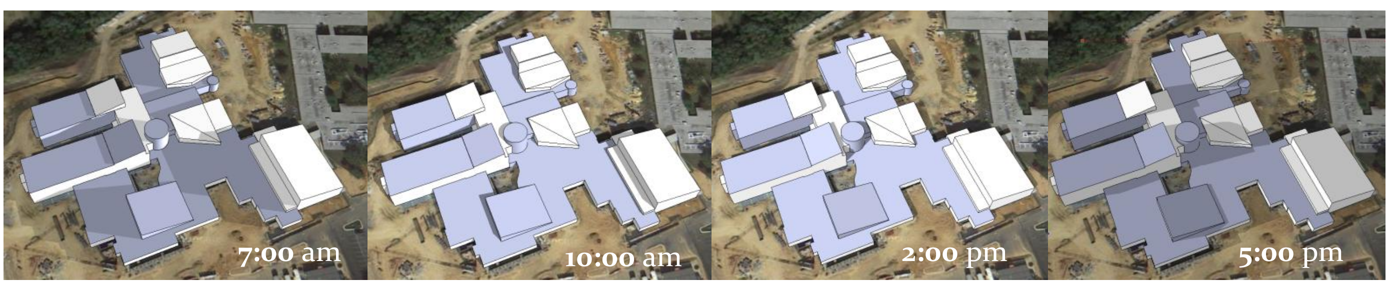


Figure 32: Solar Shading on the Equinoxes

Figure 33: Solar Shading on the Winter Solstice

Figure 34: Solar Shading on the Summer Solstice

Figure 35 depicts the shading that will occur do to the parapet wall if the solar panels are placed a distance of 7 feet away. It is important to remember that the panels will not be running parallel with the parapet wall and therefore only a corner of the string will be shaded as opposed to the entire bottom row of a string. This will only affect one module in the whole string and will not pose a problem because of the bypass diodes mentioned earlier. The months and times where the data intersects with the shaded area correlate to the time of day and month when the bottom corner of the string will be shaded. This impact is diminished even more when one considers that the solar utility during the early morning hours contributes almost nothing compared to the overall utility throughout the whole day. Figure 36 depicts the script that was used in Scilab to create these data points. The same script was used multiple times for different points along the parapet wall.

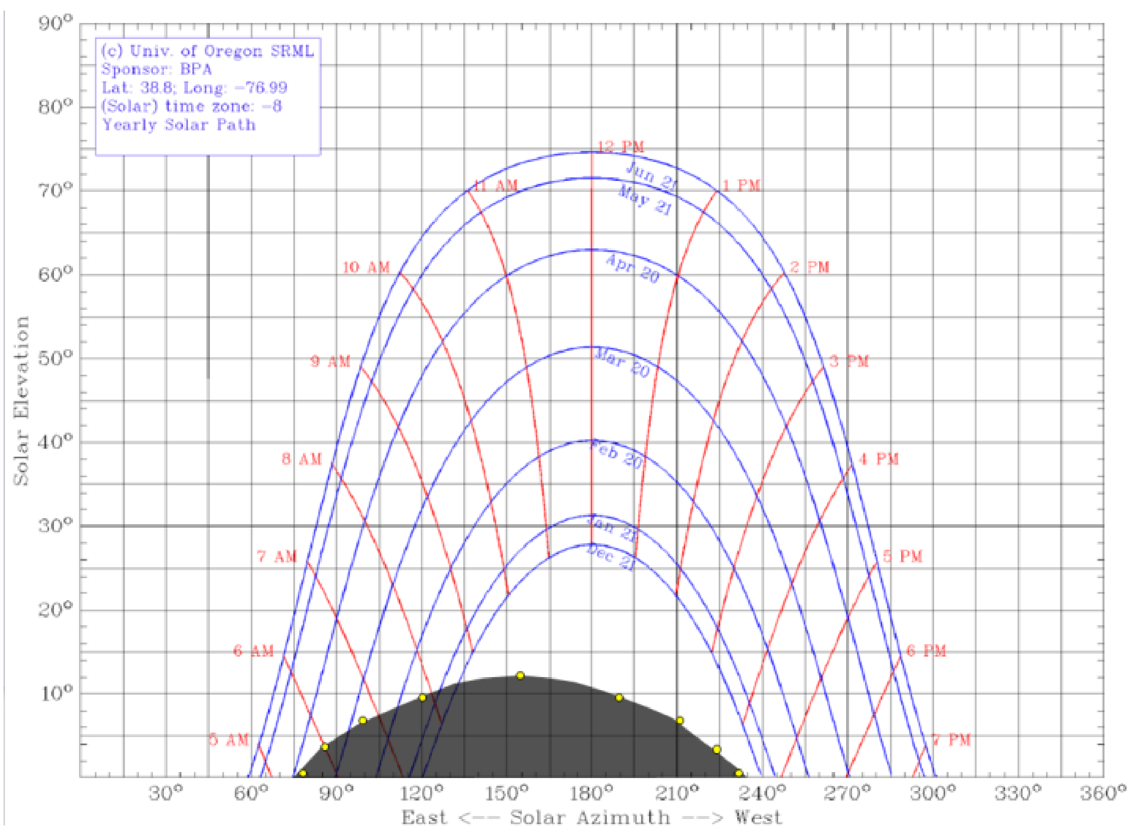


Figure 35: Shading On PV Panels Due to Parapet Wall

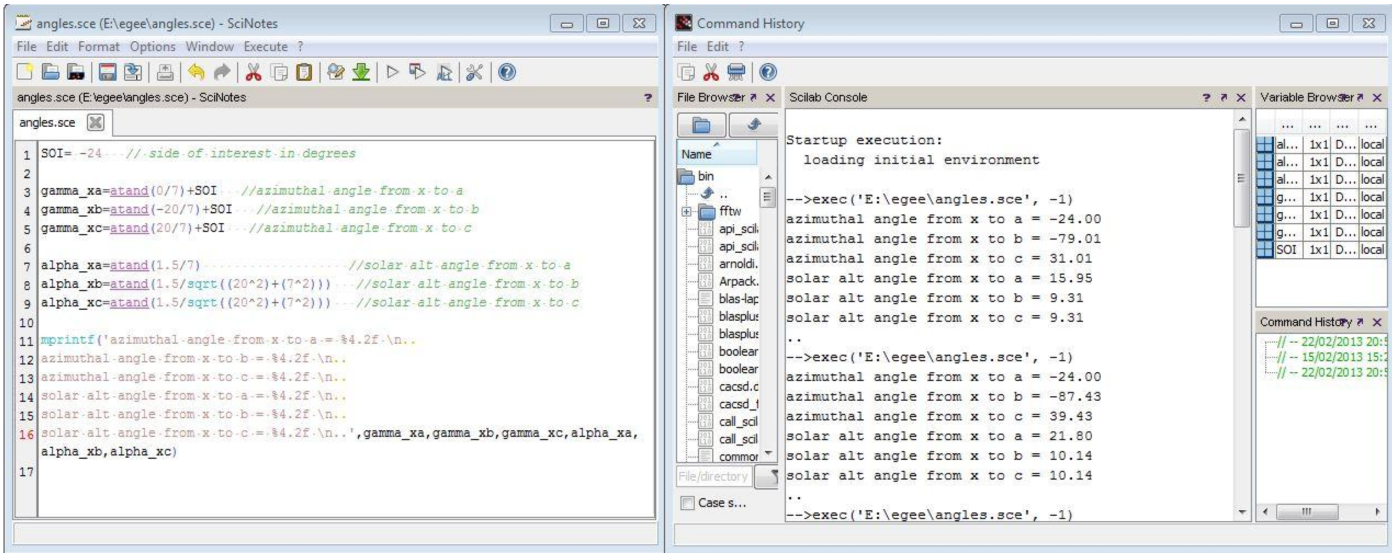


Figure 36: Scilab Script to Determine Shading Angles

The next obstacle to overcome is determining the type and quantity of modules to use. For the given coordinates of the building SAM provides an optimal tilt of 33° for the modules. It was decided that the panels would be fixed as opposed to using a solar tracking axis mount because it is significantly less expensive to install and provides much less opportunity for failures and breakdowns.

Once a module is selected it is important to find out how many can fit in a given area, and in what arrangement they can be placed. Figure 37 depicts the proposed installation roof area that was discussed above. Instinctively one might think that packing in as many panels as possible would be ideal, however this would lead to a very inefficient array design. It is imperative that the amount of shading that occurs from one module to another is taken into consideration. If panels are placed too close together they will be shaded by the ones in front of them for the majority of the day. The goal here is to maximize the number of panels and diminish solar shading which are conflicting objectives.

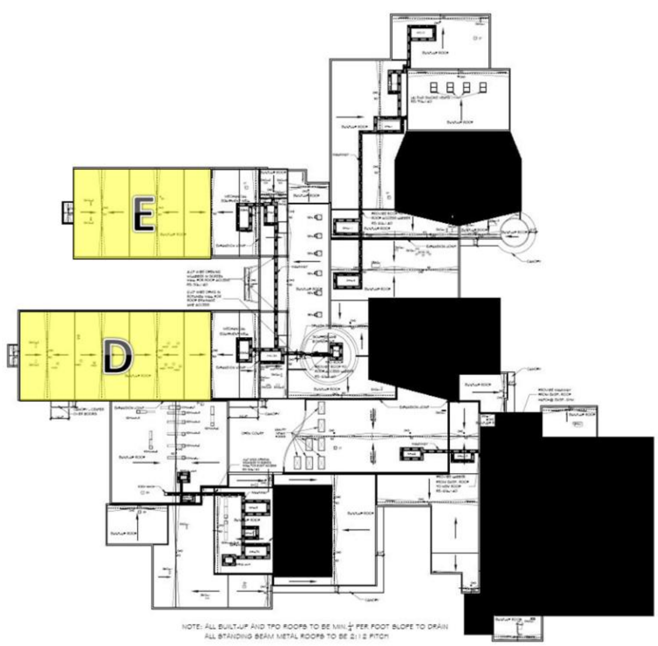


Figure 37: Optimal Area for PV Panels

PV Array Design

The following section will break down the steps taken to design the PV system.

<u>Step 1: Selecting a Module</u>

The SPR-240E-WHT-D Module from SunPower was selected because of its high efficiency of 19.31% and relatively low cost. A module from SunPower was chosen because they have some of the most efficient modules on the market.

SunPower SPR-240E-WHT-D Specs:

- *Width : 5.5'*
- *Length: 2'*
- *72 cells*
- *3 bypass diodes*
- *Maximum Power (P_{mp}): 240.165 W_{dc}*

Until recently it was believed that tilting a collector to the same angle as the latitude was the most efficient practice, but that has recently been disproven. Therefore these modules will be installed at a tilt of 33° to maximize the efficiency given a latitude of 38.8° N. This value was calculated using SAM. With this information and the module dimensions spacing criteria can be determined for the given local. Modules will be installed at a portrait orientation.

Spacing was determined by running several simulations in SAM and by performing the same shading analysis that was used on the parapet walls (see Figure 41). Based off of different row spacing's the annual Energy Output and system performance factor was determined and is depicted in Table 7. Based on the values found it was evident that a spacing of 15' would provide the most effective array (see Figure 39). By looking at Figure 38 it can be seen that right around 15' the effective energy output starts to plateau. This row spacing was chosen because it produces a high annual energy, the overall system performance is high, and it allows for many modules to be used.

Row Spacing (ft)	Annual Energy (kWh)	System Performance Factor
9	157116	58%
12	197313	72%
15	203286	75%
18	205719	76%
30	208048	76%

Table 7: Row Spacing vs. Array Efficiency

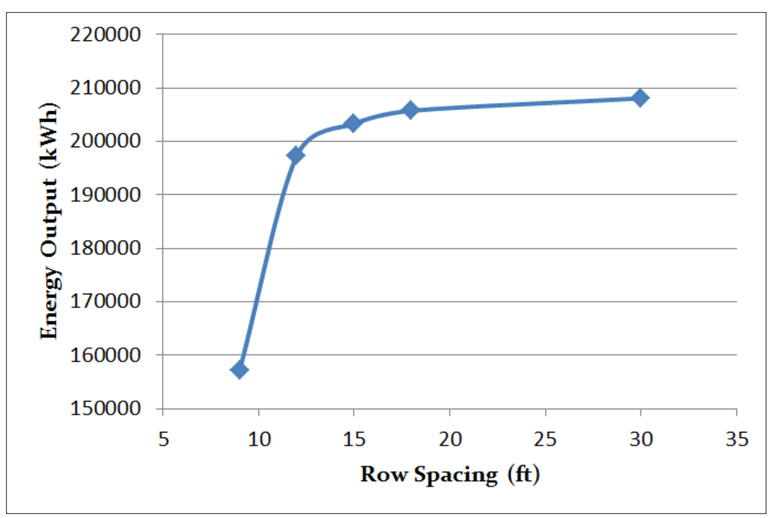


Figure 38: Depiction of Row Spacing and Efficiency

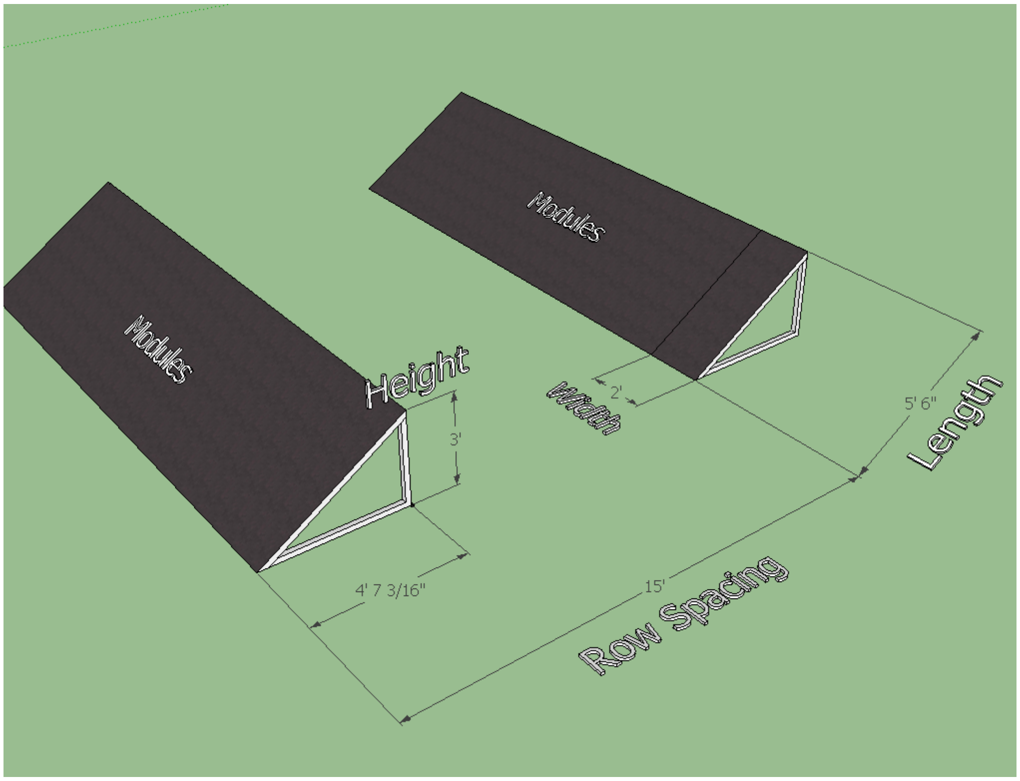


Figure 39: PV Array Layout & Dimensions

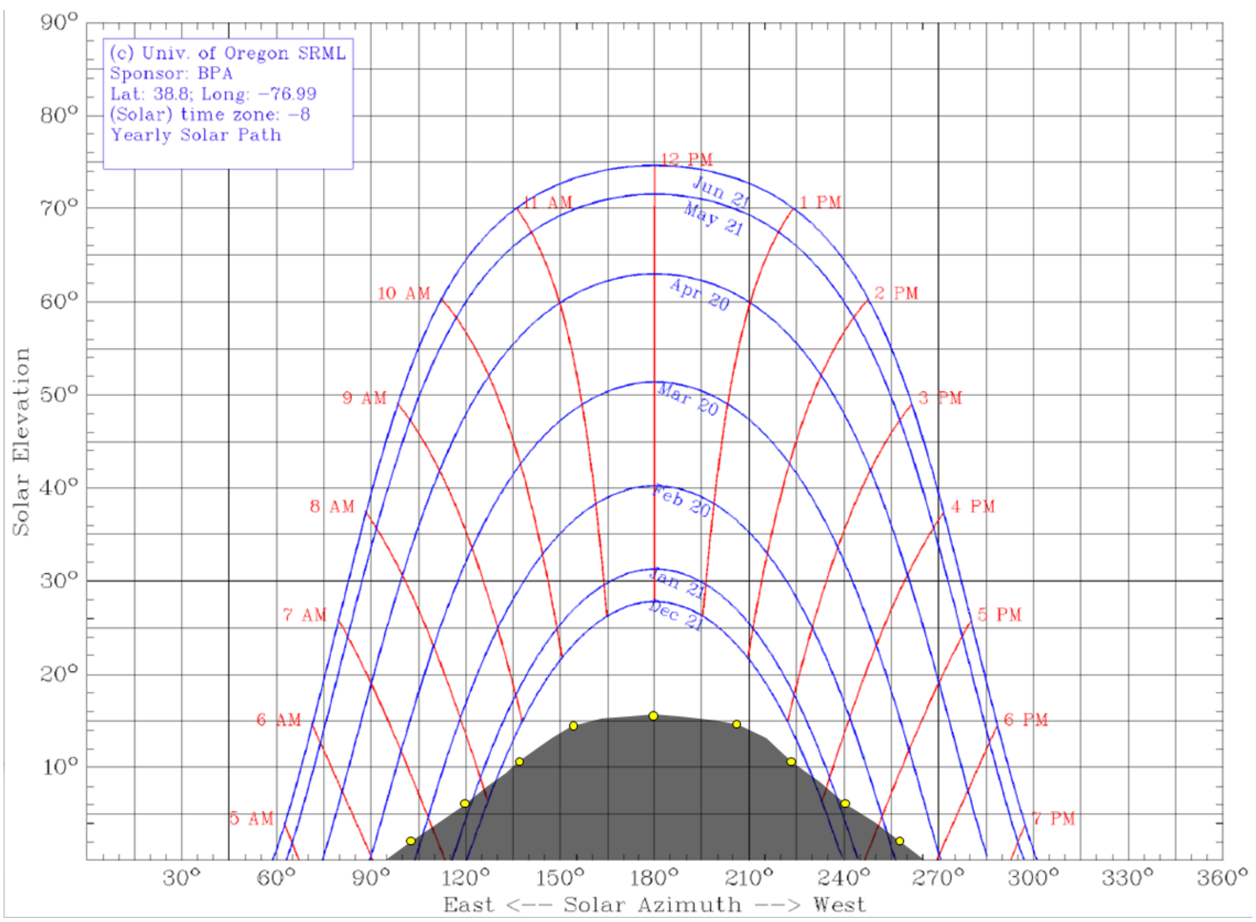


Figure 40: Shading Caused by PV Panels @ 15' Row Spacing

Step 2: Determining the # of Modules

Based off of the row spacing it was determined that 370 modules could be installed on the roof of section D and 260 could be installed on section E. This gives a total of 630 modules. Figure 41 and 42 give a visual representation of what this would look like.

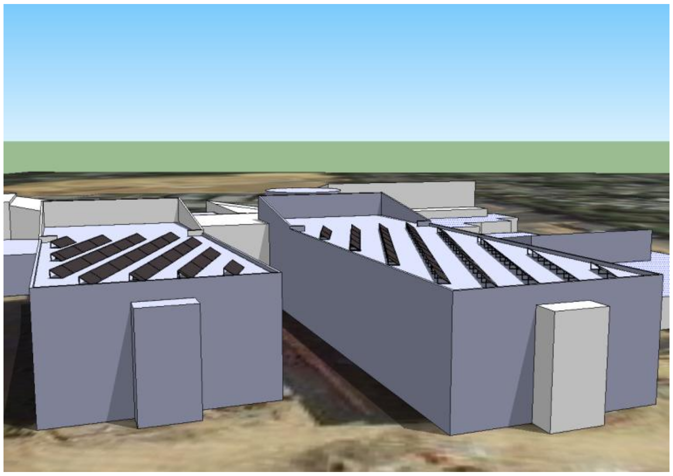


Figure 40: Model with PV Panels

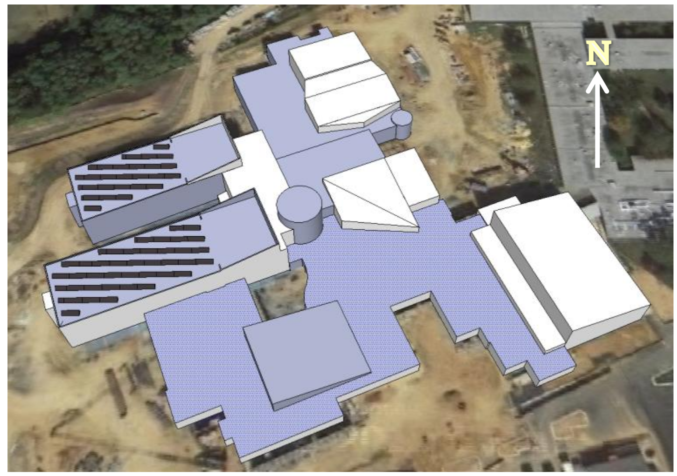


Figure 41: Alternate View of Model with PV Panels

Step 3: Sizing the Inverter

As was mentioned earlier inverters are used to convert DC current into AC current so that it can be used in a building. In order to size an inverter it needs to be determined how much load the array is capable of producing. Because the modules are set up in two different sections of the building more than one inverter will be needed. For this project 5 inverters will be utilized, 2 in section E and 3 in section D of the building. The Inverter that was selected was from Xantrex Technologies, Inc. and it was the PV30-480xfrmr 480V model. It was decided to use 5 separate inverters of this model because it was more cost efficient than other options.

Array Load: (630 Modules) x (240.165 W_{dc}/Module) = **151303.95 W_{dc}**

Total Inverter Capacity: (32206 W_{dc}/Inverter) x (5 Inverters) = **161030 W_{dc}**

Finding Capacity = (151303.95)/(161030) = **94%**

For simplicity reasons there will be 10 modules per string. With a max power voltage of 40.5 V per module this correlates to 405 V per string. The selected Inverter is rated for 330V – 480V so the string falls within the necessary range (see Figure 43).

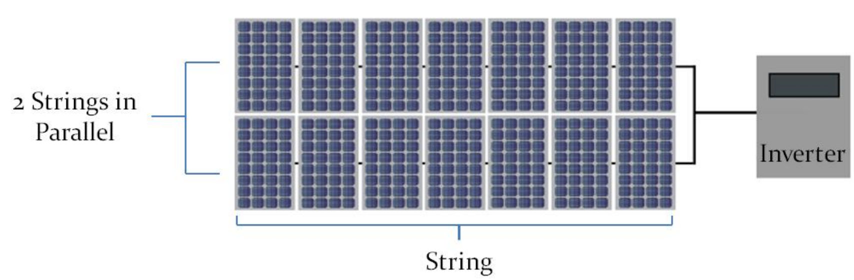


Figure 42: Visual Representation of PV System

Project Cost and Incentives

A barrier that often prevents owners from incorporating a PV system into their project is the large upfront cost of the system. Fortunately for Maryland there are a lot of incentives available that help curb this cost. The system that has been outlined above has a price tag of $662,173.54. Table 8 shows the breakdown of these costs. Because the building is a school and has been commissioned by PGCPS District they do not have to pay any sales tax which exempts them from what would have been an additional cost of $37,551.62.

Direct Capital Costs									
Module	630	units	0.2	kWdc/unit	151.304	kWdc	2.05	$/Wdc	$310,173.20
Inverter	5	units	30	KkWac/unit	149.85	kWac	0.37	$/Wac	$55,444.50
Balancing of System, equipment							0.43	$/Wdc	$65,060.72
Installation labor							0.48	$/Wdc	$72,625.92
Installer margin and overhead							0.81	$/Wdc	$122,556.24
							Total Direct Cost		**$625,860.58**

Indirect Capital Costs			
Permitting, Environmental Studies	0.23	$/Wdc	$34,799.92
Grid interconnection	0.01	$/Wdc	$1,513.04
Sales Tax	0%		$0.00
	Total Indirect Cost		**$36,312.96**

Total Installed Cost		
	Total Installed Cost:	**$662,173.54**
	Cost/Capacity:	**$4.38**

Table 8: Project Finance

A property tax exemption for solar and wind energy systems was enacted in 2008 and provides a 100% real property tax exemption in the state of Maryland. This policy applies to commercial, industrial, and residential properties. Additional the federal and state government provides a 30% and a 25% tax credit respectively. This means that within the first year PGCPS will receive $364,195 in incentives if they decided to implement this system.

Another incentive that's available comes from the utility company. Legislation mandates that a certain percentage of a utility companies energy generation must come from renewable sources such as wind or solar. By 2020 two percent of the energy utility companies generate must come from renewable sources. Because of this SREC's or Solar Renewable Energy Certificates can be sold to electricity suppliers so that they can meet the mandated requirements. One SREC is equivalent to one MWh of solar generated electricity and anyone with a PV system is allowed to sell SREC's to a utility company. The value of SRECs can be relatively volatile because it's based on a supply and demand model. Currently in Maryland one SREC sells for $120, but in previous years they have gone for as much as $375. To be conservative, this analysis will consider a value of $120 per SREC deescalating at a rate of 10% over a 10 year period.

PV System Assumptions

The following are assumptions that were made when creating the system model on SAM:

- Solar data was extrapolated from typical meteorological years.
- Flat Plate PV for Commercial Bldg.
- Modules are rack mounted
- Roof albedo (reflectance) is 0.75 due to white roof
- Performance Adjustments due to shading can be seen in Table 9
- Wiring losses 0.99
- Annual average soiling loses 0.95
- Estimated DC power derate 0.955
- 25 Year Analysis
- Net Salvage Value of 30% of installed cost after 25 years

Hourly Factors (24-hour profile for each month) 0=No Output, 1=Full Output 0

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	0	0	0	0	0	0	0	0.4	0.9	1	1	1	1	1	1	1	0.8	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0.8	1	1	1	1	1	1	1	1	1	0.8	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0.9	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Apr	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
May	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Jun	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Jul	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Aug	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Sep	0	0	0	0	0	0	0.9	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0.8	1	1	1	1	1	1	1	1	1	0.8	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0.4	0.9	1	1	1	1	1	1	1	0.8	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0.9	1	1	1	1	1	1	0.9	0.6	0	0	0	0	0	0	0

Table 9: Shading Adjustments

Payback Period

To determine if installing a PV system would be practical it is imperative that a payback period is completed. In order to properly complete a payback period it is important to know the aforementioned incentives and the local utility rate. According to NREL the National Renewable Energy Laboratory, Maryland has an average electricity rate between 13-15 cents/kWh. To be conservative 13 cents/kWh will be used in this analysis. (See Figure 44)

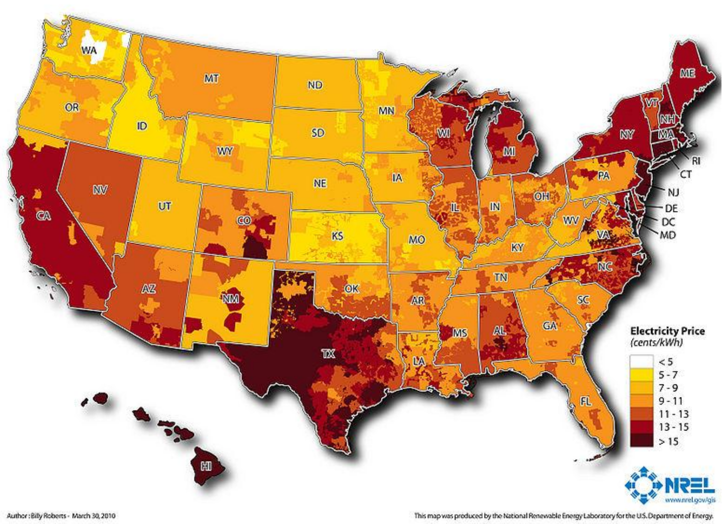


Figure 43: Electrical Rates by Region

Table 10 shows the values from the SAM input pages that were used for this model. Based off of a 2.5% inflation rate, a first year operating cost of $6,336.95, a utility cost of $0.13/kWh, and an annual performance depreciation depicted in figure 45, the payback period for this system is **4.99 years**. If no incentives were available the same system would take 18.19 years to pay off.

Values from SAM input pages

Financing	
Analysis Parameters	
Analysis Period	25
Inflation Rate	2.50%
Real Discount Rate	5.20%
Tax and Insurance Rates	
Federal Tax	28.00%
State Tax	7.00%
Sales Tax	0.00%
Insurance	0.50%
Salvage Value	
Net Salvage Value	30.00%
End of Analysis Period Value	$198,651.90
Property Tax	
Assessed Percent	20.00%
Asssessed Value	$132,434.60
Assessed Value Decline	0.00%
PropertyTax	0.00%
Loan Parameters	
Amount	$0.00
Loan (Debt) Percent	0.00%
Term	25
Rate	4.50%

System Costs	
Total Installed Cost	$662,173.00
Operation and Maintenance	
Fixed O&M ($/kW-yr)	$20.00
Fixed O&M Real Esc.	0%
Variable O&M ($/MWh)	$0.00
Variable O&M Real Esc.	0%
Fuel Cost ($/MMBtu)	$0.00
Fuel Cost Real Esc.	0%
Fixed (Annual) O&M ($/yr)	$0.00
Fixed (Annual) O&M Real Esc.	0%
System and Annual Performance	
Availability (year 1)	100.00%
Degradation (%/year)	0.50%
System Size (kW)	151.304
Heat Rate (MMBtus/MWh)	0
First Year Annual Output (kWh)	203286

Table 10: Values from SAM Input Pages

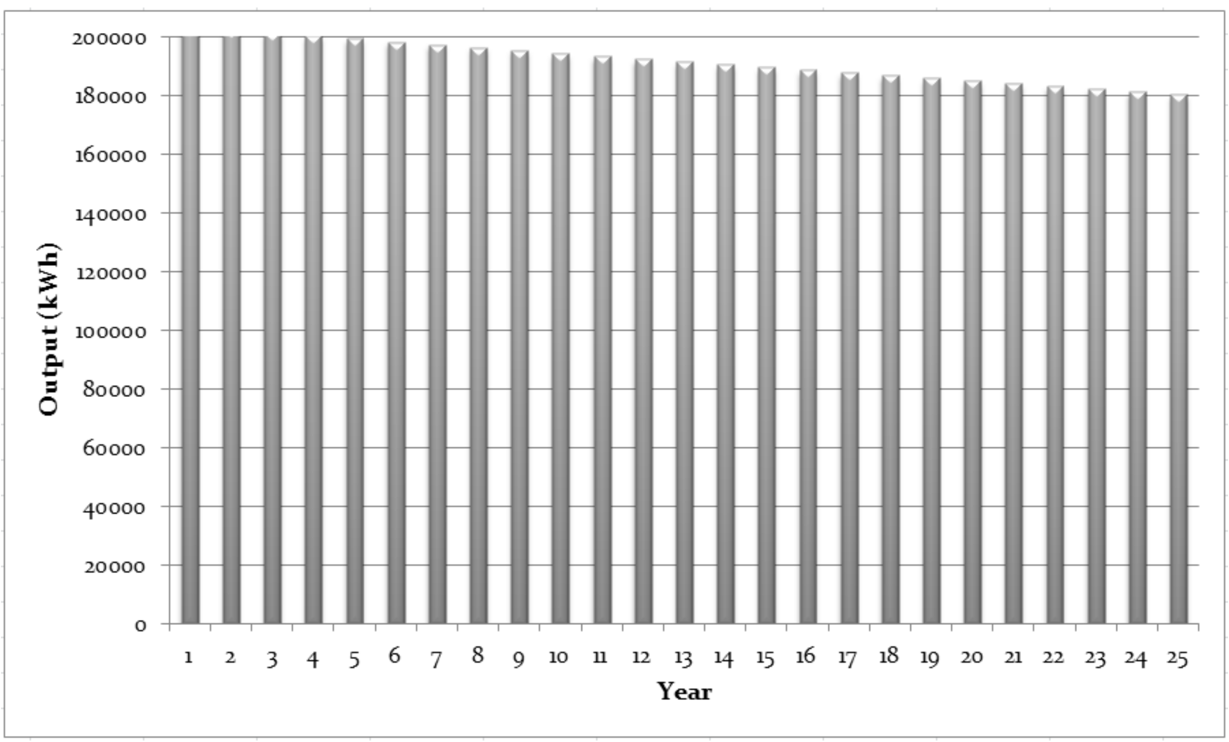


Figure 44: Annual Energy Output

Figure 46 depicts the yearly cash flow and total accrued cash value for a 25 year period. At year 25 the salvage value is added back into the model. With all things considered, after this 25 year period the PV system should make the owner a profit of $533,553.00.

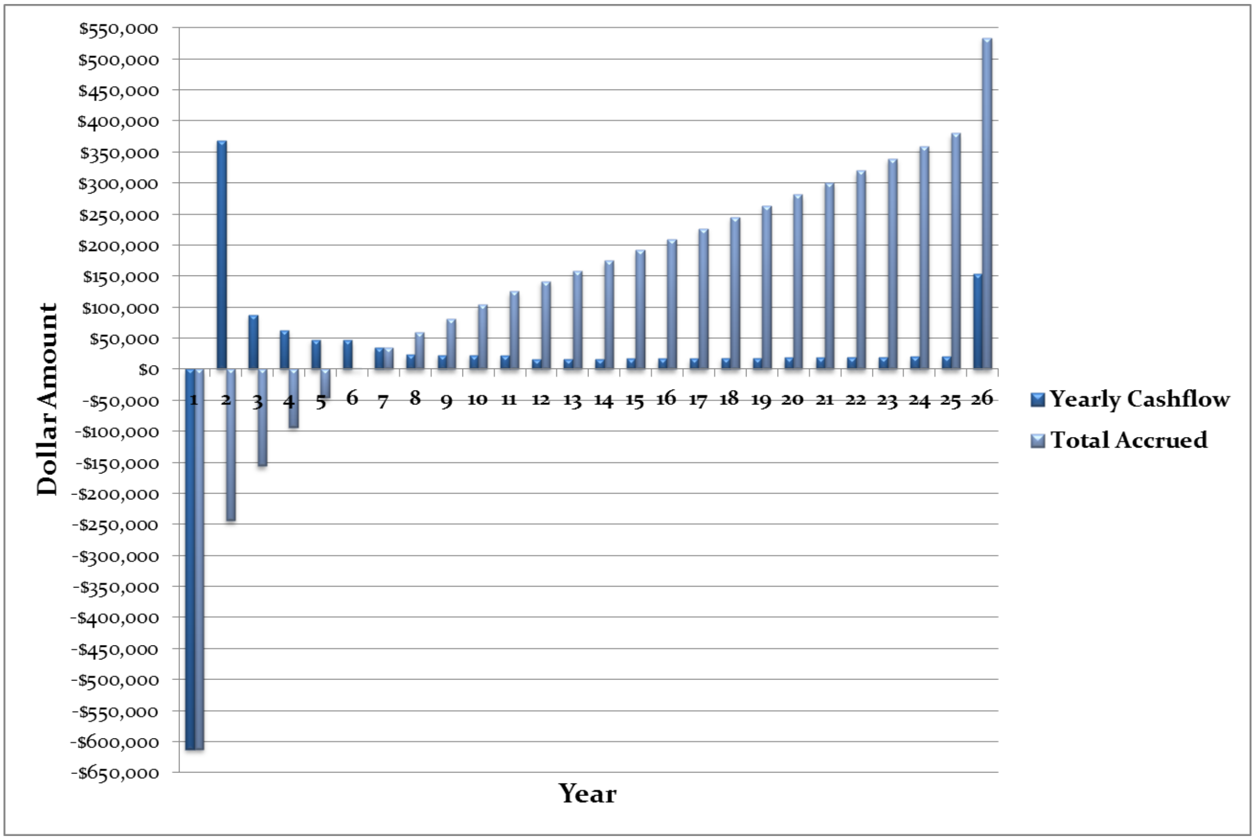


Figure 45: Cash Flow and Accrued Expenses/Revenue

Constructability

To determine how long it would take to install the system RS Means was consulted. According to the provided data an electrician would be able to install 8 modules per day and 5 inverters in 2 days. It would also take a roofer a day to install 4 mounting frames. Table 11 shows the breakdown of inverters, modules, and mounting frames per roof section.

Roof Section	Item	Quantity	Output	Duration (days)
D	Module	370	8/day/electrician	46.25
	Mounting Rack	37	4/day/roofer	9.25
	Inverter	3	3/day/electrician	1
E	Module	260	8/day/electrician	32.5
	Mounting Rack	26	4/day/roofer	6.5
	Inverter	2	2/day/electrician	1

Table 11: Installation Durations

According to the most up-to-date schedule the roof in sections E and D should be completed on December 28th and December 31st respectively. This is right around the time that the exterior enclosure will be completed in these areas too. At this time the installation of the PV panels could begin with little to no impact on other trade work.

The first step would be for the roofers to layout and install the mounting racks on sections D and E. To complete this 3 roofer's would work on the roof in section D and 2 would work in Section E. This would allow both sections to be completed within 4 days while allotting time for the initial layout.

The second step would be to install the modules on the racks. To complete this process 4 electricians would work on the roof in section D of the building and 3 would work in section E. With this distribution of labor all of the modules should be able to be installed within 12 days in section D and 11 days in section E as long as there are no delays due to weather. On the last day the Inverters will be hooked up next to the air-handling-units in each section of the roof. Figure 47 displays all possible Inverter locations.

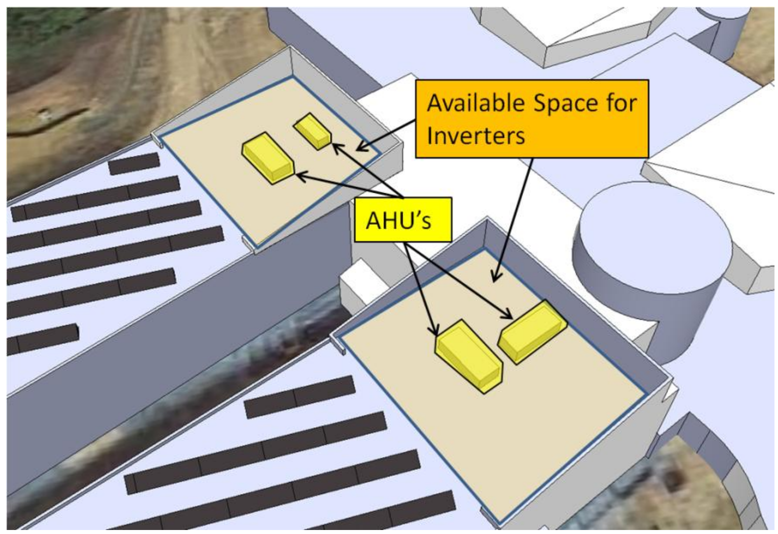


Figure 46: Possible Inverter Locations

The installation of these panels should take 17 working days for section D and 16 for section E. The whole process would not impact the completion date of the school and could be completed relatively fast. The benefit of this system is that it can be installation at any time after the roof is complete. This would allow the panels to be installed in the spring months to allow for the weather to improve so the electricians and roofers aren't working in poor weather conditions.

Conclusion

With a relatively short payback period of 4.99 years it would be advisable for PGCPS to consider implementing a PV system on their new school. After paying off the initial cost of the system PGCPS could benefit from a reduction in utility bills and reinvest any savings back into their school district. PGCPS would have to weigh the long term benefits of the system against the upfront costs and come to their own conclusion based on the presented data.

This system was chosen because it is very simple and would not require extensive maintenance or repairs. There are no moving parts which eliminates any possible mechanical failures that can occur with a tracking photovoltaic system. Additionally, PGCPS would not have to worry about cleaning the modules unless under unusual circumstances because the glass faces of the modules are self-cleaning when exposed to sunlight.

Technical Analysis #3 – Alternate Delivery Method

Problem Identification

The project had a late start due to a two month delay on the notice-to-proceed. This had a significant impact on the schedule and project team because the school was still required to be completed and open for classes in August of 2013. Unfortunately for the CM Agency (Hess Construction), the subcontractors were only required to meet the deadlines set by the original schedule, as per their contracts. This caused Hess Construction a number of problems with their subcontractors when they tried to accelerate the schedule. In one instance Hess had to pay the cost of bringing another crane on site to try and catch up.

There were also a significant amount of problems associated with the construction drawings that could have been mitigated had there been early involvement from other trades. Additionally there were problems with the design coming in well above the allotted budget for the project. This required a lot of value engineering which required compromising on a lot of the high end finishes that the owner didn't want to lose. In some cases whole packets of work were eliminated.

Research Goal

The goal of this analysis is to investigate the potential benefits of using an integrated design-build contract as opposed to the current method. The analysis will focus on comparing the two methods against each other using available data. To assist in illustrating the differences project organizational maps will be created. This will help demonstration the differences in communication and coordination throughout a projects life.

Research Steps

- Obtain a generic design-build contract from Hess Construction
- Analyze the two different contract types
- Create process maps
- Investigate the potential benefits of both contract styles
- Explain the results of the research and make recommendations

Tools used

- Microsoft Visio
- Project Staff
- Relevant Publications
- Industry Professionals

Choosing a Delivery System

There are a lot of things to consider when determining the most appropriate delivery method for a project. What works on one project could yield disastrous results for another. Some of the things to consider are: project goals, site conditions, allotted schedule, project budget, and parties at risk. Owners often want the highest quality project for the lowest cost, delivered within a short time period. However, it is likely that some of those desires will take precedence over others and there is usually a delivery method tailored to those wants.

Current Contract Approach: CM @ Risk

The delivery system used for this school was a CM at Risk, Cost plus Fee with a GMP. Prince George County Public Schools, (PGCPS) the owner, holds a contract with the architect/engineer, construction manager, and a third party consultant. Hess construction holds lump sum contracts with their subcontractors all of which are prequalified based off of quantitative experience, requisite skills, project capacity, and work history. (See Figure 48)

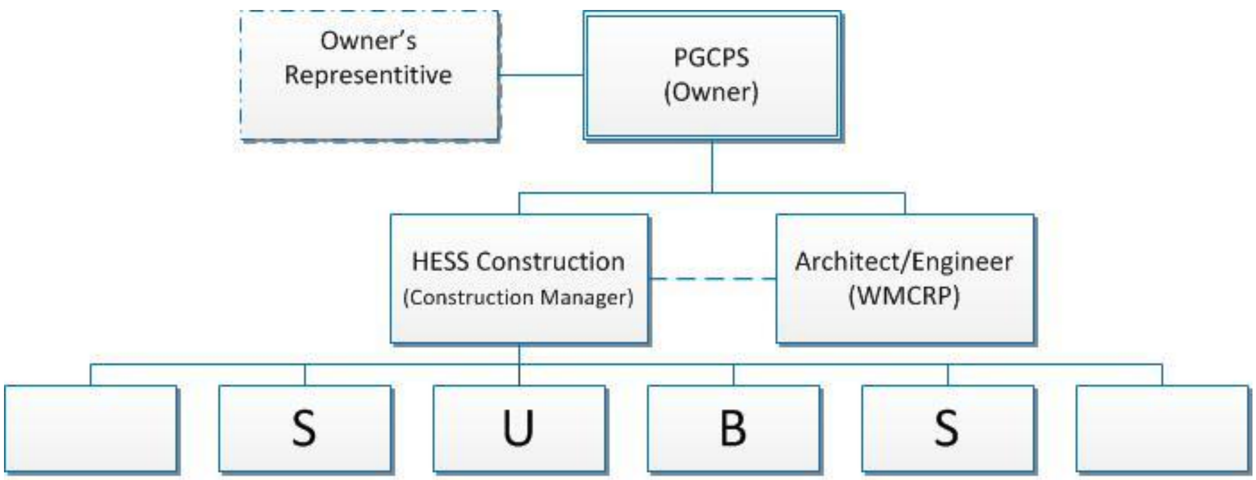


Figure 47: CM @ Risk Process

A CM at Risk delivery system is one where the owner contracts with both a designer and contractor somewhat concurrently. The owner will select a designer to design a facility; in this case it is WMCRP. They will then select the construction manager who will provide input during the design phase and ensure the work based off of the plans and specifications. However, the CM Company will not perform any of the work, instead they will subcontract parts of the construction scope to specialty contractors once a portion of the design is finished. After the facility has been constructed by the CM it is turned over to the owner. A process map of this delivery method can be seen in Figure 49.

In this delivery system the construction manager takes on the risk of getting the project completed, but does not perform any of the physical work. Instead they manage the construction processes and flow of communication. They guarantee the owner that the project will be completed by a certain date for a guaranteed maximum price (GMP). If the final cost of the project were to exceed the GMP then the construction manager would be responsible for those costs. Additionally, if the CM agency fails to deliver the building by the predetermined date they risk facing liquidation damages.

The CM agency acts as an advisor during the design and development phase of the project. They assist in estimating construction costs, scheduling, and provide constructability guidance based off of the owners and designers goals.

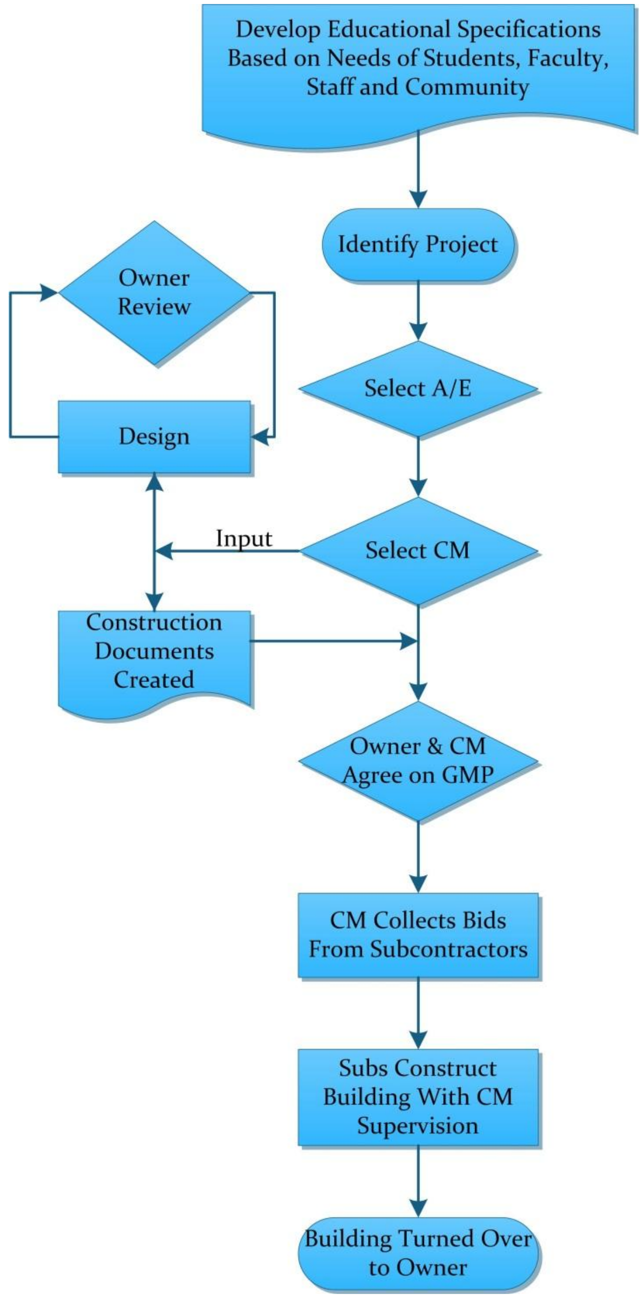


Figure 48: CM @ Risk Process Map

CM @ Risk Advantages

A CM at Risk contract allows for some overlap to occur during the design and construction phases of a project. This allows the design team to receive constructability input during the design. This is important because it mitigates otherwise potential design flaws which could be either impossible to construct or very expensive. It can also lead to earlier selections on materials and equipment. Furthermore this contract method allows for construction to begin prior to the completion of the entire design. This is advantageous on a project such as this one because of the tight time frame that the building needs to be constructed within.

Within this instance Hess Construction and PGCPS negotiated a guaranteed maximum price (GMP). This gives the owner the benefit of knowing exactly how much the school is going to cost them during the design phase. It also transfers risk from the owner onto Hess Construction by making them the single entity responsible for the completion of the job. However because they hold a separate contract with the architect PGCPS is responsible for any items missing from the construction documents.

CM @ Risk Disadvantages

Although there are many advantages to using a CM at risk delivery method there are also some negatives as well. In order for this delivery method to work all of the parties involved need to be able to work well together. The role of the CM agency switches from a design advisor to a management role once construction begins. At this time disagreements over construction quality, impacts to the schedule, budget concerns, and completeness of design documents can arise. If the contractual parties involved consistently disagree on these issues adversarial relationships might develop. Even though a fixed GMP is inherently adjusted for incomplete portions of the design disputes can still arise over assumptions that were used to come to that price.

As mentioned before, one of the biggest risks to completing this project on time came when the notice to proceed was delayed by two months. This delay was caused by the owner because of bureaucratic school policies. This posed a large problem for Hess because they were still required to complete the school by the original date, but the subcontractors could only be held liable to the bid document schedule. Because of Hess' contract with PGCPS the costs that were incurred to make up this delay, through overtime and bringing on another crane, were imposed on Hess.

Additional Drawbacks:

1. Owner has reduced control over construction process
2. Possible scope busts or overlaps
3. Higher CM fees for uncertainty due to lack of details in documents
4. Owner holds multiple contracts
5. Designer and builder could be a source of conflict due to separate contracts with the owner

Alternate Contract Approach: Design-Build

In the United States 40% of all non-residential design and construction is delivered using a design-build contract according to the Design/Build Institute of America. It is estimated that by 2015 over 50% of projects will use this method. This approach allows the owner to hold a contract with only one entity that is responsible for both design and construction. This can be achieved in four different ways: 1) the owner can contract with a design-build firm that has both construction and design abilities; 2) the contract can be held by a joint venture between a designer and contractor; 3) the contract can be with a designer who holds a contract with a contractor; or 4) vice-versa or option three. In each scenario the owner only holds one contract for the whole project instead of multiple contracts. In the past Hess Construction has used the forth method described when working on a design-build project.

In a design-build contract the firm that is hired by the owner takes on the risk for every aspect of the project. The entire cost of the job is written in their contract and they are responsible for how it is spent. In this delivery method the client chooses a design-build entity to create and build their facility based off of the clients design requirements. As the design is being developed the constructor provides input into the design and constructs finished portions of the design, similar to the CM at risk method. Once the building is complete it is turned over to the client to occupy. Refer to Figure 51 for a process map that illustrates this process.

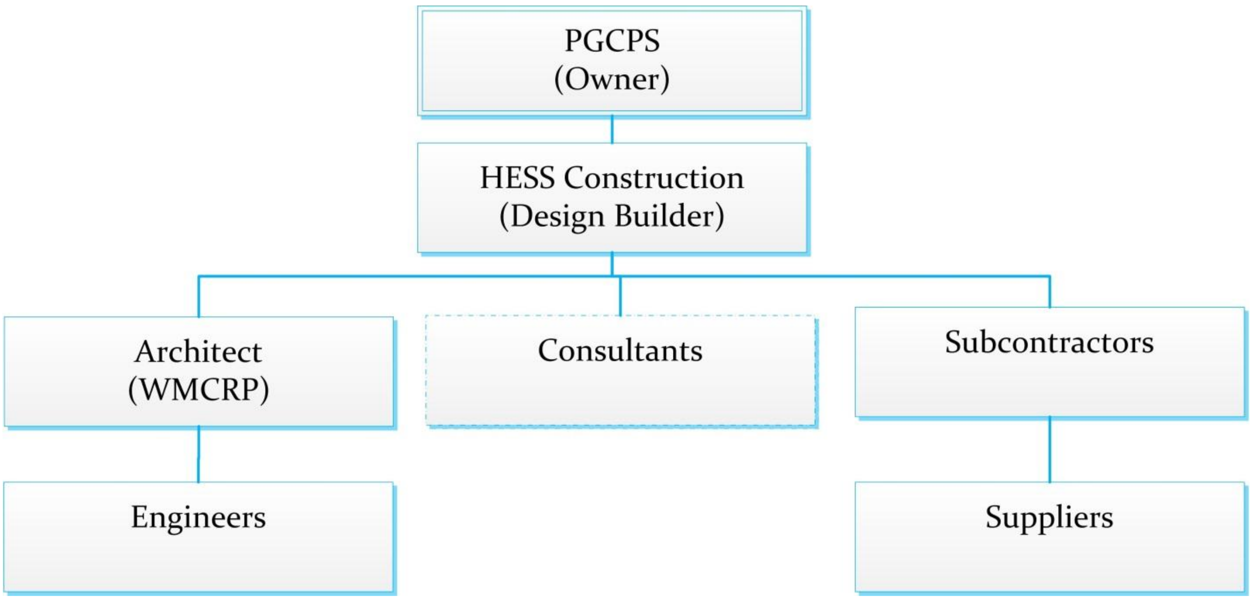


Figure 49: Design-Build Delivery Method

Design-Build Advantages

There are many benefits to using a design-build delivery system. One of the biggest advantages is that the owner essentially has no risk. The designer and contractor interact with each other sooner and are solely responsible for any and all design errors. This earlier interaction allows them to work toward the owner's goals which increases efficiency and prevents conflicts. Because the architect and contractor are not separately contracted there is no adversarial relationship between the two. Even if there were, the owner wouldn't have to mediate between the two because they only hold a single contract and therefore only have one point of contact. This also greatly reduces any problems associated with RFI's because everyone is working underneath a single umbrella. On this project that would be an extremely important benefit because of the high number of RFI's and the often slow response time.

This method would be a good choice for this project because it places an emphasis on cost control. The price of the building would be known early on and fixed; therefore there would not be any surprises to the owner later on in the project. With a design-build contract a negotiated GMP can be achieved very early on in the process as well. This is important to the owner because they are a school district and they are working within a tight budget. Additionally the owner would not have to worry about claims stemming from omissions from the construction documents or design errors because that would all fall under the responsibility of the design-build entity. Unlike a CM at risk delivery method, where the owner furnishes the specs and plans that the architect created and would therefore be responsible for the costs associated with any errors.

Additional Benefits:

1. Conducive to enhanced value engineering implementation.
2. Construction starts before the design is completed
3. Early collaboration enhances constructability
4. Schedule reduction due to earlier equipment procurement and start of construction work
5. Enhanced teamwork
6. Requires less owner expertise
7. Owner has flexibility in selecting from different design-build companies

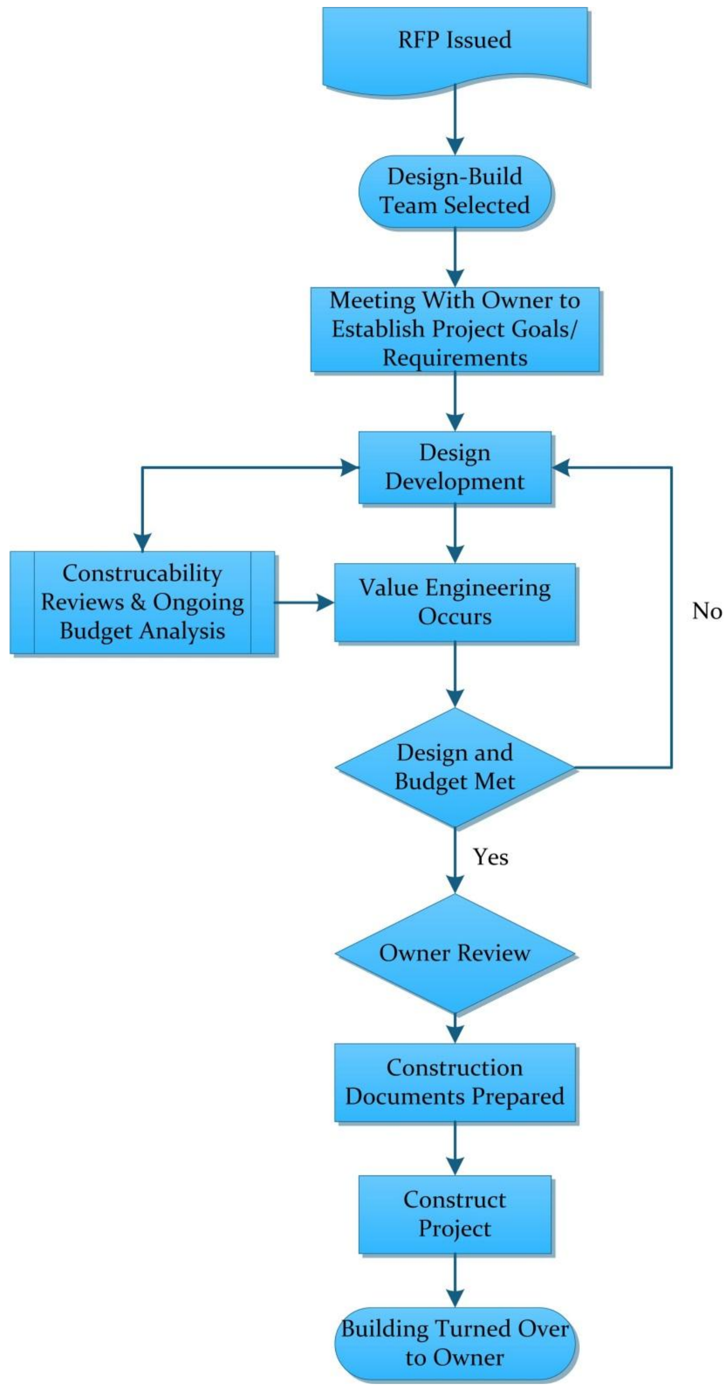


Figure 50: Design-Build Process Map

Design-Build Disadvantages

As with every type of delivery method there are some disadvantages or things to consider when selecting the design-build approach. For it to be successful the project has to be clearly defined by the owner. In this approach the owner needs to be very good at expressing what they want incorporated into the building from the very beginning of the project. Any ambiguity could result in the owner not receiving what they desire. This is because the owner has very little input into the construction of the building once the project is underway. This contract method provides the owner with a-hands-off style compared to other contract types. Due to this the owner must be willing to accept some uncertainty with the final outcome of the building.

Another disadvantage of this method is the loss of checks and balances between the contractor and architect because they are working under the same umbrella. In other contract types they typically keep each other in check because the architect is trying to represent the owner's design goals while the contractor is trying to hold the architect to a budget. When they work together no party is really responsible for representing the owner.

Lastly design changes after construction starts are expensive. This is because construction starts before the design is finalized so if something is changed, but has already been implemented, it would be expensive to change it. A design-build approach can be more expensive because more parties are involved earlier on in the life of the project. However these expenses can be recouped through the advantages previously mentioned, and can even prove to be less expensive than other delivery methods.

Additional Drawbacks:

1. Owner should be knowledgeable in design-build process
2. Difficult to obtain competitive bids
3. Possible restrictions by state laws and regulations
4. Needs extensive communication prior to start of project

Potential Impacts of Using a Design-Build Approach

Although it would be difficult to explicitly quantify, it is fairly safe to assume that a design-build contract approach on this project would have a positive impact on reducing the schedule. Throughout the duration of the project there were many RFI's that arose that needed immediate attention so that they would not hold up the construction process. Unfortunately they didn't always receive the immediate attention they required. Some of these instances included, but were not limited to: locations of bearing plates in CMU masonry walls, clarifications on the footing depth near the loading dock in section C of the building, rerouting of sewer line so paving could occur, and clarifications on column locations.

In the examples given work had to be stopped in areas of the building until a response was given. This meant that trades had to stop working in those areas and move to other parts of the building to perform work. This constant shuffling of laborers from one area to the next of the building without completing what they were initially working on created inefficiencies and therefore impacted the schedule. Even though none of these RFI's individually caused a significant delay on the schedule, collectively they did.

Had this been a design-build project the construction drawings would have been at a much higher quality based on the research that has been performed for this analysis. Even if these problems were encountered under this delivery method the responses would be much more immediate because of the closer collaboration between all of the parties involved.

There were many problems associated with the construction drawings that ranged from door and window locations not given to dimensions not lining up from one set of drawings to the next. One glaring example that took months to resolve was a clash of ductwork, ceiling height, and plumbing pipe in section D of the school. The easiest solution would have been to lower the drop ceiling, but the architect would not allow it. This caused an extensive reroute of the systems. Figure 52 and 53 shows the initial location of the incident. It is likely that this would have been able to be resolved much sooner if the contract method been different.

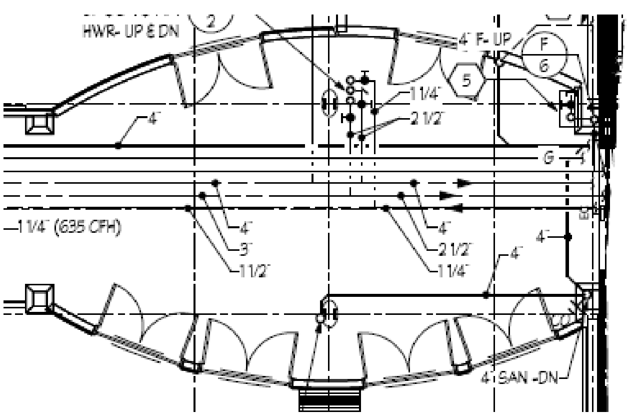


Figure 52: Plumbing Area D Football

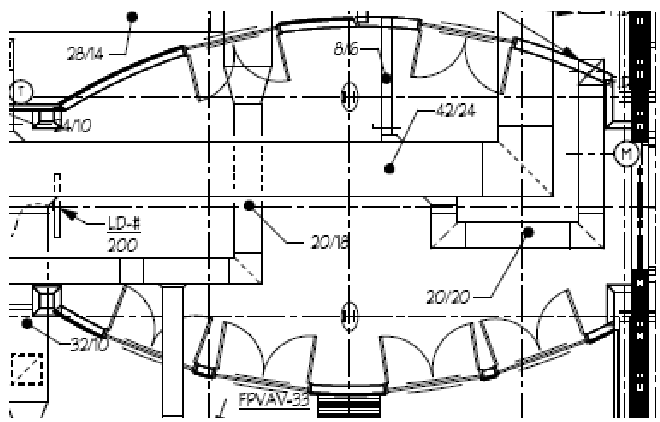


Figure 51: Mechanical Area D Football

One of the biggest issues associated with the CM at Risk delivery method was caused by the two month delay in the schedule. Financially this only affected Hess construction because the subcontractors were only held to the original bid document schedule. To make up this time the project staff had to cover the cost of bringing a second crane onto the site to erect steel. They also had to start a six day work week and cover the cost of overtime. It was very difficult for Hess to get the subcontractors to accelerate their schedules and work an additional day because the delay had very little impact on them. Had a design-build contract been used everyone would have had some "skin in the game" which would have spread out the additional costs incurred and made everyone more willing to make sacrifices to get the job finished.

Managing the project would become easier as well because there would be more support from subcontractors and collaboration and communication would increase. This would create a more streamlined project and the project staff would be better equipped to quickly adapt to unforeseen conditions. Additionally the risk would be lower because the construction documents would be better and everyone involved would share the risk.

Another problem that was encountered on this project was getting the BIM completed on schedule. Initially the goal was to have all of the modeling and clash detections completed for the trades so that the drawings could be used as fabrication models. However, due to a lack of motivation on the part of the subcontractors the construction in some areas of the building surpassed the completion of the models. Consequently the benefits of BIM were not being adequately utilized.

DB & CM @ Risk Quantitative Evidence

Mark Konchar, Author of "A Comparison of United States Project Delivery Systems", wrote a report providing empirical evidence concerning the difference between cost, schedule, and quality attributes of three different project delivery types. Those delivery methods were Design-Build, CM-at-Risk, and Design-Bid-Build. He accomplished this by using project data he gathered from 351 different building projects in the United States which were categorized into six separate facility types. By using nearly a 100 descriptive and interacting variables he was able to explain project cost, quality, and schedule performance based on the delivery method. Of the 351 projects 44% of them used a design-build delivery method, 23% used CM-at-risk, and 33% were design-bid-build. Figure 54 shows this breakdown. For the sake of this report only design-build and CM-at-risk will be discussed.

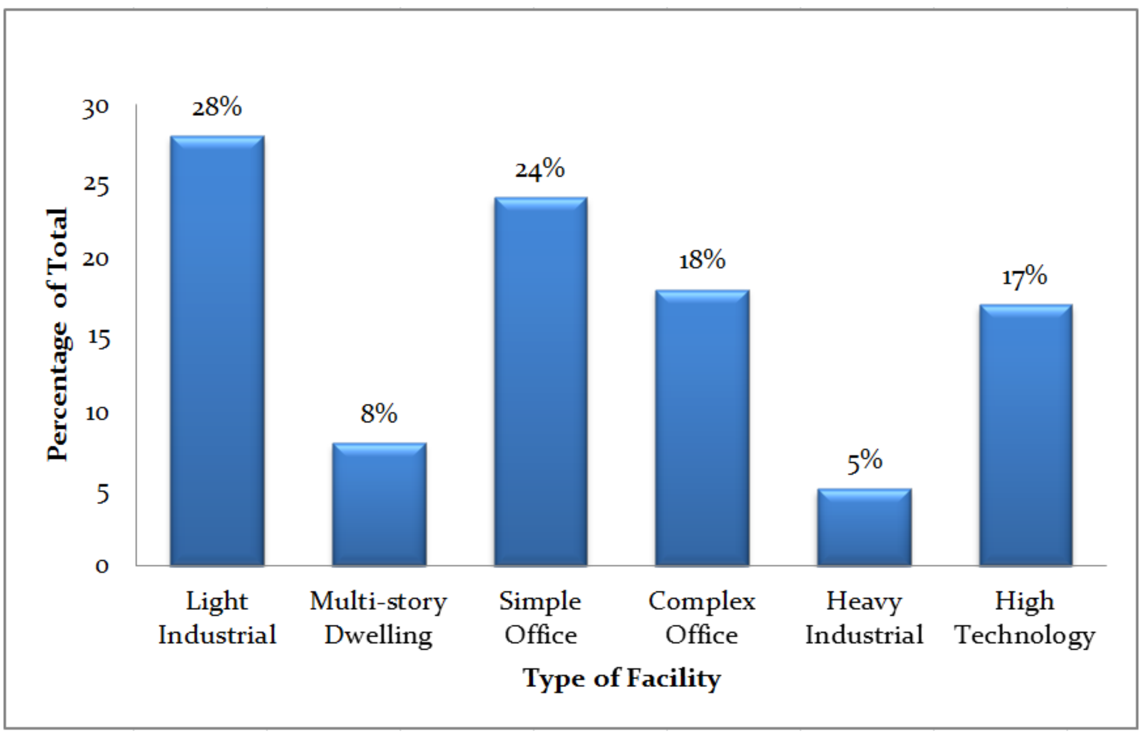


Figure 53: Distribution by Facility

Construction Speed

Construction Speed was defined in this report by the square footage of work that was installed per month. It did not take the design period into consideration. After performing extensive calculations and research Dr. Konchar found that design-build projects were on average completed 7% faster than CM-at-risk projects.

Delivery Speed

Delivery speed differed from construction speed in that it included both design and construction durations into the analysis. Dr. Konchar found that design-build projects were on average 23.5% faster than CM-at-risk projects.

Unit Cost

Unit cost is defined by the total square footage of a building divided by its final cost. According to the presented data design-build projects were 4.5% less expensive than CM-at-risk buildings.

Cost Growth

Cost growth analyzed the difference between the initial cost that was contracted at the beginning of the project and the final cost at its completion. This analysis showed that design-build projects cost growth was on average 1% less than CM at risk projects.

Schedule Growth

Schedule growth analyzed the difference between originally planned completion dates and actual completion dates. Dr. Konchars findings showed that design-build projects schedule growth was on average 2.18% less than CM-at-risk.

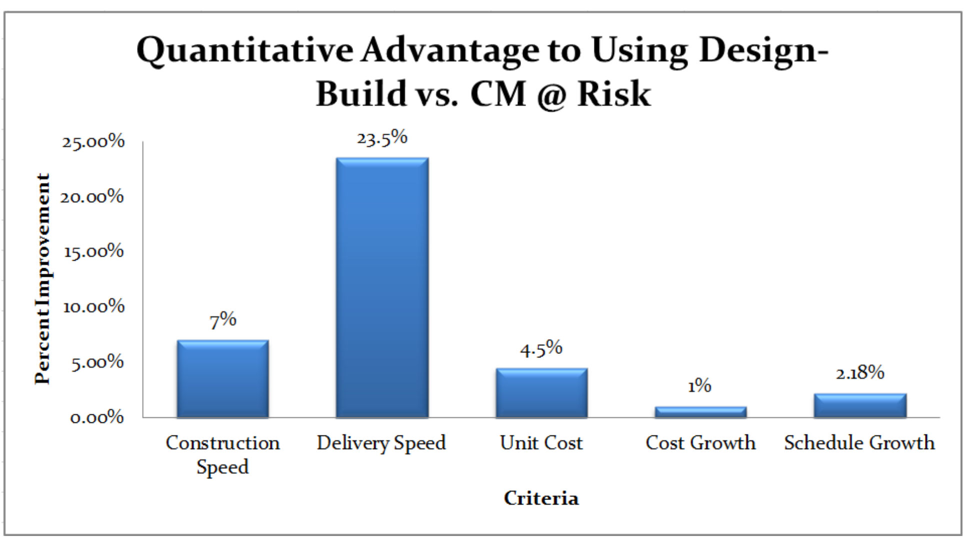


Figure 54: Design-Build vs. CM @ Risk Improvement

Conclusion

Changing the delivery method would undoubtedly foster more collaboration between all parties involved on this project. The design period would be reduced, which is critical because a poor design can cause delays in the start of construction. These delays occur due to poor planning, undefined scope, incomplete detailing, bad communication, and not selecting materials soon enough. With this delivery method many of these issues could be eliminated or mitigated. There would be fewer issues with the drawings, it would allow for faster procurement of equipment, materials, and allow construction to start sooner. After weighing all of the benefits against the potential disadvantages it is clear that this delivery method would be more advantageous for Hess Construction.

However a CM-at-risk delivery method can still be more appealing to the owner because it allows them more input throughout the duration of the project. They are also not as concerned with construction speed, delivery speed, cost growth, or schedule growth because they hold a GMP contract with a strict completion date. One benefit the owner would receive is less risk, because they could hold only one contract and would not be responsible for furnishing any of the drawings and specifications. This would eliminate any costly and unforeseen change orders.

In the end the owner would have to weigh the pros and cons of each delivery method based off of their wants and determine which best suits them.

Technical Analysis #4 – Façade Prefabrication

Problem Identification

With a two month delay on the notice-to-proceed the already tight schedule to complete the high school was reduced to only 18 months. For that reason a prefabricated façade will be analyzed for this analysis in hopes of alleviating time spent on the enclosure, which is on the critical path. The current façade of the school is comprised primarily of 4" ground-face CMU's. The architect chose to clad the exterior of the building in CMU's in order to compliment the exterior façade of the existing gymnasium.

The current procedure for installing the façade is by a process known as "stick-building", or hand laying the units one by one off of scaffolding. For a project of this size this requires an exorbitant amount of man power and time. Additionally, it is less safe than prefabricated panels because it creates a more congested and dirty site. This masonry work took a total of four months to complete, which hindered other enclosure, and finishing trades from beginning work in areas of the building.

Research Goal

The goal of this approach is to determine the ability for schedule acceleration by utilizing a precast architectural façade. This will allow the building to be enclosed at an earlier date and reduce the overall project schedule. The cost impacts, whether positive or negative, will also be investigated and evaluated to determine if this idea is viable.

Research Steps

- Investigate the current façade systems
- Determine the area of the building that will be prefabricated
- Analyze the construction schedule and cost for the current enclosure
- Contact manufacturer to determine erection times and costs
- Select a panelized system to replace the current "stick-built" method
- Rework the construction schedule and budget with the new system
- Study Feasibility

Tools

- Project Staff
- AE Department Staff
- Excel
- Microsoft Project
- Industry Professionals
- Precast Manufacturer contacts
- Revit

Current Façade Assembly

The current ground-face CMU façade is attached to the building using two different methods. Approximately 27,300 SF is attached to a structural masonry substrate, and another 41,700 SF is attached to metal studs spaced 16" on-center with a ½" gypsum sheathing backing. The façade is attached to a masonry substrate in areas A, B, C, and G of the building and connected to metal studs in areas D, E, and F. (Reference Figures 56 and 57)

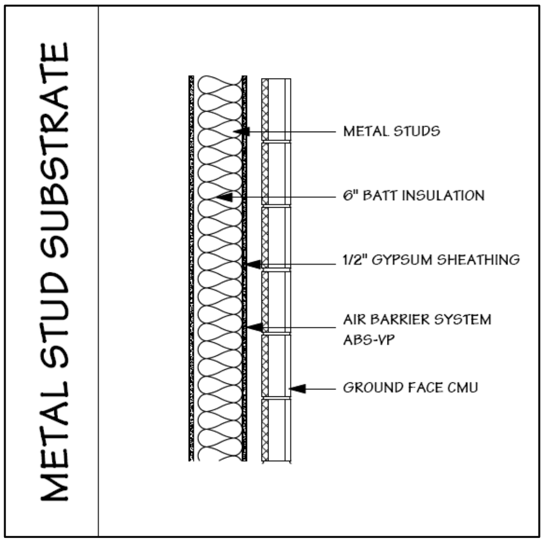


Figure 55: Current Façade Composition

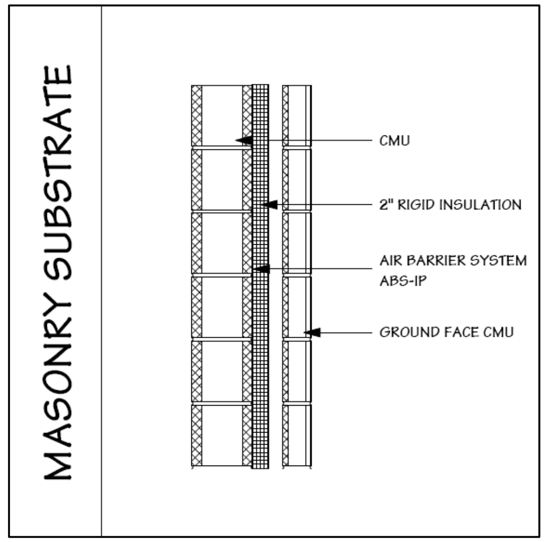


Figure 56: Current Facade Composition

The start date on the façade was dependent on the completion of the structure in the aforementioned areas. For areas D, E, and F this means that the structural studs and sheathing had to be installed around the perimeter of the building. In areas A, B, C and G this meant that the steel joists and decking had to be connected and detailed.

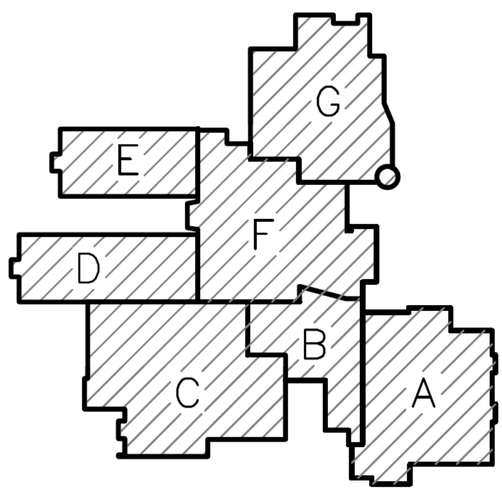


Figure 57: Building Section Breakdown

The acquisition of a second crane allowed for structural members of sections D & E to be placed while F was also being erected. Once F was complete, the crane that was used in section F of the building was used to place joist and metal deck in sections A, B, and C. Finally the crane was moved one last time to finish G. No work could be completed in areas where the cranes were performing lifts due to safety concerns.

Once the structure in an area was finished, the enclosure began. Tables 12 and 13 show the scheduled finish dates for the structure in each section of the building. They also show the subsequent start and finish dates for the ground-face CMU veneer.

Area F					
Metal Stud Installation	Start:	8/30/2012	Masonry Veneer	Start:	9/5/2012
	Finish:	9/6/2012		Finish:	9/25/2012
Area E					
Metal Stud Installation	Start:	9/18/2012	Masonry Veneer	Start:	10/16/2012
	Finish:	10/15/2012		Finish:	11/20/2012
Area D					
Metal Stud Installation	Start:	10/1/2012	Masonry Veneer	Start:	10/17/2012
	Finish:	10/23/2012		Finish:	12/21/2012

Table 12: Scheduled Completion Dates for Structure

Area G				
Structure Finished:	11/20/2012	Masonry Veneer	Start:	11/26/2012
			Finish:	1/8/2013
Area C				
Structure Finished:	10/22/2012	Masonry Veneer	Start:	10/23/2012
			Finish:	12/18/2012
Area B				
Structure Finished:	11/6/2012	Masonry Veneer	Start:	11/8/2012
			Finish:	11/20/2012
Area A				
Structure Finished:	10/12/2012	Masonry Veneer	Start:	10/15/2012
			Finish:	10/29/2012

Table 13: Scheduled Completion Dates for Structure

Prefabricated façade

The proposed design for sections F, E, and D will span all three floors and eliminate the need for metal stud installation. It will also eliminate the need for setting up and tearing down scaffolding. For these sections panels will span at least the length of a floor and half the width between columns. This means that each panel will be approximately 400 – 200 SF. In order to ship the panels without requiring a permit the heights of the panels cannot exceed 13'6". Figure 59 shows a visual representation of what the panels will look like.

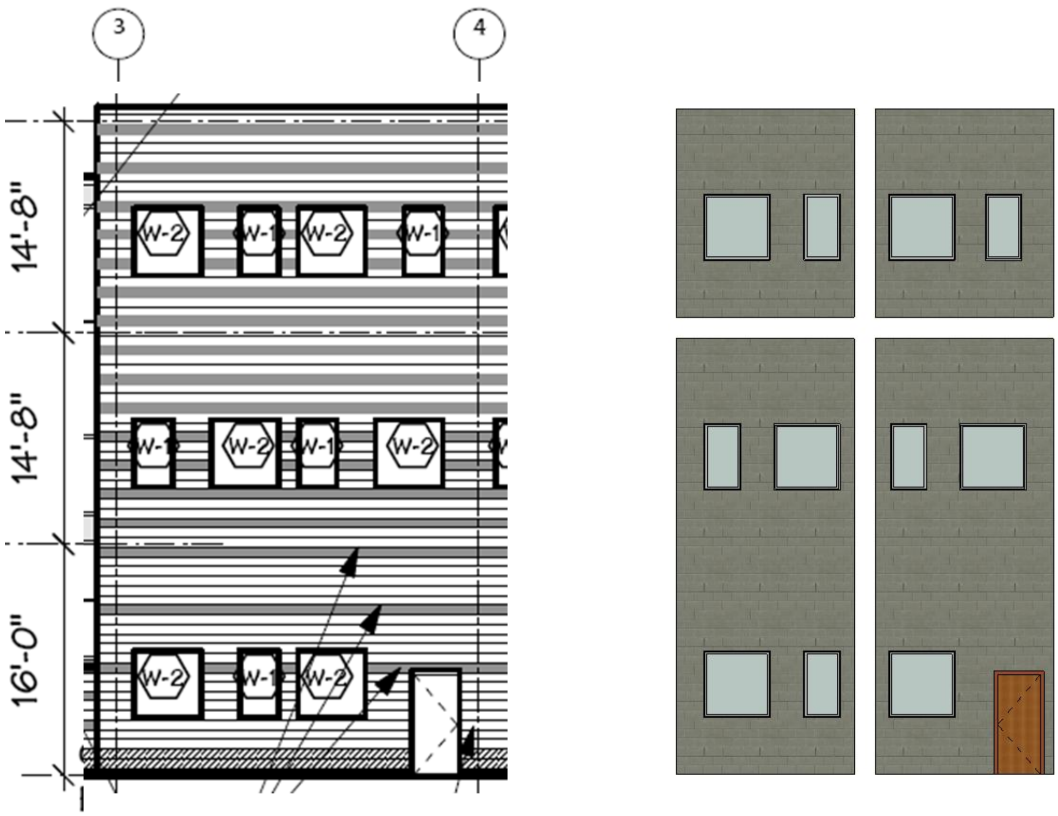


Figure 58: Section to be Panelized and Visual Representation

Upon consulting Mark Taylor of Nitterhouse Concrete, it was determined that a 9" insulated precast panel with a thin veneer could be used to meet the architects design goals. Panels will be connected to the structural frame of the building using metal flanges. A structural analysis was not performed for the sake of this analysis. Figure 60 to the right shows a cross section of the proposed panel. The panels do not incorporate an air cavity because the density of the precast panels will not allow any moisture to pass through.

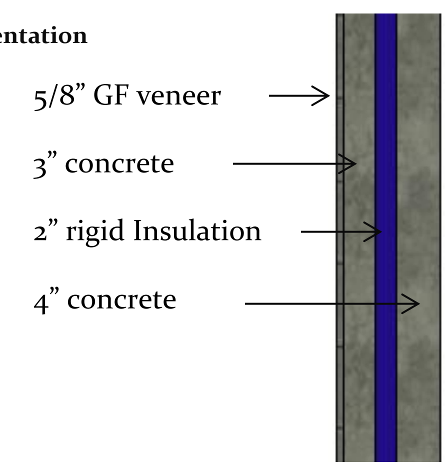


Figure 59: Cross Section of Panel

The panels that will be installed in areas A, B, C, and G of the building will be 4" thick with 2 inches of rigid insulation applied to the back.

Panel Quantity Calculation

The total number of panels that will be needed for the façade is 342. The following will give a detailed breakdown of how many panels each section of the building will have. It is important to note that the panel sizes given will have openings in them for windows and doors. (Reference Figures 61-66)

Section D

Square Footage of ground-face CMU = 18,550

(36) 29'4" x 12'6" panels
(26) 16' x 12'6" panels
(2) 10' x 8' panels
(8) 16' x 8' panels
(16) 16 x 7'4" panels
(1) 20' x 5' Panel

Total: 89 panels

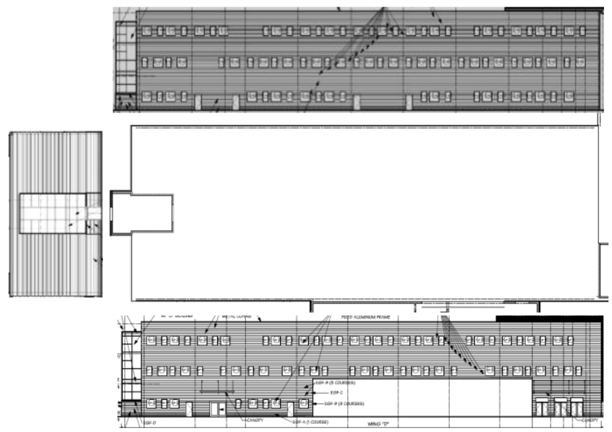


Figure 60: Section D Facade

Section E

Square Footage of ground-face CMU = 17,150

(28) 29'4" x 12'6" panels
(28) 16' x 12'6" panels
(2) 10' x 8' panels
(8) 16' x 8' panels
(16) 16 x 7'4" panels
(1) 20' x 5' panel

Total: 83 Panels

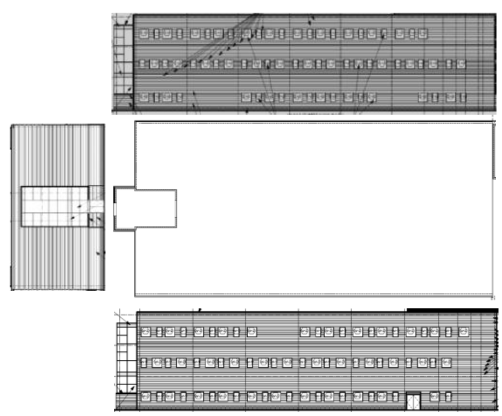


Figure 61: Section E Facade

Section F

Square footage of ground-face CMU = 6,060

(3) 17" x 10" panels
(1) 4' x 20' panel
(1) 8' x 20' panel
(4) 16' x 7'6" panels
(2) 16' x 13' panels
(2) 16' x 6'6" panels
(15) 11' x 22' panels
(3) 11' x 20' panels
(2) 11' x 31' panels

Total: 33 Panels

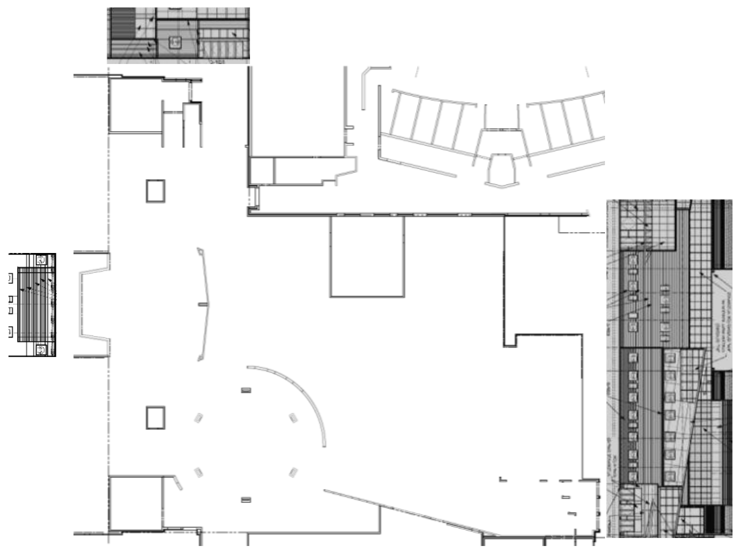


Figure 62: Section F Facade

Section G

Square footage of ground-face CMU = 11,200

(15) 10' x 25' panels
(5) 11' x 25' panels
(2) 9' x 25' panels
(2) 7'6" x 25' panels
(1) 9' x 30' panels
(2) 9' x 10' panels
(4) 12' x 25' panels
(1) 8' x 33' panel
(6) 10' x 25' panels
(10) 11' x 23' panels

Total: 48 Panels

Figure 63: Section G Facade

Section C

Square footage of ground-face = 9,950

(43) 10' x 18'9" panels
(6) 12' x 18'9" panels
(2) 6'9" x 30' panels
(2) 6'9" x 20' panels
(4) 12' x 3' panels

Total: 57 Panels

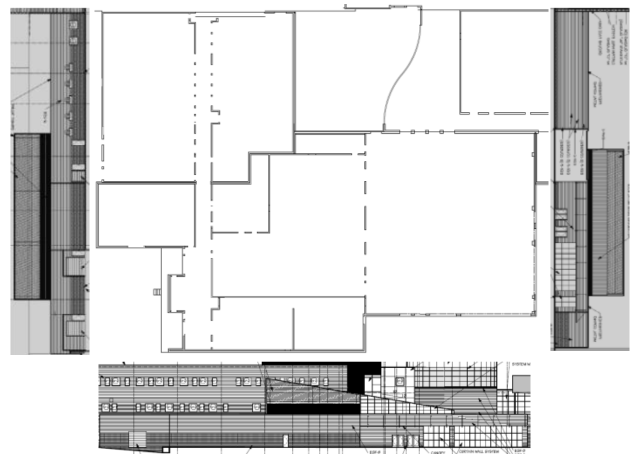


Figure 64: Section C Facade

Sections A & B

Square footage of ground-face = 5,470

(24) 10' x 18'9" panels
(4) 12' x 18'9" panels
(4) 6' x 18'9" panels

Total: 32 Panels

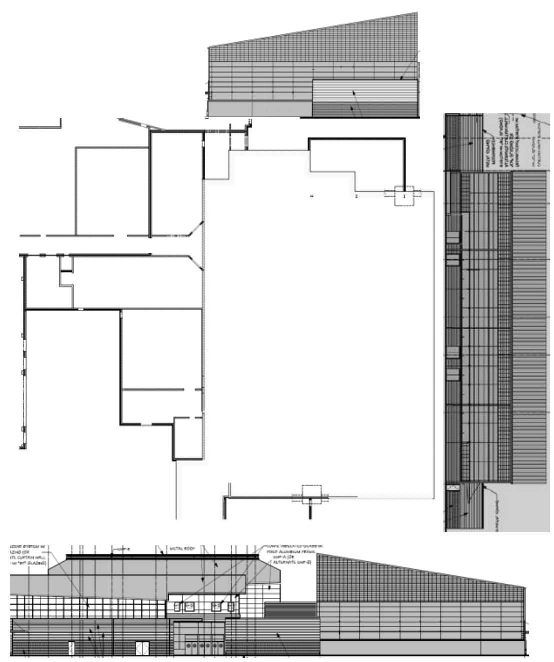


Figure 65: Section A & B Facade

Cost Impacts

The cost of the current ground face CMU façade on this building is **$2,233,500**. The cost of the CMU façade in sections A, B, C, and G, which equates to 27,300 SF, is approximately $14.10/SF. This price appears low because the Masonry substrate is not considered a part of the system. The cost for the façade in sections F, E, and D (41,700 SF) is approximately $44.33/SF.

The cost of the prefabricated panels which includes fabrication, delivery, and installation runs $35.00/SF. This means that the use of prefabricated panels on this building would cost $2,415,000, which is $181,500 more expensive than the current system. There is also an additional cost of $17,800 for keeping one of the two cranes onsite for an additional month to perform this work. This brings the total cost to $2,432,800. However, because using a precast façade is expected to decrease the overall project duration by 6 weeks $22,700 is saved in GC costs.

Total Cost of Original Façade: **$2,233,500**

Total Cost of Prefabricate Façade: **$2,410,100.**

Difference: **($176,600)**

Schedule Impacts

The use of precast panels for the façade will help speed up construction time and reduce delays caused by the weather. The lead time for these panels will typically take 5 to 6 months, so for this strategy to be viable it would have to be incorporated early on in the project.

Production rates for the installation of panels of this size vary from 15-30 minutes a panel depending on who is providing the information. For the sake of this analysis an average of one panel every 24 minutes will be allotted. It is expected that the first few panels will take longer, but because of the inherent learning curve associated with this work the process should become more streamlined over time. The 24 minutes also takes into account the need to reposition the crane throughout the process. Based on this information Table 14 was created to show the total time required to install the ground face CMU façade on each section of the building.

Section	# of Panels	Avg. Time/Panel		Total Time (min)	Total Time (Work Days)
D	89	24	min	2136	4.45
E	83	24	min	1992	4.15
F	33	24	min	792	1.65
G	48	24	min	1152	2.4
C	57	24	min	1368	2.85
A&B	32	24	min	768	1.6
					Total Days Spent: 17.1

Table 14: Time Required to Install Precast Façade Panels

By incorporating this adjusted information for installation of the façade into the original schedule, it is clear to see that this approach saves a significant amount of time (reference Table 15). In sections F, E, and D of the building this method is particularly advantageous because it eliminates the need to install metal studs. This whole process which would have originally taken approximately 4 months can be compressed down into just over 17 days. However this does not correlate to a 3 ½ month reduction in the schedule. It does allow for a reduction in schedule in each section of the building though. This means that trades that were held up by the façade can get started significantly earlier.

Section	Original Duration (8 Hr. Days)	Adjusted Duration (8 Hr. Days)	Reduction In Schedule (8 Hr. Days)
D:	60	4.45	55.55
E:	46	4.15	41.85
F:	19	1.65	17.35
G:	32	2.4	29.6
C:	41	2.85	38.15
A&B:	27	1.6	25.4

Table 15: Schedule Reduction Due to Precast

In terms of the overall project schedule, the building should be able to be completed 6 weeks sooner by utilizing a precast façade (see Figure 67).

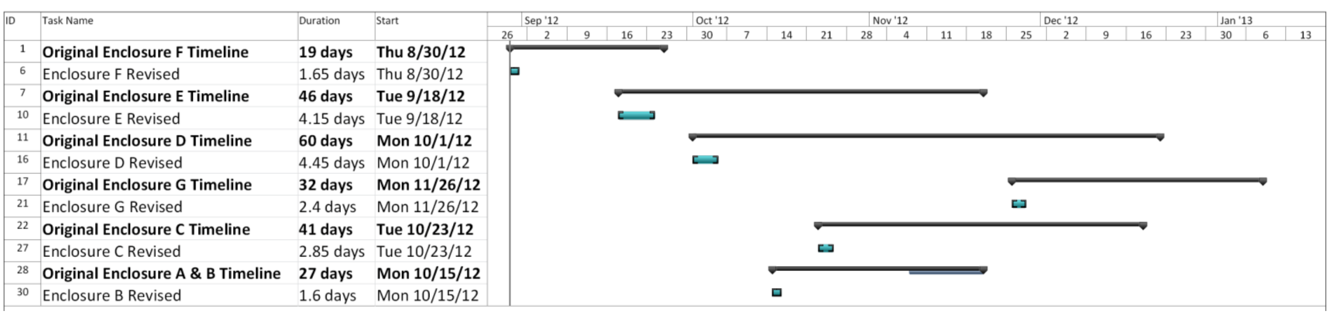


Figure 66: Adjusted Schedule Gant Chart

Conclusion

Switching the installation method of the envelope on this project has a wide range of benefits. The results of this analysis show that the cost of using a prefabricated façade is 8% more expensive than the currently proposed method. However this additional cost is diminished by the fact that it allows the overall project to be completed 6 weeks sooner, which is extremely important because this job is so time constrained. Switching to precast also creates a much cleaner site with less congestion, frees up work space sooner, allows for higher quality control, and is much safer than having laborers working off of scaffolding.

Based on the current time constraints on the project and additional benefits received from switching to precast, it is advised that this method be used.

Final Conclusion

By completing the four in-depth analyses which focused on critical industry issues, value engineering, constructability, and schedule the validity of the proposals for each analysis can be evaluated. The goal behind each one of these analyses was to try and find areas of the project that could be improved or altered to make the overall project run more smoothly.

The results of the mechanical analysis and breadths showed that by changing the current geothermal mechanical system into a hybrid system that it would be more efficient. This could be easily done by altering the structural design on the roof of the mechanical room so that it would be able support a 352 ton cooling tower. This change would result in the elimination of 4 joists to be replaced with three girders. This would have very little impact on constructability; one would only have to take into consideration new bearing plate heights for the girders. Installing the tower is not a large concern either because the 150 ton crane that would already be on site could easily place the unit. Due to the load characteristics of the building this cooling tower would typically only run a couple months out of the year. It would also greatly reduce the first cost of the system.

The owner was very adamant about creating a state-of-the-art facility, particularly in the field of science and technology. A great way of approaching this goal would be to implement systems that are cutting edge and gaining notoriety. Solar energy conversion systems definitely fall within that spectrum and Maryland provides great incentives for renewable energy projects. The system that was proposed would begin making money for the school district within five years of its implementation which is a strong reason for implementing a SECS on the school. The money that the system would generate could be extremely valuable to the district. Additionally it would not have a noticeable impact on the schedule of the project and it would be very easy to install.

Due to many of the difficulties that were associated with the project it was important to investigate the effect that an alternate delivery approach might have. A considerable amount of investigation was performed and it was determined that a design-build approach could potentially be a more efficient delivery method based on the problems occurred on this job. The findings showed that a design-build approach would increase construction and delivery speeds, reduce cost and schedule growth, foster more collaboration between parties, and reduce owner risk. However it would reduce owner input as well. The main beneficiary of this change in delivery method would be the construction manager and at the end of the day it is a decision that is up to the owner. Although they would receive some benefits by switching to this method they also receive some disadvantages. The major advantages gained by switching to this method are not necessarily seen by the owner.

Lastly schedule was a huge concern for this project and it was made even more important when the notice to proceed was given two months late. In an attempt to find ways to reduce the schedule a prefabricated façade system was investigated. Even though this approach added an additional 8% to the current price of the façade, it is still suggested that it be used. A precast façade would reduce the schedule by 6 weeks, create a cleaner site, allow for higher quality control, and create a safer site, among other things.

APPENDIX A: References

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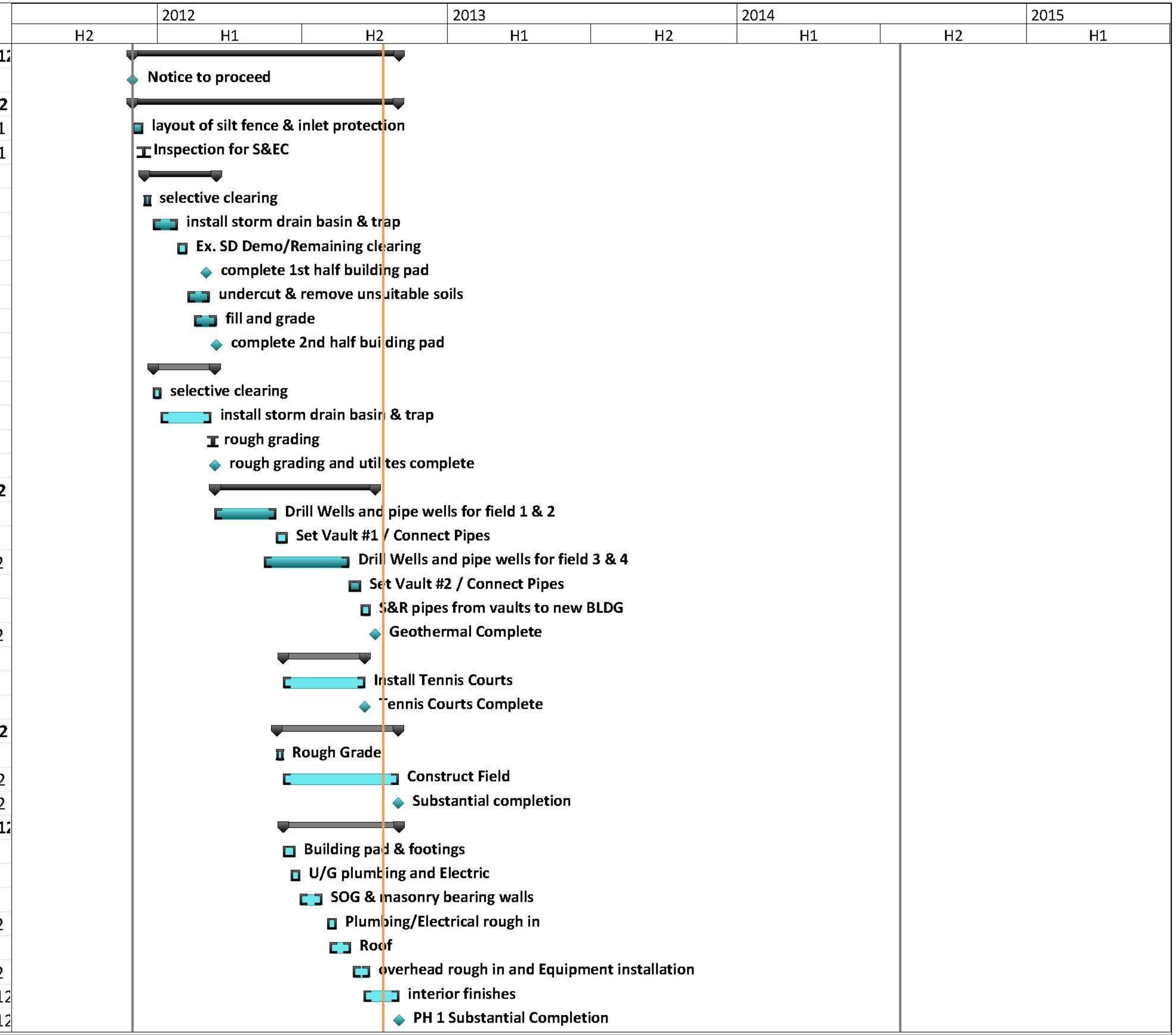
APPENDIX B: Detailed Project Schedule

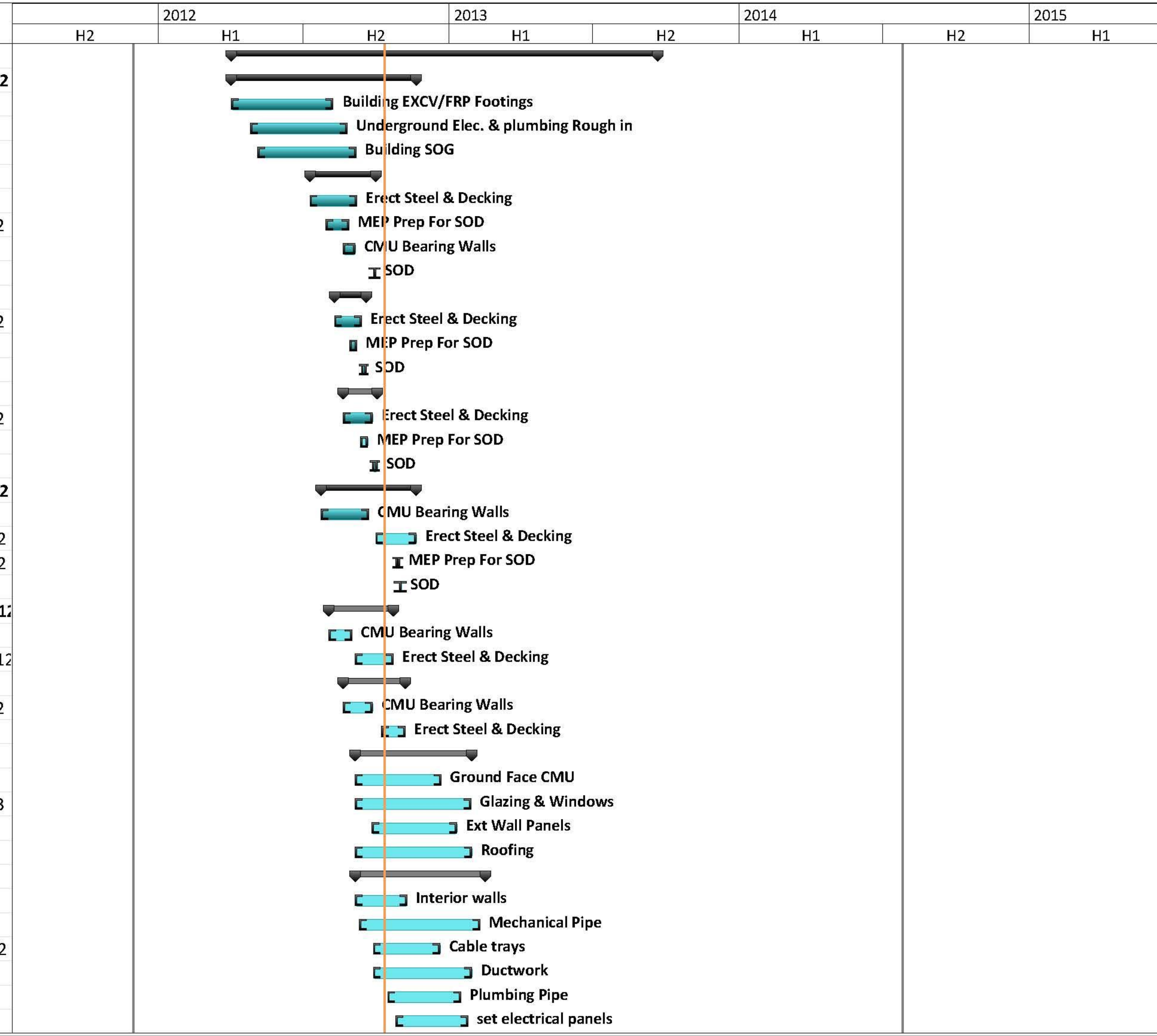
ID	Task Name	Duration	Start	Finish
1	**PH 1 BLDG Pad/FB Stadium/Field House/ Tennis CTS**	**240 days**	**Thu 12/1/11**	**Wed 10/31/12**
2	Notice to proceed	0 days	Thu 12/1/11	Thu 12/1/11
3	**Site Work**	**239 days**	**Thu 12/1/11**	**Tue 10/30/12**
4	layout of silt fence & inlet protection	9 days	Thu 12/1/11	Tue 12/13/11
5	Inspection for S&EC	1 day	Thu 12/15/11	Thu 12/15/11
6	**BLDG pad Preparation**	**65 days**	**Fri 12/16/11**	**Thu 3/15/12**
7	selective clearing	6 days	Fri 12/16/11	Fri 12/23/11
8	install storm drain basin & trap	23 days	Tue 12/27/11	Thu 1/26/12
9	Ex. SD Demo/Remaining clearing	8 days	Fri 1/27/12	Tue 2/7/12
10	complete 1st half building pad	0 days	Fri 3/2/12	Fri 3/2/12
11	undercut & remove unsuitable soils	19 days	Thu 2/9/12	Tue 3/6/12
12	fill and grade	20 days	Fri 2/17/12	Thu 3/15/12
13	complete 2nd half building pad	0 days	Thu 3/15/12	Thu 3/15/12
14	**Rough Grade & Utilities @ East Side of Site**	**56 days**	**Tue 12/27/11**	**Tue 3/13/12**
15	selective clearing	8 days	Tue 12/27/11	Thu 1/5/12
16	install storm drain basin & trap	45 days	Fri 1/6/12	Thu 3/8/12
17	rough grading	3 days	Fri 3/9/12	Tue 3/13/12
18	rough grading and utilites complete	0 days	Tue 3/13/12	Tue 3/13/12
19	**Geothermal Fields**	**144 days**	**Wed 3/14/12**	**Mon 10/1/12**
20	Drill Wells and pipe wells for field 1 & 2	55 days	Wed 3/14/12	Tue 5/29/12
21	Set Vault #1 / Connect Pipes	10 days	Wed 5/30/12	Tue 6/12/12
22	Drill Wells and pipe wells for field 3 & 4	77 days	Tue 5/15/12	Wed 8/29/12
23	Set Vault #2 / Connect Pipes	11 days	Thu 8/30/12	Thu 9/13/12
24	S&R pipes from vaults to new BLDG	8 days	Fri 9/14/12	Tue 9/25/12
25	Geothermal Complete	0 days	Mon 10/1/12	Mon 10/1/12
26	**Tennis Courts**	**73 days**	**Fri 6/8/12**	**Tue 9/18/12**
27	Install Tennis Courts	73 days	Fri 6/8/12	Tue 9/18/12
28	Tennis Courts Complete	0 days	Tue 9/18/12	Tue 9/18/12
29	**Football Field**	**109 days**	**Thu 5/31/12**	**Tue 10/30/12**
30	Rough Grade	6 days	Thu 5/31/12	Thu 6/7/12
31	Construct Field	103 days	Fri 6/8/12	Tue 10/30/12
32	Substantial completion	0 days	Tue 10/30/12	Tue 10/30/12
33	**Field House**	**104 days**	**Fri 6/8/12**	**Wed 10/31/12**
34	Building pad & footings	11 days	Fri 6/8/12	Fri 6/22/12
35	U/G plumbing and Electric	9 days	Mon 6/18/12	Thu 6/28/12
36	SOG & masonry bearing walls	20 days	Fri 6/29/12	Thu 7/26/12
37	Plumbing/Electrical rough in	7 days	Fri 8/3/12	Mon 8/13/12
38	Roof	20 days	Mon 8/6/12	Fri 8/31/12
39	overhead rough in and Equipment installation	15 days	Tue 9/4/12	Mon 9/24/12
40	interior finishes	32 days	Tue 9/18/12	Wed 10/31/12
41	PH 1 Substantial Completion	0 days	Wed 10/31/12	Wed 10/31/12



Project: Detailed Schedule
Date: Fri 10/12/12

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

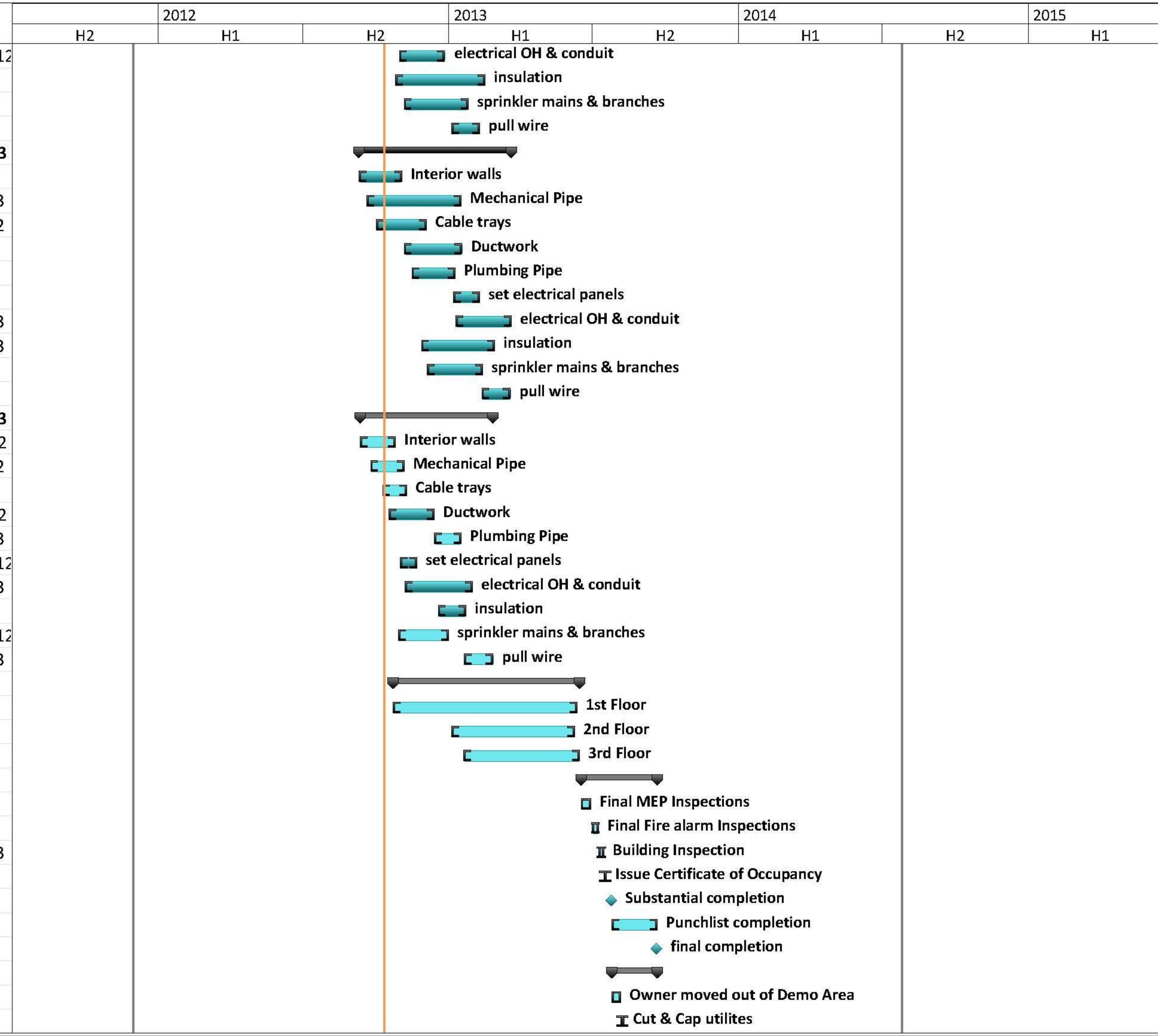
ID	Task Name	Duration	Start	Finish
42	**PH 2A: New School & Associated Work**	**385 days**	**Mon 4/2/12**	**Fri 9/20/13**
43	**Structure**	**167 days**	**Mon 4/2/12**	**Tue 11/20/12**
44	Building EXCV/FRP Footings	92 days	Mon 4/2/12	Tue 8/7/12
45	Underground Elec. & plumbing Rough in	88 days	Thu 4/26/12	Sat 8/25/12
46	Building SOG	89 days	Sat 5/5/12	Wed 9/5/12
47	**Area F**	**59 days**	**Tue 7/10/12**	**Sun 9/30/12**
48	Erect Steel & Decking	43 days	Tue 7/10/12	Thu 9/6/12
49	MEP Prep For SOD	21 days	Mon 7/30/12	Mon 8/27/12
50	CMU Bearing Walls	11 days	Tue 8/21/12	Tue 9/4/12
51	SOD	2 days	Fri 9/28/12	Sun 9/30/12
52	**Area E**	**28 days**	**Fri 8/10/12**	**Tue 9/18/12**
53	Erect Steel & Decking	24 days	Fri 8/10/12	Wed 9/12/12
54	MEP Prep For SOD	7 days	Wed 8/29/12	Thu 9/6/12
55	SOD	4 days	Thu 9/13/12	Tue 9/18/12
56	**Area D**	**31 days**	**Tue 8/21/12**	**Tue 10/2/12**
57	Erect Steel & Decking	27 days	Tue 8/21/12	Wed 9/26/12
58	MEP Prep For SOD	7 days	Wed 9/12/12	Thu 9/20/12
59	SOD	4 days	Thu 9/27/12	Tue 10/2/12
60	**Area G**	**86 days**	**Tue 7/24/12**	**Tue 11/20/12**
61	CMU Bearing Walls	44 days	Tue 7/24/12	Fri 9/21/12
62	Erect Steel & Decking	37 days	Mon 10/1/12	Tue 11/20/12
63	MEP Prep For SOD	3 days	Fri 10/26/12	Tue 10/30/12
64	SOD	2 days	Wed 10/31/12	Thu 11/1/12
65	**Area C**	**57 days**	**Fri 8/3/12**	**Mon 10/22/12**
66	CMU Bearing Walls	21 days	Fri 8/3/12	Fri 8/31/12
67	Erect Steel & Decking	34 days	Wed 9/5/12	Mon 10/22/12
68	**Area B & A**	**56 days**	**Tue 8/21/12**	**Tue 11/6/12**
69	CMU Bearing Walls	27 days	Tue 8/21/12	Wed 9/26/12
70	Erect Steel & Decking	22 days	Mon 10/8/12	Tue 11/6/12
71	**Enclosure**	**105 days**	**Wed 9/5/12**	**Tue 1/29/13**
72	Ground Face CMU	78 days	Wed 9/5/12	Fri 12/21/12
73	Glazing & Windows	104 days	Wed 9/5/12	Mon 1/28/13
74	Ext Wall Panels	77 days	Wed 9/26/12	Thu 1/10/13
75	Roofing	105 days	Wed 9/5/12	Tue 1/29/13
76	**1st Floor Rough-Ins**	**118 days**	**Wed 9/5/12**	**Fri 2/15/13**
77	Interior walls	47 days	Wed 9/5/12	Thu 11/8/12
78	Mechanical Pipe	110 days	Mon 9/10/12	Fri 2/8/13
79	Cable trays	60 days	Fri 9/28/12	Thu 12/20/12
80	Ductwork	88 days	Fri 9/28/12	Tue 1/29/13
81	Plumbing Pipe	66 days	Tue 10/16/12	Tue 1/15/13
82	set electrical panels	65 days	Fri 10/26/12	Thu 1/24/13



Project: Detailed Schedule
Date: Fri 10/12/12

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

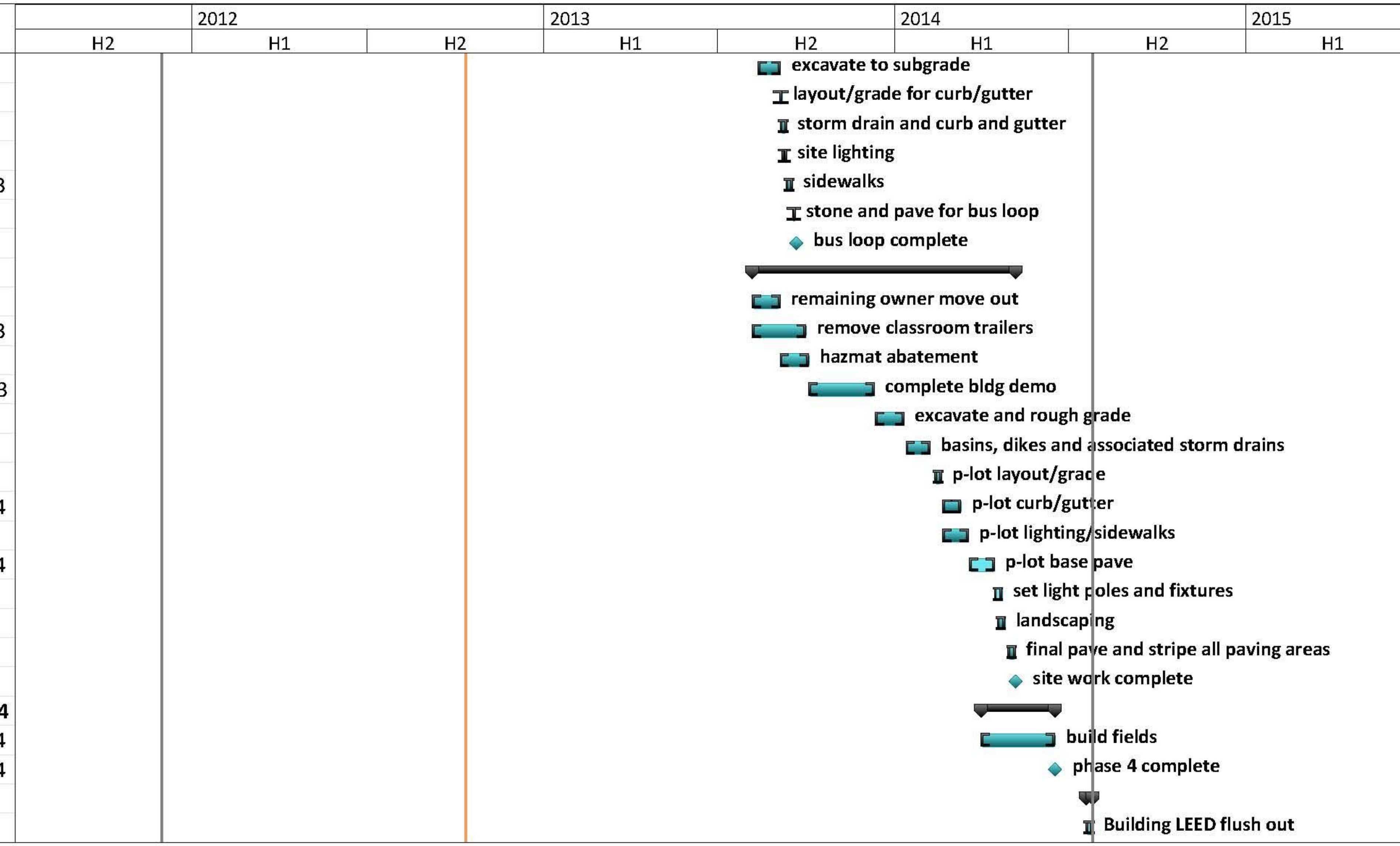
ID	Task Name	Duration	Start	Finish
83	electrical OH & conduit	41 days	Wed 10/31/12	Wed 12/26/12
84	insulation	81 days	Fri 10/26/12	Fri 2/15/13
85	sprinkler mains & branches	59 days	Tue 11/6/12	Fri 1/25/13
86	pull wire	26 days	Sat 1/5/13	Fri 2/8/13
87	**2nd Floor Rough-Ins**	**138 days**	**Mon 9/10/12**	**Wed 3/20/13**
88	Interior walls	40 days	Mon 9/10/12	Fri 11/2/12
89	Mechanical Pipe	85 days	Thu 9/20/12	Wed 1/16/13
90	Cable trays	45 days	Tue 10/2/12	Mon 12/3/12
91	Ductwork	53 days	Tue 11/6/12	Thu 1/17/13
92	Plumbing Pipe	38 days	Fri 11/16/12	Tue 1/8/13
93	set electrical panels	25 days	Mon 1/7/13	Fri 2/8/13
94	electrical OH & conduit	50 days	Thu 1/10/13	Wed 3/20/13
95	insulation	66 days	Wed 11/28/12	Wed 2/27/13
96	sprinkler mains & branches	50 days	Wed 12/5/12	Tue 2/12/13
97	pull wire	26 days	Tue 2/12/13	Tue 3/19/13
98	**3rd Floor Rough-Ins**	**119 days**	**Wed 9/12/12**	**Mon 2/25/13**
99	Interior walls	32 days	Wed 9/12/12	Thu 10/25/12
100	Mechanical Pipe	30 days	Tue 9/25/12	Mon 11/5/12
101	Cable trays	22 days	Wed 10/10/12	Thu 11/8/12
102	Ductwork	41 days	Thu 10/18/12	Thu 12/13/12
103	Plumbing Pipe	24 days	Fri 12/14/12	Wed 1/16/13
104	set electrical panels	15 days	Thu 11/1/12	Wed 11/21/12
105	electrical OH & conduit	61 days	Wed 11/7/12	Wed 1/30/13
106	insulation	25 days	Wed 12/19/12	Tue 1/22/13
107	sprinkler mains & branches	45 days	Tue 10/30/12	Mon 12/31/12
108	pull wire	26 days	Mon 1/21/13	Mon 2/25/13
109	**Finishes**	**169 days**	**Tue 10/23/12**	**Fri 6/14/13**
110	1st Floor	166 days	Tue 10/23/12	Tue 6/11/13
111	2nd Floor	112 days	Sat 1/5/13	Sat 6/8/13
112	3rd Floor	106 days	Sun 1/20/13	Fri 6/14/13
113	**Building Close-Out**	**70 days**	**Mon 6/17/13**	**Fri 9/20/13**
114	Final MEP Inspections	10 days	Mon 6/17/13	Fri 6/28/13
115	Final Fire alarm Inspections	6 days	Mon 7/1/13	Mon 7/8/13
116	Building Inspection	5 days	Tue 7/9/13	Mon 7/15/13
117	Issue Certificate of Occupancy	3 days	Tue 7/16/13	Thu 7/18/13
118	Substantial completion	0 days	Thu 7/25/13	Thu 7/25/13
119	Punchlist completion	41 days	Fri 7/26/13	Fri 9/20/13
120	final completion	0 days	Fri 9/20/13	Fri 9/20/13
121	**Phase 2B: Drive Isle**	**41 days**	**Fri 7/26/13**	**Fri 9/20/13**
122	Owner moved out of Demo Area	7 days	Fri 7/26/13	Mon 8/5/13
123	Cut & Cap utilites	4 days	Tue 8/6/13	Fri 8/9/13



Project: Detailed Schedule
Date: Fri 10/12/12

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

ID	Task Name	Duration	Start	Finish
124	excavate to subgrade	17 days	Mon 8/12/13	Tue 9/3/13
125	layout/grade for curb/gutter	2 days	Wed 9/4/13	Thu 9/5/13
126	storm drain and curb and gutter	5 days	Wed 9/4/13	Tue 9/10/13
127	site lighting	3 days	Fri 9/6/13	Tue 9/10/13
128	sidewalks	5 days	Tue 9/10/13	Mon 9/16/13
129	stone and pave for bus loop	3 days	Tue 9/17/13	Thu 9/19/13
130	bus loop complete	0 days	Fri 9/20/13	Fri 9/20/13
131	**Phase 3: BLDG DEMO/NEW PKG LOT**	**196 days**	**Tue 8/6/13**	**Tue 5/6/14**
132	remaining owner move out	21 days	Tue 8/6/13	Tue 9/3/13
133	remove classroom trailers	40 days	Tue 8/6/13	Mon 9/30/13
134	hazmat abatement	22 days	Wed 9/4/13	Thu 10/3/13
135	complete bldg demo	48 days	Fri 10/4/13	Tue 12/10/13
136	excavate and rough grade	22 days	Thu 12/12/13	Fri 1/10/14
137	basins, dikes and associated storm drains	19 days	Mon 1/13/14	Thu 2/6/14
138	p-lot layout/grade	5 days	Wed 2/12/14	Tue 2/18/14
139	p-lot curb/gutter	13 days	Thu 2/20/14	Mon 3/10/14
140	p-lot lighting/sidewalks	19 days	Thu 2/20/14	Tue 3/18/14
141	p-lot base pave	18 days	Thu 3/20/14	Mon 4/14/14
142	set light poles and fixtures	6 days	Tue 4/15/14	Tue 4/22/14
143	landscaping	6 days	Fri 4/18/14	Fri 4/25/14
144	final pave and stripe all paving areas	6 days	Tue 4/29/14	Tue 5/6/14
145	site work complete	0 days	Tue 5/6/14	Tue 5/6/14
146	**Phase 4: Baseball & Softball Fields**	**55 days**	**Tue 4/1/14**	**Mon 6/16/14**
147	build fields	55 days	Tue 4/1/14	Mon 6/16/14
148	phase 4 complete	0 days	Mon 6/16/14	Mon 6/16/14
149	**Close Out**	**5 days**	**Sat 7/19/14**	**Fri 7/25/14**
150	Building LEED flush out	6 days	Sat 7/19/14	Fri 7/25/14

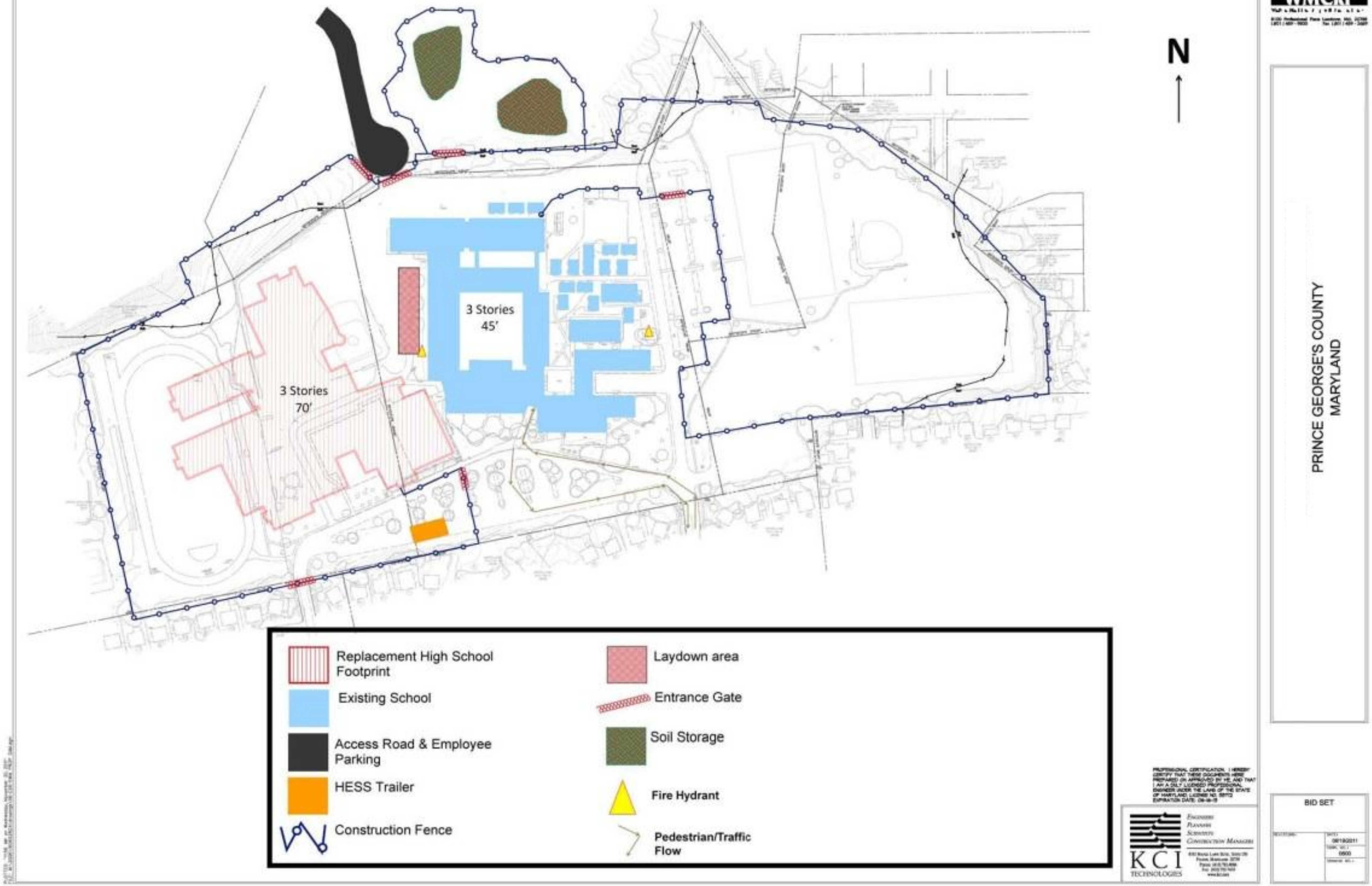


Project: Detailed Schedule
Date: Fri 10/12/12

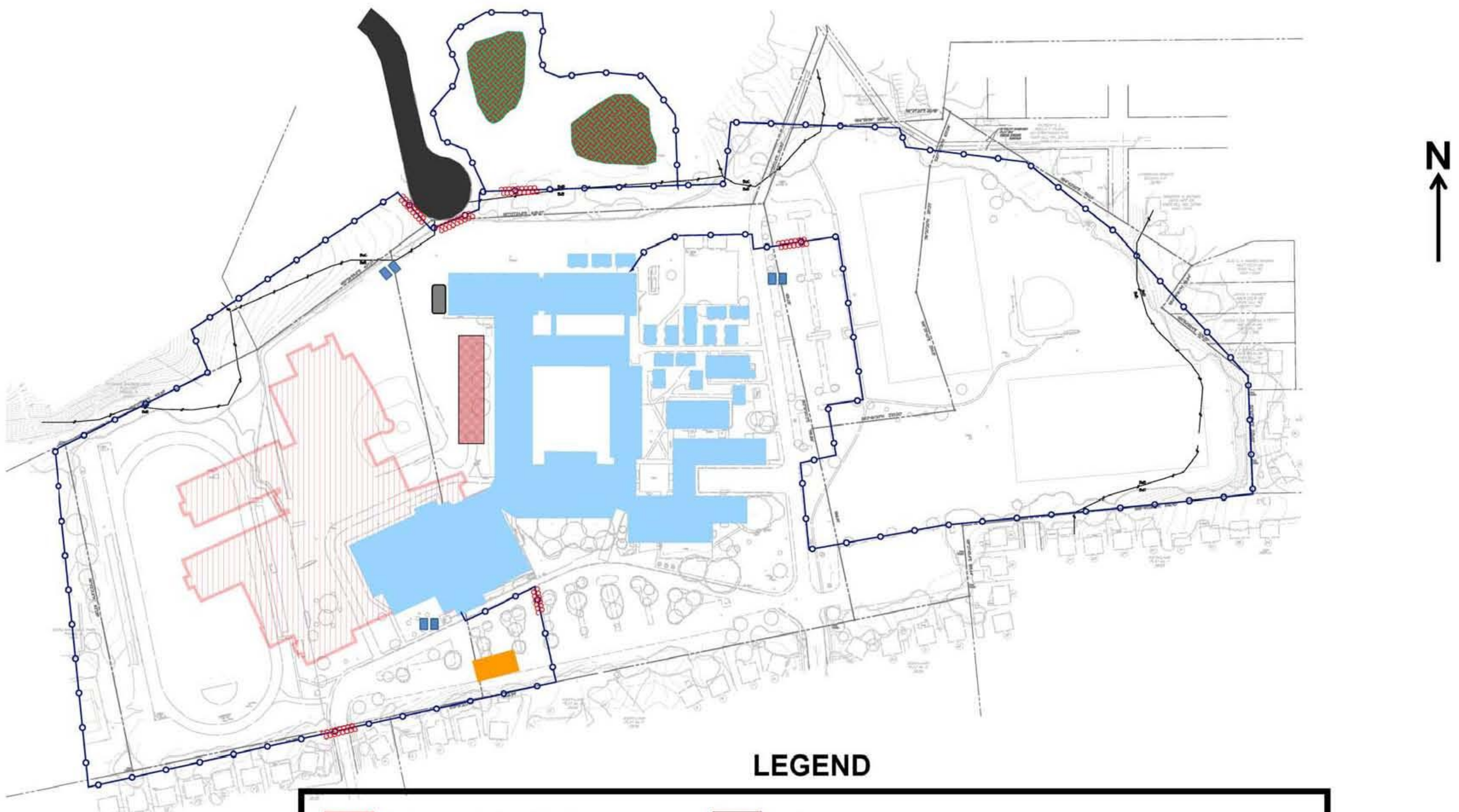
Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

APPENDIX C: Existing Conditions & Site Plans

HIGH SCHOOL REPLACEMENT
Site Plan of Existing Conditions
BRADY SHEERIN



HIGH SCHOOL REPLACEMENT
SITE CLEARING & BUILDING PAD FILL SITE PLAN
BRADY SHEERIN



LEGEND

Replacement High School Footprint	Laydown area
Existing School	Entrance Gate
Access Road & Employee Parking	Soil Storage
HESS Trailer	Toilets
Construction Fence	Dumpster

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MARYLAND

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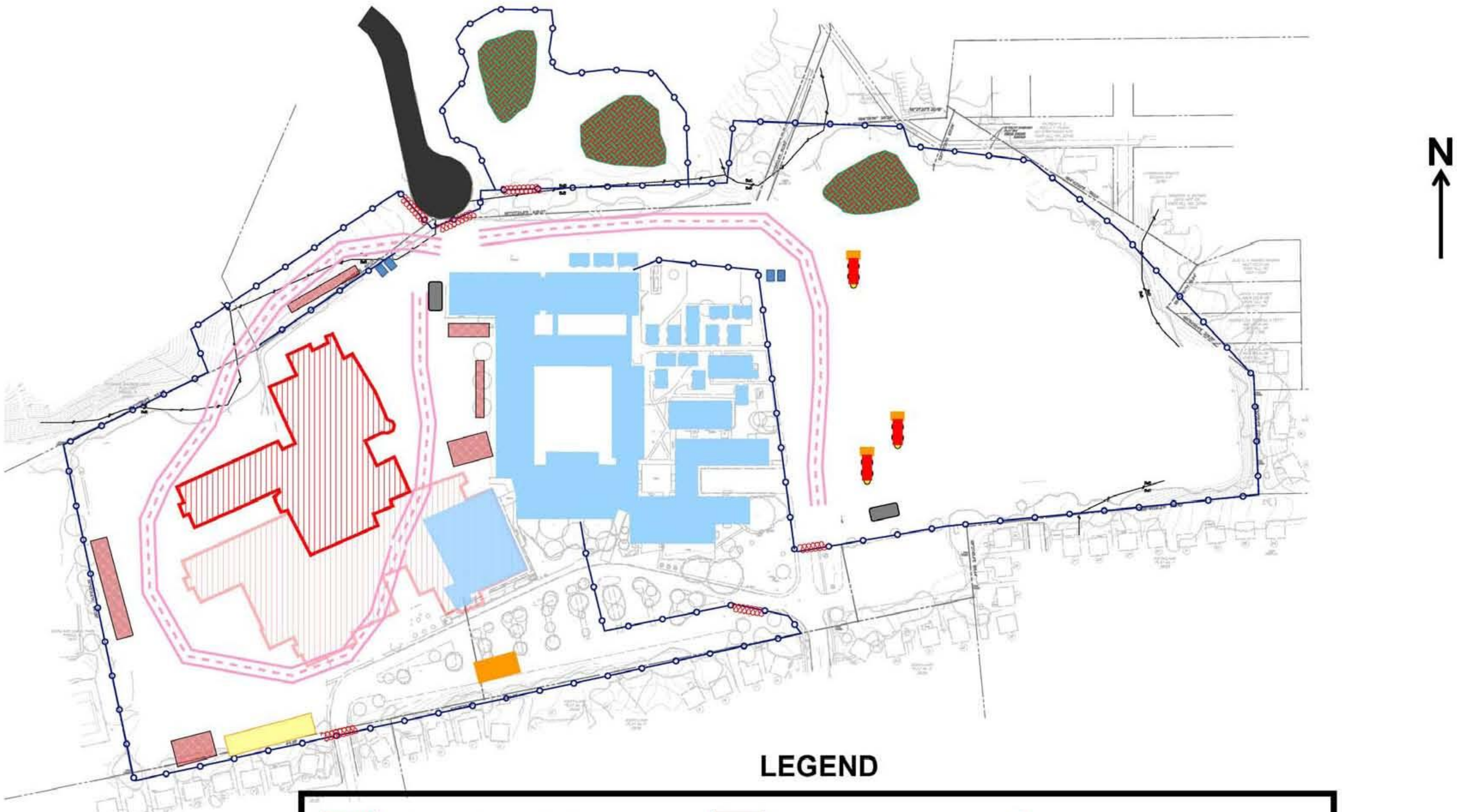
REVISIONS:	
	DATE: 09/19/2011
	COMM. NO.: 0600
	DRAWING NO.:

HIGH SCHOOL REPLACEMENT

FOUNDATIONS & SOG SITE PLAN

BRADY SHEERIN



LEGEND

Replacement High School Footprint	Laydown area
Existing School	Entrance Gate
Access Road & Employee Parking	Soil Storage
HESS Trailer	Storage Containers & Sub Trailers
Construction Fence	Geothermal Well Driller
Access Paths	Dumpster
Toilets	

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	DRAWING NO.:

HIGH SCHOOL REPLACEMENT
SUPERSTRUCTURE SITE PLAN
BRADY SHEERIN

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CONSTRUCTION MANAGERS

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DATE: 09/19/2011

0600

APPENDIX D: ASHRAE Tables

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multi-use assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
General									
Break rooms	5	2.5	0.06	0.3		25	10	5.1	1
Coffee stations	5	2.5	0.06	0.3		20	11	5.5	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	–	–	0.06	0.3		–			1
Storage rooms	–	–	0.12	0.6	B	–			1
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Office Buildings									
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
Electrical equipment rooms	–	–	0.06	0.3	B	–			1
Elevator machine rooms	–	–	0.12	0.6	B	–			1
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	–	–	0.12	0.6	B	–			1
Telephone closets	–	–	0.00	0.0		–			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	–	–	0.06	0.3	B	–			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	–	–	0.06	0.3					1
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.06	0.3		20	11	5.3	2

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(continued)*

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Sports and Entertainment									
Sports arena (play area)	–	–	0.30	1.5	E	–			1
Gym, stadium (play area)	–	–	0.30	1.5		30			2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	–	–	0.48	2.4	C	–			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	1
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6-1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.

2 **Smoking:** This table applies to no-smoking areas. Rates for smoking-permitted spaces must be determined using other methods. See Section 6.2.9 for ventilation requirements in smoking areas.

3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.

5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.

6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.

7 **Health-care facilities:** Rates shall be determined in accordance with Appendix E.

ITEM-SPECIFIC NOTES FOR TABLE 6-1

A For high school and college libraries, use values shown for Public Assembly Spaces—Libraries.

B Rate may not be sufficient when stored materials include those having potentially harmful emissions.

C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.

D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.

E When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.

F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

TABLE 9.6.1 Lighting Power Densities Using the Space-by-Space Method *(continued)*

Common Space Types[a]	*LPD*, W/ft^2	Building-Specific Space Types	*LPD*, W/ft^2
Workshop	1.9	Religious Buildings	
Sales Area [for accent lighting, see Section 9.6.2(b)]	1.7	Worship Pulpit, Choir	2.4
		Fellowship Hall	0.9
		Retail	
		Sales Area [for accent lighting, see Section 9.6.3(c)]	1.7
		Mall Concourse	1.7
		Sports Arena	
		Ring Sports Area	2.7
		Court Sports Area	2.3
		Indoor Playing Field Area	1.4
		Warehouse	
		Fine Material Storage	1.4
		Medium/Bulky Material Storage	0.9
		Parking Garage—Garage Area	0.2
		Transportation	
		Airport—Concourse	0.6
		Air/Train/Bus—Baggage Area	1.0
		Terminal—Ticket Counter	1.5

[a] In cases where both a common space type and a building-specific type are listed, the building specific space type shall apply.

TABLE 9.6.1 Lighting Power Densities Using the Space-by-Space Method

Common Space Types[a]	LPD, W/ft²	Building-Specific Space Types	LPD, W/ft²
Office—Enclosed	1.1	Gymnasium/Exercise Center	
Office—Open Plan	1.1	Playing Area	1.4
Conference/Meeting/Multipurpose	1.3	Exercise Area	0.9
Classroom/Lecture/Training	1.4	Courthouse/Police Station/Penitentiary	
For Penitentiary	1.3	Courtroom	1.9
Lobby	1.3	Confinement Cells	0.9
For Hotel	1.1	Judges' Chambers	1.3
For Performing Arts Theater	3.3	Fire Stations	
For Motion Picture Theater	1.1	Engine Room	0.8
Audience/Seating Area	0.9	Sleeping Quarters	0.3
For Gymnasium	0.4	Post Office—Sorting Area	1.2
For Exercise Center	0.3	Convention Center—Exhibit Space	1.3
For Convention Center	0.7	Library	
For Penitentiary	0.7	Card File and Cataloging	1.1
For Religious Buildings	1.7	Stacks	1.7
For Sports Arena	0.4	Reading Area	1.2
For Performing Arts Theater	2.6	Hospital	
For Motion Picture Theater	1.2	Emergency	2.7
For Transportation	0.5	Recovery	0.8
Atrium—First Three Floors	0.6	Nurses' Station	1.0
Atrium—Each Additional Floor	0.2	Exam/Treatment	1.5
Lounge/Recreation	1.2	Pharmacy	1.2
For Hospital	0.8	Patient Room	0.7
Dining Area	0.9	Operating Room	2.2
For Penitentiary	1.3	Nursery	0.6
For Hotel	1.3	Medical Supply	1.4
For Motel	1.2	Physical Therapy	0.9
For Bar Lounge/Leisure Dining	1.4	Radiology	0.4
For Family Dining	2.1	Laundry—Washing	0.6
Food Preparation	1.2	Automotive—Service/Repair	0.7
Laboratory	1.4	Manufacturing	
Restrooms	0.9	Low Bay (<25 ft Floor to Ceiling Height)	1.2
Dressing/Locker/Fitting Room	0.6	High Bay (≥25 ft Floor to Ceiling Height)	1.7
Corridor/Transition	0.5	Detailed Manufacturing	2.1
For Hospital	1.0	Equipment Room	1.2
For Manufacturing Facility	0.5	Control Room	0.5
Stairs—Active	0.6	Hotel/Motel Guest Rooms	1.1
Active Storage	0.8	Dormitory—Living Quarters	1.1
For Hospital	0.9	Museum	
Inactive Storage	0.3	General Exhibition	1.0
For Museum	0.8	Restoration	1.7

APPENDIX E: Cooling Tower Spec Sheet

SPX

ENGINEERING DATA

NC® 8400 steel

COOLING TOWER

Marley®

Overview

Marley's flagship factory-assembled cooling tower, providing higher performance, fast installation and easy maintenance.

Primary Benefits

- Higher tonnage and efficiency per cell can lower energy costs up to 20%
- Up to 64% less installation time per cell, providing over $1400 savings per cell, over previous designs
- Less than half the maintenance costs for gear drives compared to belt drive systems

Benefit Detail

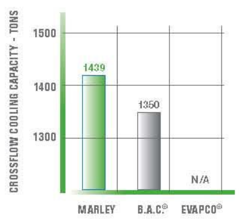
Higher Tonnage and Efficiency:

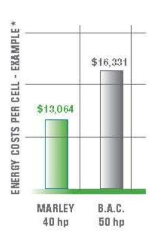
- Highest capacity package cooling tower in the market* helps to reduce the number of cells required, saving purchasing costs
- Higher efficiency design can provide up to 20% lower energy costs

Fast Installation:

- Up to 64% faster installation than previous designs provides over $1000 in savings per cell
- Quick Installation features include:
  - – Factory-mounted terminal box option — provides a single location for all controls wiring
  - – Quick-Install guardrails and aluminum ladders and welded aluminum safety cages options
  - – Four-point support allows parallel I-beams in any direction or separate piers

*as of May, 2010





* assumes nameplate motor horsepower for a 610 ton cooling tower with a footprint of 250 sq ft — $0.10/kWh and 50% annual usage

field installation hours	*latest design*	*previous design*
Ladder and Guardrail	2	3
Ladder Safety Cage	.25	4
Fan Cylinder	0	1
Access Platform	5	7
Factory Installed Terminal Box	4	16
total	11.25	31

based on $75/hour, savings per tower cell would be over $1,480

Benefit Detail

Easy Maintenance:

- Gear drive standard — 5 year no-hassle operation
- Integral louvers and eliminators provide water containment and freezing prevention compared to blade louvers used by other manufacturers
- Bolted and/or welded basins stop leaks better than tap screwed connections used by other manufacturers
- Large access doors and a flat fan deck designed as a walking surface makes tower service checks easier

	No-Hassle System 5 Geareducer®	belt drive
Annual Maintenance	$624	$2,380
5 Year Maintenance	$4,270	$11,900
example savings	$7,630	

Special Design Considerations

- ASHRAE® Std. 90.1 compliant
- Full set of design options:
  - – CTI Certified sound options including attenuation and/or Ultra Quiet fan
  - – Splash fill for dirty water applications - NC Alpha
  - – Plume abatement - NCWD
  - – Marley controls and VFD options for superior energy management
- 3D configuration specific drawings provided with quotes and orders
- FM Approval option on every model including FRP fan cylinder and PVC inlet piping

Capacity Range

101 to 1439 tons per cell at 95°/85°/78°F

303 to 4307 GPM per cell hydraulic limit

Technical Features

- Induced draft, crossflow design with vertical air discharge
- Non-corrosive stainless steel or galvanized structure with bolted galvanized or welded stainless steel cold water basin
- TEFC motor, low sound fan standard
- Drift rates as low as 0.001%
- Belt drive available on all models up to 60hp
- Assembled with as much as 71% recycled content

Common Applications

HVAC

- Mission critical data centers, hospitals and health treatment facilities, commercial buildings, schools and colleges

Industrial

- Chemical, fertilizer, grain processing, ethanol production, metals, mining, oil refining, textiles and steel production

Power Generation

- Turbine inlet cooling, jacket cooling and trim cooling during peak heat load

THE NC—QUIET BY DESIGN

The NC is the result of extensive design studies focused on cooling tower sound control. These studies were complicated by the fact that the cooling tower market is typically driven by one of two powerful, yet often conflicting requirements. The most common is for a cooling tower that provides the required heat rejection capacity with a high level of reliability at low cost. Sound control, while important, is not the primary consideration for this application.

The other requirement, which is becoming ever more important in our crowded, fast-paced society, is driven by conditions that demand the lowest practical sound level. Energy efficiency, reliability, ease of maintenance and reasonable cost, while still extremely important, are not the highest priorities

In the first case, sound is important, while in the second case it is extremely important. To best satisfy these two competing market requirements we created a multi-tiered approach, through key mechanical equipment selections, to sound control. The result is more options than any other cooling tower on the market today.

The result is a line of towers capable of meeting all but the most restrictive noise limitations—and that will react favorably to natural attenuation. Where the tower has been sized to operate within an enclosure, the enclosure itself will have a damping effect on sound. Sound also declines with distance—by about 6 dBA each time the distance doubles.

All standard NC cooling towers are equipped with low sound fans. This in combination with zero-splash crossflow film-fill results in a line of towers capable of meeting most noise limitations. Where noise at a critical point is likely to exceed an acceptable limit, several other options are available—listed below in ascending order of cost impact:

- The Marley "Quiet Package" includes the affordable Quiet Fan mechanical option, optimized to achieve the lowest possible sound levels while maintaining efficiency.
- A Marley Variable Speed Drive automatically minimizes the tower's noise level during periods of reduced load and/or reduced ambient temperature without sacrificing the system's ability to maintain a constant cold water temperature. This is a relatively inexpensive solution, and can pay for itself quickly in reduced energy costs. The natural nighttime reduction in wet-bulb temperature makes this a very feasible solution in most areas of the world. It also eliminates fan cycling. In combination with a Marley Quiet Package, the Marley Variable Speed Drive is capable of meeting all but the most restrictive noise limitations.
- The most extreme cases may require inlet and discharge sound attenuator sections—however, the static pressure loss imposed by discharge attenuators may necessitate an increase in tower size. Two stages of inlet or discharge attenuators supported by the tower and designed and tested for the most stringent requirements are available as an option. See page 24.
- For more severe cases requiring the lowest possible fan sound levels the Marley "Ultra Quiet" fan option is now available on most NC models. Tower height will increase—obtain current sales drawings from your Marley sales representative for accurate dimensions.

The advantage is yours. You now have the choices you need to balance your project's performance, space and cost requirements with your sound level needs for a win-win solution to your cooling system design.

ENCLOSURES

Occasionally, cooling towers are located inside architectural enclosures for aesthetic reasons. Although NC towers adapt well to enclosures, the designer must realize the potential impact of a poorly arranged enclosure on the tower's performance and operation. The designer must take care to provide generous air inlet paths, and the tower's fan cylinder discharge height should not be lower than the elevation of the top of the enclosure. *Marley Technical Report #H-004* "External Influences on Cooling Tower Performance" is available at spxcooling.com or from your Marley sales representative.

As suggested in the aforementioned Technical Report, it may also be advisable to specify a design wet-bulb temperature 1°F higher than normal to compensate for potential recirculation initiated by the enclosure. You'll benefit from discussing your project with your Marley sales representative.

Marley "Ultra Quiet" fan

SYSTEM CLEANLINESS

Cooling towers are very effective air washers. Atmospheric dust able to pass through the relatively small louver openings will enter the circulating water system. Increased concentrations can intensify system maintenance by clogging screens and strainers—and smaller particulates can coat system heat transfer surfaces. In areas of low flow velocity—such as the cold water basin—sedimentary deposits can provide a breeding ground for bacteria.

In areas prone to dust and sedimentation, you should consider installing some means for keeping the cold water basin clean. Typical devices include side stream filters and a variety of filtration media.

WATER TREATMENT

To control the buildup of dissolved solids resulting from water evaporation, as well as airborne impurities and biological contaminants including Legionella, an effective consistent water treatment program is required. Simple blowdown may be adequate to control corrosion and scale, but biological contamination can only be controlled with biocides.

An acceptable water treatment program must be compatible with the variety of materials incorporated in a cooling tower—ideally the pH of the circulating water should fall between 6.5 and 8.0. Batch feeding of chemicals directly into the cooling tower is not a good practice since localized damage to the tower is possible. Specific startup instructions and additional water quality recommendations can be found in the **NC User Manual** which accompanies the tower and also is available from your local Marley sales representative. For complete water treatment recommendations, consult a competent, qualified water treatment supplier.

⚠ **CAUTION**

The cooling tower must be located at such distance and direction to avoid the possibility of contaminated discharge air being drawn into building fresh air intake ducts. The purchaser should obtain the services of a Licensed Professional Engineer or Registered Architect to certify that the location of the cooling tower is in compliance with applicable air pollution, fire and clean air codes.

TYPICAL APPLICATIONS

The NC tower is an excellent choice for normal applications requiring cold water for the dissipation of heat. This includes condenser water cooling for air conditioning, refrigeration, and thermal storage systems, as well as their utilization for free-cooling in all of those systems. The NC can also be used in the cooling of jacket water for engines and air compressors, and are widely applied to dissipate waste heat in a variety of industrial, power and manufacturing processes.

Choosing the all stainless steel construction option, the NC can be confidently applied in unusually corrosive processes and operating environments. However, no single product line can answer all problems, and selective judgement should be exercised in the following situations

APPLICATIONS REQUIRING ALTERNATIVE COOLING TOWER SELECTIONS

Certain types of applications are incompatible with any cooling tower with film fill—whether NC or a competitive tower of similar manufacture. Film fill is subject to distortion in high water temperatures, and the narrow passages are easily clogged by turbid or debris-laden water. Some of the applications, which call for alternative tower designs are:

- **Ethylene glycol content**—can plug fill passages as slime and algae accumulate to feed on the available organic materials.
- **Fatty acid content**—found in processes such as soap and detergent manufacturing and some food processing—fatty acids pose a serious threat for plugging fill passages.
- **Particulate carry over**—often found in steel mills and cement plants—can both cause fill plugging, and can build up to potentially damaging levels on tower structure.
- **Pulp carry over**—typical of the paper industry and food processing where vacuum pumps or barometric condensers are used. Causes fill plugging which may be intensified by algae.

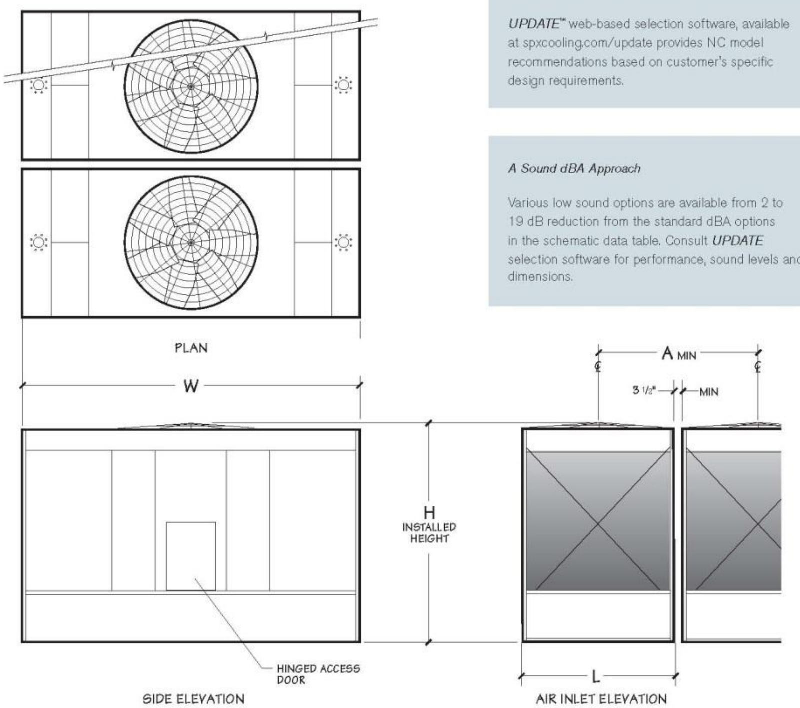
ALTERNATIVE SELECTIONS

In addition to the NC, SPX Cooling Technologies offers a full scope of products in various designs and capacities to meet the special demands of specific applications.

spxcooling.com—visit us on the web for a complete list of products, services, publications and to find your nearest sales representative.

NC Steel Cooling Tower — Schematic 4

NC8401 NC8402 NC8403 NC8405



Use this data for preliminary layouts only. Obtain current drawing from your Marley sales representative.

UPDATE™ web-based selection software, available at spxcooling.com/update provides NC model recommendations based on customer's specific design requirements.

A Sound dBA Approach

Various low sound options are available from 2 to 19 dB reduction from the standard dBA options in the schematic data table. Consult *UPDATE* selection software for performance, sound levels and dimensions.

NC Steel Cooling Tower — Schematic Data 5

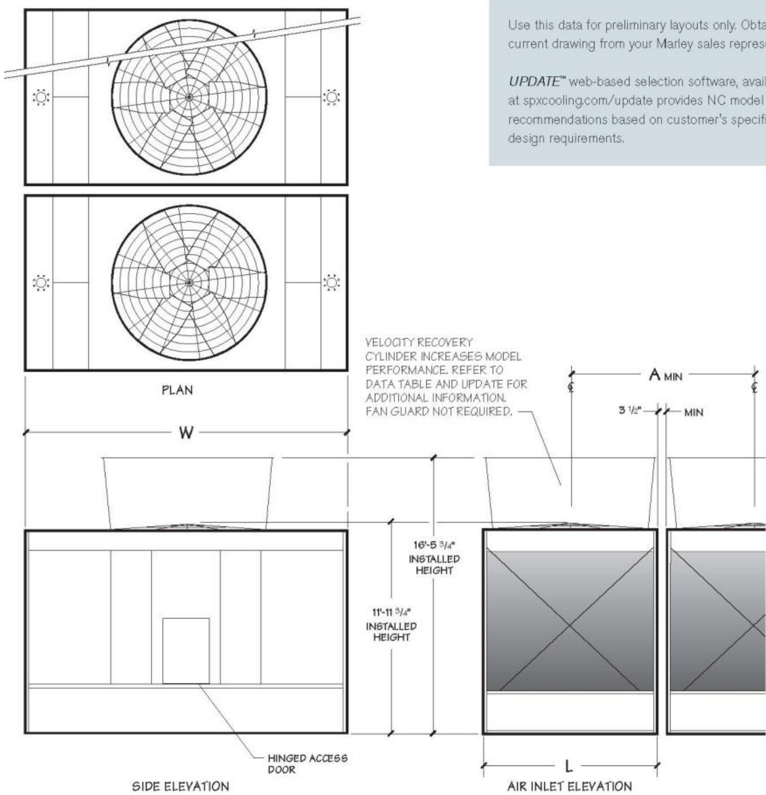
NC8401 NC8402 NC8403 NC8405

Model note 2	Nominal Tons note 3	Motor hp	dBA 5'-0" from air inlet face	Design Operating Weight lb	Shipping Weight lb	Dimensions			
						L	W	H	A
NC8401G-1	101	2	63	7889	4062	6'-6¼"	12'-10"	10'-2½"	6'-9¾"
NC8401H-1	117	3	65						
NC8401K-1	139	5	71						
NC8401M-1	159	7.5	73						
NC8401N-1	175	10	76						
NC8401P-1	198	15	78						
NC8402G-1	131	2	64	10319	4890	8'-4¾"	14'-2"	10'-3"	8'-8¼"
NC8402H-1	148	3	65						
NC8402K-1	175	5	68						
NC8402M-1	205	7.5	74						
NC8402N-1	228	10	76						
NC8402P-1	256	15	79						
NC8402Q-1	277	20	81						
NC8403K-1	213	5	68	15844	7442	8'-4¾"	18'-2"	11'-11¼"	8'-8¼"
NC8403M-1	243	7.5	72						
NC8403N-1	275	10	76						
NC8403P-1	312	15	79						
NC8403Q-1	342	20	80						
NC8403R-1	366	25	81						
NC8403S-1	386	30	84						
NC8403T-1	423	40	85						
NC8405N-1	331	10	74	19480	8685	9'-10¾"	19'-11"	11'-11¼"	10'-2¼"
NC8405P-1	377	15	76						
NC8405Q-1	412	20	78						
NC8405R-1	445	25	81						
NC8405S-1	472	30	84						
NC8405T-1	515	40	87						

NOTE

1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative. All table data is per cell.
2 Last numeral of model number indicates number of cells. Change as appropriate for your selection.
3 Nominal tons are based upon 95°F HW, 85°F CW, 78°F WB and 3 GPM/ton. The UPDATE web-based selection software provides NC model recommendations based on specific design requirements.
4 Standard overflow is a 4" dia. standpipe in the collection basin floor. The standpipe removes for flush-out and draining. See page 18 for side overflow option.
5 Outlet sizes vary according to GPM and arrangement. See pages 18 and 19 for outlet sizes and details.
6 Makeup water connection may be 1" or 2" dia., depending upon tower heat load, water pressure, and desired connections. See page 13 for additional information.

NC8407 NC8409



Use this data for preliminary layouts only. Obtain current drawing from your Marley sales representative.

UPDATE™ web-based selection software, available at spxcooling.com/update provides NC model recommendations based on customer's specific design requirements.

NC8407 NC8409

Model note 2	Nominal Tons note 3	Nominal Tons with VR Cylinder note 3	Motor hp	dBA 5′-0″ from air inlet face	Design Operating Weight lb	Shipping Weight lb	Dimensions		
							L	W	A
NC8407M-1	338	352	7.5	66	25333	11664	11′-10¾″	21′-0″	12′-2¼″
NC8407N-1	372	385	10	69					
NC8407P-1	428	448	15	70					
NC8407Q-1	468	490	20	72					
NC8407R-1	510	531	25	77					
NC8407S-1	540	561	30	79					
NC8407T-1	590	612	40	82					
NC8407U-1	629	653	50	83					
NC8407V-1	664	690	60	84					
NC8409P-1	488	502	15	65	30654	13700	13′-10¾″	22′-5″	14′-2¼″
NC8409Q-1	530	546	20	67					
NC8409R-1	586	602	25	75					
NC8409S-1	616	636	30	79					
NC8409T-1	678	696	40	79					
NC8409U-1	721	741	50	81					
NC8409V-1	761	782	60	83					

A Sound dBA Approach

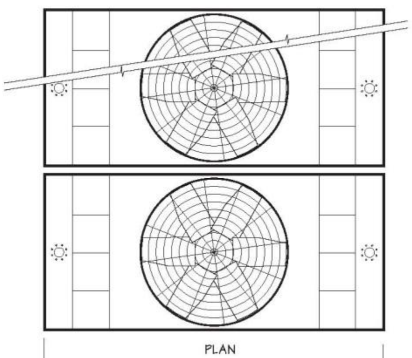
Various low sound options are available from 2 to 19 dB reduction from the standard dBA options in the schematic data table. Consult *UPDATE* selection software for performance, sound levels and dimensions.

NOTE

1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative. All table data is per cell.
2 Last numeral of model number indicates number of cells. Change as appropriate for your selection.
3 Nominal tons are based upon 95°F HW, 85°F CW, 78°F WB and 3 GPM/ton. The UPDATE web-based selection software provides NC model recommendations based on specific design requirements.
4 Standard overflow is a 4″ dia. standpipe in the collection basin floor. The standpipe removes for flush-out and draining. See page 18 for side overflow option.
5 Outlet sizes vary according to GPM and arrangement. See pages 18 and 19 for outlet sizes and details.
6 Makeup water connection may be 1″ or 2″ dia., depending upon tower heat load, water pressure, and desired connections. See page 13 for additional information.

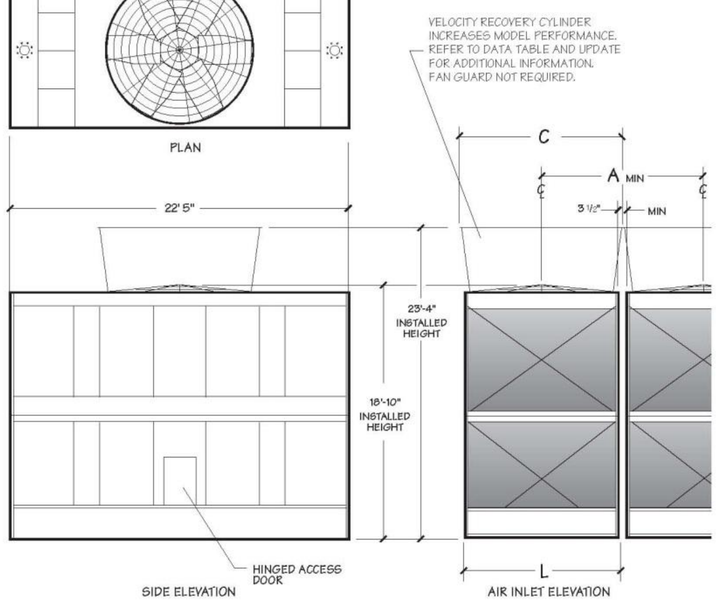
NC Steel Cooling Tower — Schematic

NC8411 NC8412



Use this data for preliminary layouts only. Obtain current drawing from your Marley sales representative.

UPDATE™ web-based selection software, available at spxcooling.com/update provides NC model recommendations based on customer's specific design requirements.



NC Steel Cooling Tower — Schematic Data

NC8411 NC8412

Model note 2	Nominal Tons note 3	Nominal Tons with VR Cylinder note 3	Motor hp	dBA 5'-0" from air inlet face	Design Operating Weight lb	Shipping Weight lb	Dimensions		
							L	A	C
NC8411Q-1	636	671	20	67					
NC8411R-1	680	717	25	69					
NC8411S-1	720	759	30	71					
NC8411T-1	809	854	40	77	37680	17953	11'-10¾"	12'-2¼"	11'-9⅛"
NC8411U-1	865	913	50	78					
NC8411V-1	910	961	60	82					
NC8411W-1	974	1019	75	84					
NC8412Q-1	711	747	20	67					
NC8412R-1	762	799	25	69					
NC8412S-1	805	845	30	70					
NC8412T-1	906	951	40	74	43515	20358	13'-10¾"	14'-2¼"	13'-9³⁄₁₆"
NC8412U-1	968	1012	50	78					
NC8412V-1	1020	1068	60	80					
NC8412W-1	1087	1136	75	84					
NC8412X-1	1183	1239	100	83					

A Sound dBA Approach

Various low sound options are available from 2 to 19 dB reduction from the standard dBA options in the schematic data table. Consult *UPDATE* selection software for performance, sound levels and dimensions.

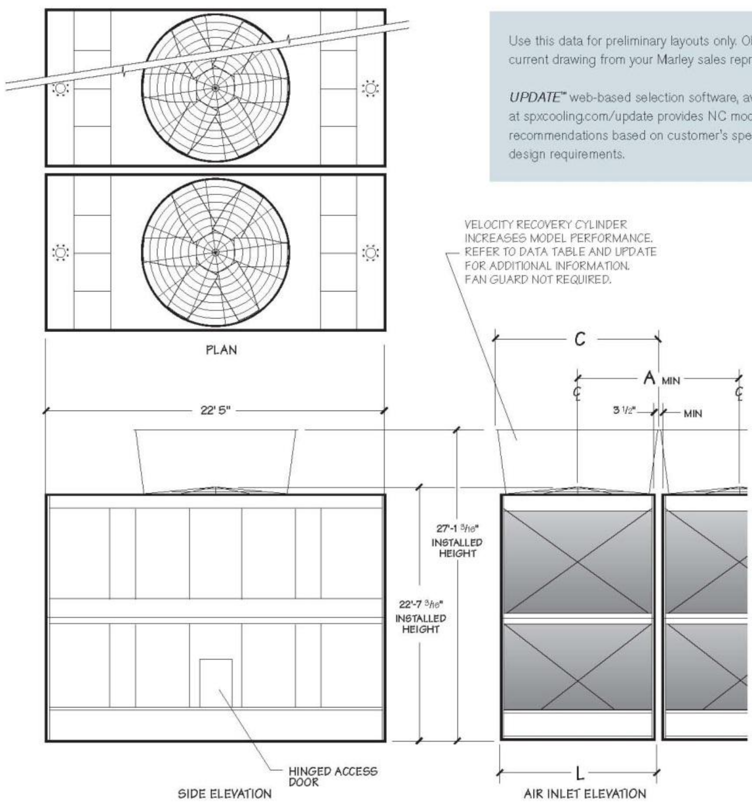
NOTE

1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative. All table data is per cell.
2 Last numeral of model number indicates number of cells. Change as appropriate for your selection.
3 Nominal tons are based upon 95°F HW, 85°F CW, 78°F WB and 3 GPM/ton. The UPDATE web-based selection software provides NC model recommendations based on specific design requirements.
4 Standard overflow is a 4" dia. standpipe in the collection basin floor. The standpipe removes for flush-out and draining. See page 18 for side overflow option.
5 Outlet sizes vary according to GPM and arrangement. See pages 18 and 19 for outlet sizes and details.
6 Makeup water connection may be 1" or 2" dia., depending upon tower heat load, water pressure, and desired connections. See page 13 for additional information.

NC8413 NC8414

Use this data for preliminary layouts only. Obtain current drawing from your Marley sales representative.

UPDATE™ web-based selection software, available at spxcooling.com/update provides NC model recommendations based on customer's specific design requirements.



NC8413 NC8414

Model note 2	Nominal Tons note 3	Nominal Tons with VR Cylinder note 3	Motor hp	dBA 5'-0" from air inlet face	Design Operating Weight lb	Shipping Weight lb	Dimensions		
							L	A	C
NC8413Q-1	692	735	20	67	42930	20561	11'-10¾"	12'-2¼"	11'-9⅛"
NC8413R-1	741	785	25	69					
NC8413S-1	780	833	30	72					
NC8413T-1	855	906	40	73					
NC8413U-1	941	1003	50	78					
NC8413V-1	993	1058	60	82					
NC8413W-1	1062	1129	75	84					
NC8413X-1	1147	1214	100	86					
NC8414Q-1	771	814	20	87	48930	22671	13'-10¾"	14'-2¼"	13'-9³⁄₁₆"
NC8414R-1	825	872	25	89					
NC8414S-1	873	921	30	70					
NC8414T-1	949	999	40	71					
NC8414U-1	1048	1108	50	78					
NC8414V-1	1107	1170	60	80					
NC8414W-1	1178	1242	75	84					
NC8414X-1	1288	1358	100	83					
NC8414Y-1	1366	1439	125	85					

A Sound dBA Approach

Various low sound options are available from 2 to 19 dB reduction from the standard dBA options in the schematic data table. Consult *UPDATE* selection software for performance, sound levels and dimensions.

NOTE

1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative. All table data is per cell.
2 Last numeral of model number indicates number of cells. Change as appropriate for your selection.
3 Nominal tons are based upon 95°F HW, 85°F CW, 78°F WB and 3 GPM/ton. The UPDATE web-based selection software provides NC model recommendations based on specific design requirements.
4 Standard overflow is a 4" dia. standpipe in the collection basin floor. The standpipe removes for flush-out and draining. See page 18 for side overflow option.
5 Outlet sizes vary according to GPM and arrangement. See pages 18 and 19 for outlet sizes and details.
6 Makeup water connection may be 1" or 2" dia., depending upon tower heat load, water pressure, and desired connections. See page 13 for additional information.

Tired of having to design your piping and tower layout to accommodate the standards of cooling tower manufacturers? Marley's multiple variety of piping systems accommodates your design intentions to make your layout of the NC both expedient and economical.

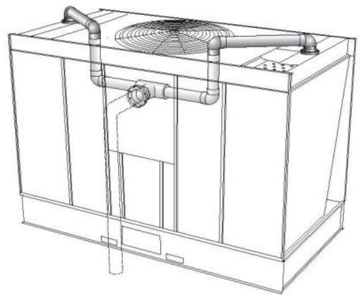
- Single or dual hot water inlet connections.
- Side inlet, bottom inlet or top inlet connections.
- Side or bottom cold water outlet connections.
- A variety of makeup, overflow and drain options.

For the single inlet connection all piping to the distribution basins is part of the tower package. Installation and design costs are reduced and the need for extra piping and supports are eliminated. The single bottom inlet connection is perfect for multicell applications—keeping all the inlet piping below the tower.

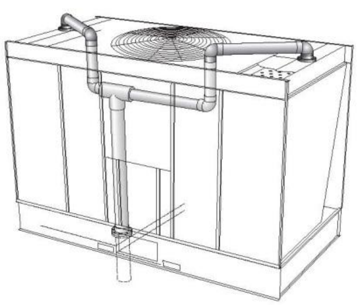
Unless otherwise specified, single-cell towers normally have a cased-face outlet appropriate for the design water flow rate—see pages 18 and 19. This usually assures the lowest possible installed tower elevation. Cased-face outlet connection pipes extend approximately 3" outside the basin, and are beveled for weld connection and also grooved for a mechanical coupling.

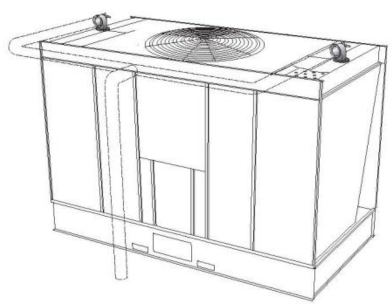
Outlet piping can be kept below the cold water basin level by choosing either a depressed sump or a bottom outlet connection in lieu of the cased-face outlets. Both outlet designs conform to standard class 125 ANSI pipe flange specifications. Easily removable debris screens are optional on bottom outlets and are standard on all other outlet arrangements.

Depressed sumps are made of inert fire-retardant FRP or heavy-gauge welded stainless steel. Unless otherwise specified towers with galvanized steel collection basins are supplied with FRP sumps and towers with stainless steel basins are supplied with stainless sumps.



Multicell towers, intended to operate together as a common unit, are joined by steel flumes between the collection basins. These flumes equalize the operating water level between basins and also provide a flow passage from cells not equipped with outlets or makeup valves, often eliminating the need to specify an outlet and makeup valve for each cell on a multicell installation. Select the number of outlets required to maintain a maximum flow of 1371 GPM through each flume for NC8401 through NC8405 models and 2203 GPM for NC8407 through NC8414 models. Flow values are for cased-face outlet or bottom-outlets without trash screen. Refer to NC sales drawings to obtain flow values for sumps and bottom outlets with trash screens.





If each cell is to be equipped with an outlet, cased-face outlet can be used on end cells of multicell towers, but not on interior cells. For direct outlet from each cell on installations of three or more cells, use either the depressed sump or bottom outlet on interior cells.

The best choice for a tower used with a remote or indoor storage tank—see page 22—or on a concrete cold water basin is usually a bottom outlet.

A cased-face outlet equipped tower can be installed on a flat concrete slab if a side drain and overflow are also specified—see page 18. Consult your Marley sales representative for complete information.

MAKEUP

The amount of water constantly evaporated from a cooling tower varies directly with the heat load applied. In addition to evaporation, water is normally lost to the blowdown (bleed-off) necessary to maintain dissolved solids concentration at an acceptable level in the circulating water system.

The NC is equipped with one or more float-operated, mechanical makeup valves to automatically replenish this lost water. The tables on this page, calculated for a concentration of 3 times normal, indicate the rate of water loss—and the size of valve(s) required. If your installation's cold water basin will drain by gravity to a remote storage tank—or if you plan a separate means of controlling makeup water—a price reduction is available for deleting the Marley valve(s). We also offer an optional electronic liquid-level control.

In most instances cooling towers will see the highest water usage at design heat load. Off design conditions (99% of the time) water usage will be less. For a better understanding of how much water your application will use throughout the year, consult our water usage calculator at:

spxcooling.com/watercalc

If too much water is still being consumed consult your Marley sales representative for water saving alternatives.

Makeup Water Flow Required–GPM to Maintain Three (3) Concentrations						
Tower GPM	Cooling "Range" (HW – CW)					
	5°F	10°F	15°F	20°F	30°F	40°F
200	2	3	4	5	8	10
400	3	5	8	10	15	20
600	4	8	12	15	23	30
800	5	10	15	20	30	40
1000	7	13	19	25	38	50
1500	10	19	29	38	57	75
2000	13	25	38	50	75	100
3000	19	38	57	75	113	150
4000	25	50	75	100	150	200
5000	32	63	94	125	188	250
6000	38	75	113	150	225	300
8000	50	100	150	200	300	400

NOTE

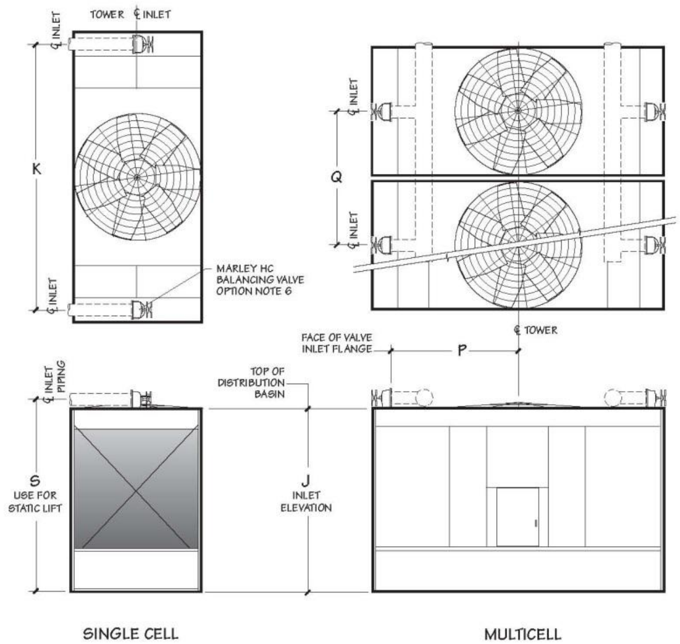
- If circulating water is to be maintained at 2 concentrations instead of 3, multiply table GPM values by 1.36 before sizing makeup valve.

Makeup Valve Flow Capacities–GPM		
Pressure at Valve Inlet while flowing–psig	1" Diameter Valve	2" Diameter Valve
10	56	90
20	78	120
30	92	143
40	106	160
50	117	167

NOTE

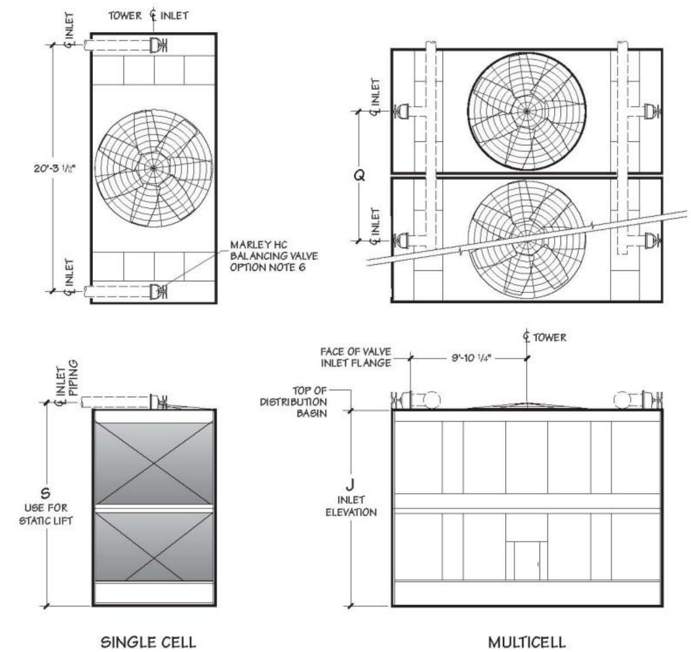
- If makeup water pressure exceeds 50 psig, use pressure reducer ahead of valve.
- For flow requirements exceeding the above limitations, use multiples of the same size valve.

NC Steel Cooling Tower — Dual Inlet Connection



Model	Dimensions					Fan Diameter	Inlet Diameter
	J	K	S	P	Q		
NC8401	9'-9"	11'-1"	10'-5³/₁₆"	5'-3"	6'-9¾"	72"	2 at 6"
NC8402	9'-9"	12'-5"	10'-5³/₁₆"	5'-11"	8'-8¼"	84"	2 at 6"
NC8403	11'-5⁵/₁₆"	16'-0½"	12'-2⁷/₁₆"	7'-8 ¾"	8'-8¼"	84"	2 at 8"
NC8405	11'-5⁵/₁₆"	17'-9½"	12'-2⁷/₁₆"	8'-7¼"	10'-2¼"	108"	2 at 8"
NC8407	11'-5⁵/₁₆"	19'-0⅞"	12'-2⁷/₁₆"	9'-2¹⁵/₁₆"	12'-2¼"	120"	2 at 8"
NC8409	11'-5⁵/₁₆"	20'-3½"	12'-4⁷/₁₆"	9'-9½"	14'-2¼"	144"	2 at 10"

NC Steel Cooling Tower — Dual Inlet Connection

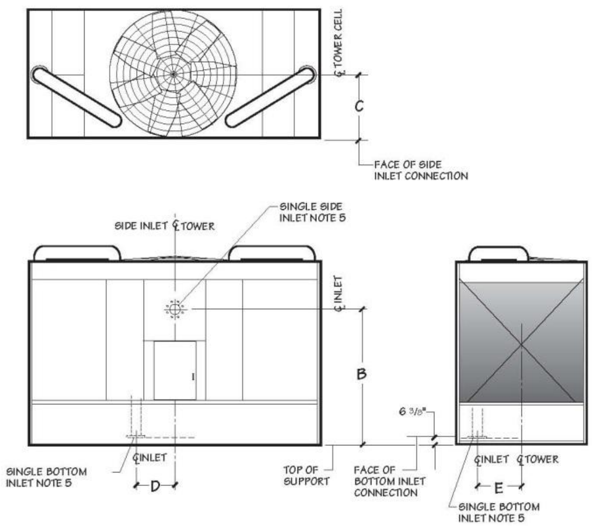


Model	Dimensions			Fan Diameter	Inlet Diameter
	J	S	Q		
NC8411	18'-3⅝"	19'-2¾"	12'-2¼"	132"	2 at 10"
NC8412	18'-3⅝"	19'-2¾"	14'-2¼"	144"	2 at 10"
NC8413	22'-0¾"	22'-11⅜"	12'-2¼"	132"	2 at 10"
NC8414	22'-0¾"	22'-11⅜"	14'-2¼"	144"	2 at 10"

NOTE

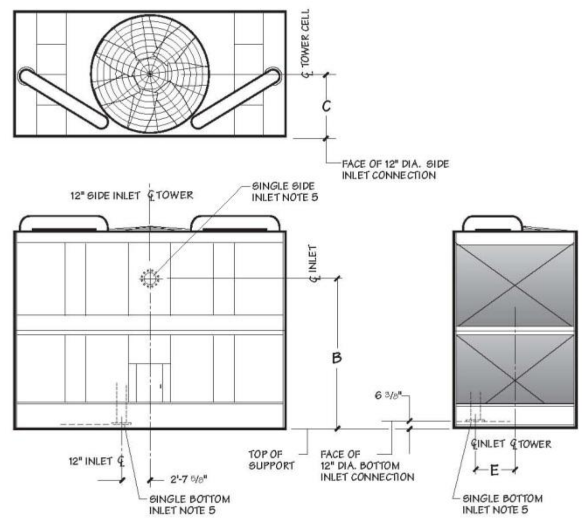
1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative.
2 Pumping head contributed by the tower is static lift "S". Add your system dynamic pipe losses for total.
3 The tower will support the vertical weight of piping shown within the plan area of the tower only. All piping loads, including thrust and lateral loads of riser and horizontal piping must be supported independent of the tower. See inlet piping drawings for details.
4 All piping and supports—and their design—are by others.
5 Allow adequate clearance for entry to tower access doors and safe use of optional ladder. Refer to appropriate Marley drawings.
6 You may choose to use 90° short radius flanged elbows in place of HC balancing valves on single-cell towers where inlet piping is balanced for equal flow. Pipe elevation remains as shown.

NC Steel Cooling Tower — Single Inlet Connection 16



Model	Dimensions				Inlet Diameter
	B	C	D	E	
NC8401	7'-6 7/16"	3'-3 1/16"			6"
NC8402	7'-6 5/8"	5'-0 19/16"	2'-4 1/8"	2'-0"	8"
NC8403	9'-3 9/16"	5'-0 11/16"	2'-4 3/16"	2'-5"	8"
NC8405	9'-2 9/16"	5'-11 7/8"	2'-7 11/16"	3'-0 1/4"	10"
NC8407	9'-1 11/16"	7'-0 1/16"	2'-10 5/8"	4'-2"	10"
NC8409	9'-2 1/8"	8'-0"	2'-10 7/8"	4'-8"	10"

NC Steel Cooling Tower — Single Inlet Connection 17

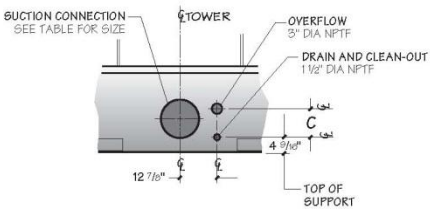


Model	Dimensions		
	B	C	E
NC8411	16'-1 1/2"	7'-3 7/16"	4'-6"
NC8412	16'-1 1/2"	8'-2 1/2"	5'-5 15/16"
NC8413	19'-10 5/8"	7'-3 7/16"	4'-6"
NC8414	19'-10 5/8"	8'-2 1/2"	5'-5 15/16"

NOTE

1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative.
2 All external piping loads, including weight, thrust and lateral loads of riser and horizontal piping plus the weight of water in the internal riser must be supported independent of the tower. Internal riser adds additional vertical operating loads to external piping at the bottom inlet flange.
3 All piping and supports beyond the inlet connection—and their design—are by others.
4 Allow adequate clearance for entry to tower access doors and safe use of optional ladder. Refer to appropriate Marley drawings.
5 You may choose either a bottom inlet connection or a side inlet connection. The bottom inlet connects at the tower collection basin floor. Refer to appropriate Marley drawings.
6 Contact your Marley sales representative for the required pump head for single-inlet applications.
7. Weight of internal piping must be added to tower weights. Contact your Marley sales representative for combined tower weight information.

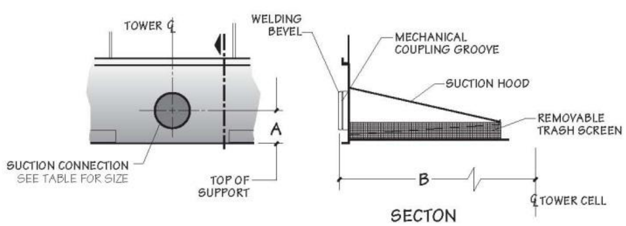
NC Steel Cooling Tower — Outlet Connection



DRAIN AND OVERFLOW CONNECTION
OPTION

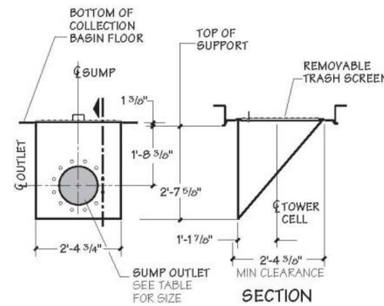
NOTE
- Standard overflow is a 4" dia. standpipe in the collection basin floor. The standpipe removes for flush-out and draining.

Model	Dimensions		
	A	B	C
NC8401	10"	3'-4 1/8"	8 1/8"
NC8402	10"	4'-3 3/8"	8 1/8"
NC8403	11 1/4"	4'-3 3/8"	10 3/16"
NC8405	11 1/4"	5'-0 3/8"	10 3/16"
NC8407	11 1/4"	6'-0 3/8"	10 3/16"
NC8409	11 1/4"	7'-0 3/8"	10 3/16"
NC8411	11 1/4"	6'-0 3/8"	11 15/16"
NC8412	11 1/4"	7'-0 3/8"	11 15/16"
NC8413	11 1/4"	6'-0 3/8"	11 15/16"
NC8414	11 1/4"	7'-0 3/8"	11 15/16"

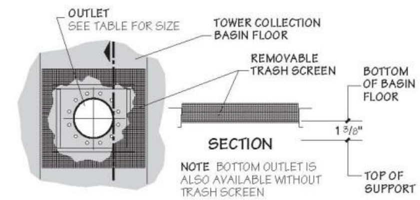


CASED-FACE OUTLET CONNECTION

NC Steel Cooling Tower — Outlet Connection



DEPRESSED SIDE-OUTLET
SUMP CONNECTION
STAINLESS STEEL OR FRP

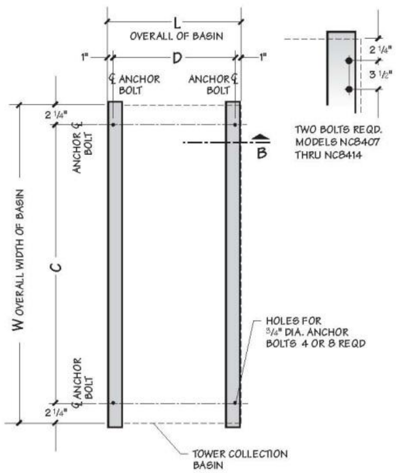


BOTTOM OUTLET CONNECTION

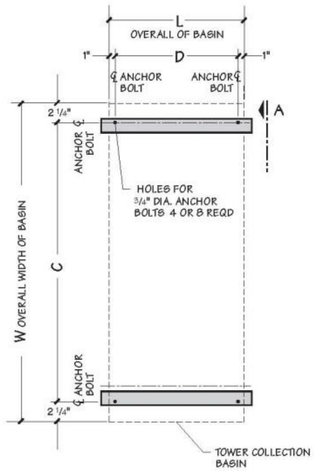
Maximum GPM Per Outlet Diameter												
Outlet Type	Flow Type	Model	Outlet Diameter									
			4"	6"	8"	10"	12"	14"	16"	18"	20"	24"
Bottom	pump flow w/ anti-vortex plate or gravity flow w/ or w/o anti-vortex plate	NC8401 thru NC8405	157	355	630	993	1413	1729	2285	2509	3322	4019
		NC8407 thru NC8414	167	380	673	1061	1510	1848	2442	3164	3829	4896
	pump flow w/o anti-vortex plate	NC8401 thru NC8414	71	162	287	453	644	788	1042	1349	1676	2433
Sump	pump flow w/ anti-vortex plate or gravity flow w/ or w/o anti-vortex plate	NC8401 thru NC8405		900	1595	2515	3578	4284				
		NC8407 thru NC8414		900	1595	2515	3578	4379				
	pump flow w/o anti-vortex plate	NC8401 thru NC8414		630	1116	1761	2505	3065				
Cased-Face Outlet	pump flow only	NC8401 thru NC8405		900	1595	2515	3578					
		NC8407 thru NC8414		900	1595	2515	3578	4379				

NOTE
- Flow rate may be limited by the maximum GPM for unit size.
- For gravity-flow situations (as to an indoor tank), use bottom outlet or depressed side outlet sump. Cased-face outlet is not recommended for gravity flow.
- GPM limits are the outlet capacities per outlet based on the design operating water level—8 1/2" above the top of support on models NC8401 through NC8405—9 1/2" on NC8407 thru NC8414.

NC Steel Cooling Tower — Support 20



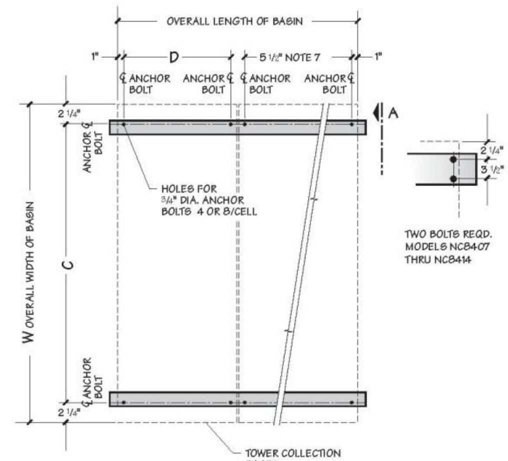
SUPPORTING STEEL
SINGLE CELL



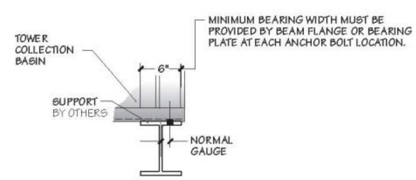
SUPPORTING STEEL ALTERNATE
SINGLE CELL

Model	Dimensions				Design Operating Weight/Cell lb	Design Operating Load at Anchor lb	Wind p and Seismic g Loads lb note 4			
	W	L	C	D			Max Vertical Reaction at Anchor		Max Horizontal Reaction at Anchor	
NC8401	12'-10"	6'-6¼"	12'-5½"	6'-4¼"	7889	1972	48.41 x p	3025 x g	31.41 x p	1972 x g
NC8402	14'-2"	8'-4¾"	13'-9½"	8'-2¾"	10319	2580	41.26 x p	2962 x g	34.68 x p	2603 x g
NC8403	18'-2"	8'-4¾"	17'-9½"	8'-2¾"	15844	3961	72.72 x p	5147 x g	52.13 x p	3755 x g
NC8405	19'-11"	9'-10¾"	19'-6½"	9'-8¾"	19480	4870	67.43 x p	5186 x g	57.16 x p	4672 x g
NC8407	21'-0"	11'-10¾"	20'-7½"	11'-8¾"	25333	6333	58.98 x p	5248 x g	60.26 x p	5837 x g
NC8409	22'-5"	13'-10¾"	22'-0½"	13'-8¾"	30654	7663	53.79 x p	5058 x g	64.33 x p	6268 x g
NC8411	22'-5"	11'-10¾"	22'-0½"	11'-8¾"	37680	9420	160.70 x p	14373 x g	102.78 x p	9422 x g
NC8412	22'-5"	13'-10¾"	22'-0½"	13'-8¾"	43515	10879	137.29 x p	14412 x g	102.78 x p	10929 x g
NC8413	22'-5"	11'-10¾"	22'-0½"	11'-8¾"	42930	10733	233.33 x p	18387 x g	123.85 x p	10735 x g
NC8414	22'-5"	13'-10¾"	22'-0½"	13'-8¾"	48930	12232	199.34 x p	20173 x g	123.85 x p	12466 x g
NC Models with Velocity Recovery Cylinder										
NC8407	21'-0"	11'-10¾"	20'-7½"	11'-8¾"	25498	6375	73.88 x p	5875 x g	66.51 x p	5875 x g
NC8409	22'-5"	13'-10¾"	22'-0½"	13'-8¾"	30949	7737	69.06 x p	6342 x g	71.83 x p	6342 x g
NC8411	22'-5"	11'-10¾"	22'-0½"	11'-8¾"	37863	9466	185.13 x p	14563 x g	109.65 x p	9468 x g
NC8412	22'-5"	13'-10¾"	22'-0½"	13'-8¾"	43810	10952	160.06 x p	14599 x g	110.28 x p	11003 x g
NC8413	22'-5"	11'-10¾"	22'-0½"	11'-8¾"	43113	10778	262.17 x p	18607 x g	130.72 x p	10781 x g
NC8414	22'-5"	13'-10¾"	22'-0½"	13'-8¾"	49957	12489	226.22 x p	20389 x g	131.35 x p	12574 x g

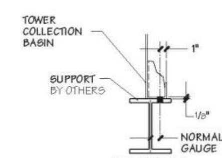
NC Steel Cooling Tower — Support 21



SUPPORTING STEEL
MULTICELL



VIEW A



SECTION B

NOTE

1. **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative for final design.
2. Purchaser to provide tower support complete with holes and anchor bolts. Do not use studs! Anchor points must be framed flush and level at top.
3. Design operating weight occurs with collection basin full to overflow level. Actual operating weight varies with GPM and piping scheme.
4. Wind reactions can be calculated by multiplying by p, which is the wind pressure in psf. Seismic reactions can be calculated by design g. Wind loads are additive to operating loads.
5. Tower may be placed on a flat concrete slab. Side outlet and optional side drain and overflow must be specified. See pages 13 and 18 and consult your Marley sales representative.
6. Tower may be supported from piers at each anchor bolt location, as a support alternative.
7. Dimensions between anchor bolts may vary depending on the number of cells and options. Dimensions shown are for a standard two cell arrangement. Obtain current drawings from your Marley sales representative for final dimension.

When the ambient air temperature falls below 32°F, the water in a cooling tower can freeze. *Marley Technical Report #H-003* **"Operating Cooling Towers in Freezing Weather"** describes how to prevent freezing during operation. Available at spxcooling.com or ask your Marley sales representative for a copy.

During shutdown, water collects in the cold water basin and may freeze solid. You can prevent freezing by adding heat to the water left in the tower—or, you can drain the tower and all exposed pipework at shutdown.

ELECTRIC BASIN HEATERS

An automatic basin water heater system is available consisting of the following components:

- Stainless steel electric immersion heater(s).

  —Threaded couplings are provided in the side of the collection basin.

- NEMA 4 enclosure containing:

  —Magnetic contactor to energize heater.

  —Transformer to convert power supply to 24 volts for control circuit.

  —Solid state circuit board for temperature and low-water cutoff.

  Enclosure may be mounted on the side of the tower.

- Control probe in the collection basin to monitor water temperature and level.

Heater components are normally shipped separately for installation by others.

Note: any exposed piping that is still filled with water at shutdown—including the makeup water line—should be electrically traced and insulated (by others).

STEAM JET BASIN HEATERS

Penberthy Houdaille bronze steam jet heaters (¼" to ¾") are available for freeze protection (installation by others). Injectors install in a coupling provided in the side of the collection basin. Live steam, as required, is injected directly into the water. Condensed steam adds water to the basin, and the excess will exit the overflow of the tower.

INDOOR STORAGE TANK

With this type of system, water flows from an indoor tank, through the load system, and back to the tower, where it is cooled. The cooled water flows by gravity from the tower to the tank located in a heated space. At shutdown, all exposed water drains into the tank, where it is safe from freezing.

The table on page 23 lists typical drain-down capacities for all NC tower models. Although we do not produce tanks, many of our representatives offer tanks supplied by reputable manufacturers.

The amount of water needed to successfully operate the system depends on the tower size and GPM and on the volume of water contained in the piping system to and from the tower. You must select a tank large enough to contain those combined volumes—plus a level sufficient to maintain a flooded suction on your pump. Control makeup water according to the level where the tank stabilizes during operation.

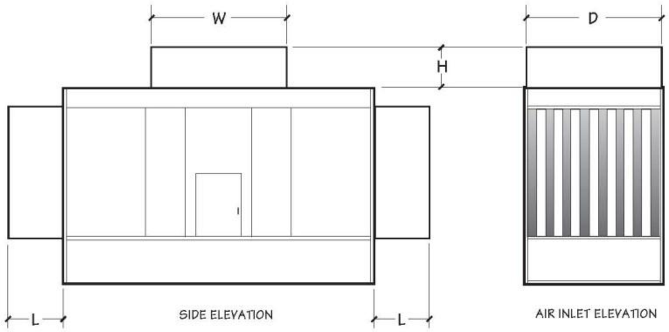
NC Drain-Down Capacity

Model	Range of Tower Design GPM	Drain Down Maximum Gallons	Model	Range of Tower Design GPM	Drain Down Maximum Gallons
NC8401	132-280	371	NC8409	481-1200	1673
	290-450	402		1210-1800	1769
	460-620	421		1810-2400	1877
	630-780	442		2410-3000	1910
	790-919	457		3010-3565	1993
NC8402	183-380	508	NC8411	410-1300	1763
	390-590	537		1310-2000	1974
	600-800	568		2010-2700	2128
	810-1010	590		2710-3300	2216
	920-1200	606		3310-4049	2360
NC8403	285-700	811	NC8412	481-1400	2050
	710-1030	877		1410-2200	2231
	1040-1390	925		2210-3000	2422
	1400-1700	960		3010-3800	2571
	1710-2113	1009		3810-4753	2770
NC8405	337-810	969	NC8413	410-1200	1919
	820-1230	1041		1210-1900	2124
	1240-1610	1120		1910-2600	2331
	1620-2030	1173		2610-3300	2494
	2040-2509	1211		3310-4049	2672
NC8407	410-1000	1320	NC8414	481-1400	2244
	1010-1500	1424		1410-2200	2471
	1510-2000	1493		2210-3000	2711
	2010-2500	1542		3010-3900	2940
	2510-3037	1614		3910-4753	3137

NOTE

- Volumes shown are maximums for the GPM ranges indicated. Actual volumes will usually be less. Contact your Marley sales representative for more specific information.

NC Steel Cooling Tower — Sound Attenuators

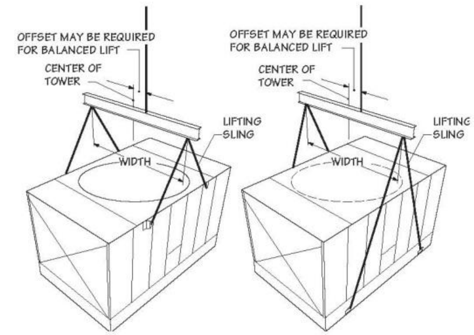


Model	Dimensions				Add To Design Operating Weight lb	
	L	W	D	H	Discharge Attenuator	Inlet Attenuators
NC8401	2'-3¼"	6'-10"	6'-1½"	2'-3"	620	1523
	4'-6½"	6'-10"	6'-1½"	4'-6"	1241	3045
NC8402	2'-3¼"	7'-10¼"	8'-0"	2'-3"	774	1869
	4'-6½"	7'-10¼"	8'-0"	4'-6"	1547	3738
NC8403	2'-3¼"	7'-10¼"	8'-0"	2'-3"	774	2101
	4'-6½"	7'-10¼"	8'-0"	4'-6"	1547	4201
NC8405	2'-3¼"	9'-9"	9'-6"	2'-3"	1051	2460
	4'-6½"	9'-9"	9'-6"	4'-6"	2102	4920
NC8407	2'-3¼"	10'-8⅜"	11'-6"	2'-3"	1395	3115
	4'-6½"	10'-8⅜"	11'-6"	4'-6"	2791	6231
NC8409	2'-3¼"	12'-9⅜"	13'-6"	2'-3"	1616	3508
	4'-6½"	12'-9⅜"	13'-6"	4'-6"	3233	7016
NC8411	2'-3¼"	11'-8⅞"	11'-6"	2'-3"	1564	5562
	4'-6½"	11'-8⅞"	11'-6"	4'-6"	3128	11125
NC8412	2'-3¼"	12'-9⅜"	13'-6"	2'-3"	1616	6272
	4'-6½"	12'-9⅜"	13'-6"	4'-6"	3233	12545
NC8413	2'-3¼"	11'-8⅞"	11'-6"	2'-3"	1564	6417
	4'-6½"	11'-8⅞"	11'-6"	4'-6"	3128	12834
NC8414	2'-3¼"	12'-9⅜"	13'-6"	2'-3"	1616	7051
	4'-6½"	12'-9⅜"	13'-6"	4'-6"	3233	14103

NOTE

1. **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative. All table data is per cell.
2. Attenuators are field installed by others with hardware provided by Marley
3. Attenuators are supported by the tower. Additional support not required.
4. Discharge attenuators are not available for NC models with velocity recovery cylinders.

NC Steel Cooling Tower — Hoisting Information



Model	Width	Minimum Sling Length
NC8401	6'-7"	6'-0"
NC8402	8'-6"	6'-0"
NC8403	8'-6"	8-0"
NC8405	10'-0"	8'-0"
NC8407	12'-0"	9'-0"
NC8409	14-0"	18'-0"
NC8411 Top	12'-0"	9'-0"
NC8411 Bottom	12'-0"	18'-0"
NC8412 Top	14'-0"	9'-0"
NC8412 Bottom	14'-0"	18'-0"
NC8413 Top	12'-0"	9'-0"
NC8413 Bottom	12'-0"	18'-0"
NC8414 Top	14'-0"	9'-0"
NC8414 Bottom	14'-0"	18'-0"

NOTE

- All hoisting clip holes are 1¼".
- On multicell tower installations, overall length of shackle pins should not exceed 5¼".
- For overhead lifts or where additional safety is required, add slings beneath the tower unit.

NC 8400 steel cooling tower

ENGINEERING DATA

SPX COOLING TECHNOLOGIES, INC.
7401 WEST 129 STREET
OVERLAND PARK, KANSAS 66213 USA
P: 913 664 7400
F: 913 664 7439
spxcooling@spx.com
spxcooling.com

In the interest of technological progress, all products are subject to design and/or material change without notice

ISSUED 12/2012 TECH-NC-12A

APPENDIX F: LEED Scorecard

Yes	?	No				
11		3	**Sustainable Sites**		14 Points	
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required	Required
1			Credit 1	**Site Selection**	1	1
1			Credit 2	**Development Density & Community Connectivity**	1	5
1			Credit 3	**Brownfield Redevelopment**	1	1
1			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1	6
1			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1	1
1			Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel-Efficient Vehicles	1	3
1			Credit 4.4	**Alternative Transportation**, Parking Capacity	1	2
		1	Credit 5.1	**Site Development,** Protect or Restore Habitat	1	1
1			Credit 5.2	**Site Development,** Maximize Open Space	1	1
1			Credit 6.1	**Stormwater Design,** Quantity Control	1	1
1			Credit 6.2	**Stormwater Design,** Quality Control	1	1
		1	Credit 7.1	**Heat Island Effect,** Non-Roof	1	1
1			Credit 7.2	**Heat Island Effect,** Roof	1	1
		1	Credit 8	**Light Pollution Reduction**	1	1

Yes	?	No				
4		1	**Water Efficiency**		5 Points	
						Required
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1	2
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1	2
		1	Credit 2	**Innovative Wastewater Technologies**	1	2
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1	2
1			Credit 3.2	**Water Use Reduction**, 30% Reduction	1	2

Yes	?	No				
8	1	8	**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
6		4	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
				6	28% New Buildings or 21% Existing Building Renovations	6
					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

***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			
6	1	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 Regi	1
1			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regi	1
		1	Credit 6	**Rapidly Renewable Materials**	1
	1		Credit 7	**Certified Wood**	1

Yes	?	No			
11		4		**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			
5				**Innovation & Design Process**	5 Points
1			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
1			Credit 1.2	**Innovation in Design**: Provide Specific Title	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		
45	2	22	**Project Totals** (pre-certification estimates)	69 Points

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