April 4th, 2012

Final Report

Unionville High School
Additions and Renovations

Michael Beam | Construction Option | Advisor: Dr. Messner

Architectural

- Rock faced CMU, red brick, and limestone sills create a new look while maintaining the look of the existing portion of the building.
- Barrelled roofs on the new auditorium and gymnasium update the elevations
- Unionville-Chadds Ford School district administrative offices located at the south of the building
- New auditorium added to northwest corner of building
    - High end finishes including acoustical CMU block, oak molding, and hard wood stage floor
- New gymnasium added to northeast corner of building

Construction

- 4 primary phases with 17 total subphases developed to efficiently complete the project
    - Phase 1: Construction of new Unionville-Chadds Ford Administractive Offices
    - Phase 2: Construction of new auditorium and renovations of existing classroom space on first, second, and third floor
    - Phase 3: Renovation of existing auditorium and completion of classroom renovations
    - Phase 4: Demolition of existing 1 story, construction of new gymnasium, renovation of classroom space on first floor.

www.engr.psu.edu/ae/thesis/portfolios/2012/MSB5153

MICHAEL BEAM - CM OPTION

UNIONVIONVILLE HIGH SCHOOL ADDITIONS AND RENOVATIONS

Kennett Square, Pennsylvania

Owner:
Unionville-Chadds Ford School District

Architect:
MM Architects, Inc.

General Contractor:
Wohlsen Construction

Site/Civil Engineer:
ELA Group, Inc.

Structural Engineer:
Joseph Barbato Associates, LLC.

Mechanical/Electrical Engineer:
Gipe Associates, Inc.

Kitchen Design Consultant:
Clark Food Service Equipment

Building Information

Total Height: 3 Stories
Building Area: 319,000 Square Ft
Contract Value: $51,895,000.00
Timeline: June 2009 - Dec 2012

Structural System

Foundation

- Structural steel columns on reinforced concrete piers
- CMU Block foundation walls and reinforced concrete footings

Building Structure

- Predominantly wide flange members with some hollow structural section members
    - Most Common:
    - W10x33
    - W14x90
- Floors either slab on grade or 4" of concrete over metal decking

Roof

- Structural steel trusses and joists
- Curved members for barrelled roofs:
    - 48LH13 joists for new auditorium
    - W10x39 truss for new gymnasium

Eletrical/Lighting System

- 35000 Volt service entrance
- 2500KVA 34.5/19.9KV to 4.16/2.4KV outdoor oil filled transformer
- 4160 Volt, 3 phase primary system and 480/277V, 3 phase, 4 wire Y secondary system
- Building utilizes both 480/277V and 208/120V power
- Classrooms and corridors use primarily 2' x 4' recessed fluorescent fixtures, F32T8 lamps
- 50W MH Metal halide and Q250 T4 fluorescent lamps used in 9" diameter x 16" long suspended metal cylindrical down fixtures in new auditorium

Mechanical

- 22 Total AHU's: 18 new units and 4 existing units
- 15 new and the 4 existing AHU's located on the roof
- 3 new AHU's located in mechanical rooms
- Primarily DOAS AHU's with several VAV and CAV units
    - DOAS AHU's supply fan loads ranging from 5,500 to 9,900 CFM
- 10 trane BCU's, each interlocking with a specific AHU

Executive Summary

This comprehensive Senior Thesis Final Report has been compiled to present information obtained through research concerning four analysis depth topics and two depth topics in regards to the Unionville High school Building Project. With an overall size of 319,000 square feet and three stories above grade, the UHS building project has four main phases with both additions and renovations.

Analysis 1: Delivery Method Study highlights UHS' use of a Single Prime delivery method and compares this method to the PA mandated Multiple Prime delivery method. Based on past experience, the school district was able to receive a waiver to use a Single Prime. Ultimately, *the district benefited* from this arrangement due to better communication, fewer delays, and even cost savings.

Analysis 2: 4D Safety and Phase Plan discusses the implementation of BIM on the project. With no BIM used as part of the original project design, the possibility of added value existed by introducing BIM in some capacity. Ultimately, a phase by phase safety plan using a 3D model will be developed for use by the School district. Increased information regarding the project leads to a safer project and based on the proposed application, it is believed that the owner would *benefit greatly from implementing BIM*.

Analysis 3: On Site Renewable Energy aimed to add an on-site energy source to the project, which strived for LEED certification but lacked renewable energy. After comparing the two, Photovoltaic Cells were chosen over Wind energy. Following system design and implementation, it was determined that based on use of Purchase Power Agreement, UCFSD stands to *save over $400,000* over the life of the contract, providing significant benefit to the owner.

Analysis 4: Façade Redesign aimed to improve upon the stick-built façade of the original design. Using Phase 1 as a microcosm of the building, a precast façade panel design was chosen and implementation was studied. Despite a savings in installation duration, added cost, a change in aesthetics, and reduced thermal properties show that *the original façade is a better option for the UHS project*.

Table of Contents

Abstract — ii
Executive Summary — iii
Table of Contents — iv
Building Introduction — 1
Project Information — 2
  Local Conditions — 2
  Existing Conditions — 4
  Client Information — 5
  Project Delivery System — 7
  Staffing Plan — 9
Building Systems — 10
Project Cost Evaluation — 18
General Conditions Estimate — 20
Detailed Project Schedule — 22
Analysis 1: Delivery Method Study — 24
  Problem Identification — 24
  Research Goal — 24
  Research Methods — 24
  UHS Delivery Method Selection – Single Prime — 25
  Delivery Method Background Information — 27
  PA Separations Act — 31
  Delivery Method Comparison — 35
  Conclusion and Research Result — 40

Analysis 2: 4D Safety and Phase Plan — **41**
Problem Identification — **41**
Research Goal — **41**
Research Methods — **42**
Background Information — **43**
Project Phasing Information — **44**
Case Study — **45**
UHS BIM Applications — **47**
Hazardous Area Identification — **48**
Conclusions and Findings — **53**
Analysis 3: Sustainability – On Site Renewable Energy — **54**
Problem Identification — **54**
Research Goal — **54**
Research Methods — **54**
Background Information — **55**
Case Studies — **61**
Renewable Energy Source Selection – Photovoltaic Cells — **67**
Solar Design Parameters — **68**
Photovoltaic System Design — **73**
Cost Analysis — **77**
Conclusions and Findings — **80**
Analysis 4: Façade Redesign – Prefabricated Panel Facade — **82**
Problem Identification — **82**
Research Goal — **82**
Research Methods — **83**
Background Information — **84**
Current Façade Information — **85**
Prefabricated Panel Selection — **87**
Panel Implemenation — **89**
Conclusions and Findings — **93**

Mechanical Breadth: Façade Mechanical Impact — **95**
Structural Breadth: Façade Structural Impact — **99**
Sources — **104**
Acknowledgements — **107**
APPENDICES — **108**
APPENDIX A: Phasing Plan and Area Key — **108**
APPENDIX B: Existing Conditions Site Plan — **110**
APPENDIX C: Square Foot Estimate Calculations — **112**
APPENDIX D: General Conditions Estimate Calculations — **117**
APPENDIX E: Detailed Project Schedule — **120**
APPENDIX F: Interview with Wohlsen PM Brian Laub — **131**
APPENDIX G: Delivery Method Diagrams — **133**
APPENDIX H: Potential Roof Regions for PV Array — **136**
APPENDIX I: PV Array Shadow Analysis Images — **138**
APPENDIX J: Selected Roof Regions for PV Array — **147**
APPENDIX K: Solar Panel & Inverter Specifications — **150**
APPENDIX L: PVWatts Data Output — **157**
APPENDIX M: UHS Electricity Cost Savings — **159**
APPENDIX N: UHS Payback Period — **161**
APPENDIX O: Façade Assembly Comparison — **163**
APPENDIX P: Precast Panel Calculations and Information — **165**
APPENDIX Q: HAM Toobox Original Façade Analysis — **173**
APPENDIX R: DesignBuilder Analysis Outputs — **176**
APPENDIX S: Structural Breadth Hand Calculations — **180**

Unionville High School Building Introduction

Unionville High School is a public education building located in Kennett Square, Pennsylvania. The Building is 3 stories tall with a total square footage of 319,000 square feet, and houses both Unionville High School as well as the Unionville-Chadds Ford School District Administrative Offices. The project has an initial project cost of around $52 Million and a schedule spanning from June 2009 to December 2012, the UHS project is a project incorporates demolition, renovations, and new additions.

During the first phase of the project, a brand new wing will be constructed housing new Administrative Offices, classrooms, and science labs. Following this additions completion, the existing administrative offices will be renovated into classroom space. During phase two, a brand new auditorium will be constructed, with more classroom space renovation occurring as well. Phase three will see the existing auditorium renovated into new classroom and athletic education spaces. Finally, Phase 4 will see the construction of a new gymnasium followed by the renovation of the existing gymnasium and demolition of the existing auxiliary gymnasium. A detailed phasing plan and area key are available for APPENDIX A.

Building Information

Building Name	**Unionville High School**
Location and Site	**750 Unionville Road, Kennett Square PA**
Occupant Name	**Unionville-Chadds Ford School District**
Building Area	**319,00 Square Feet**
Stories Above Grade	**3 Stories**

Construction Information

Construction Cost	**$51,895,000**
Construction Timeframe	**June 2009 – December 2012**
Contract Type	**Hard Bid Public Work**
Delivery Method	**Single Prime**

Project Team

Owner	**Unionville-Chadds Ford School District**
Architect	**MM Architects, Inc.**
General (Prime) Contractor	**Wohlsen Construction Company**

Project Information

Local Conditions

Kennett Square Pennsylvania, known as the "The Mushroom Capital of the World", is home to the Unionville-Chadds Ford school district. Designed at a size of 3 stories above grade with an overall size of 319,000 square feet, the Unionville High School Building will undergo demolition, renovation, and addition during the course of the project. The map below (figure 1) shows an aerial view of the site prior to the beginning of construction. With students onsite it is vitally important that as little of the building is disturbed during construction as possible. Phasing was utilized during this project in order to keep the school in operation and disturb building inhabitants as little as possible. All material removed during the construction process is to be recycled according to LEED requirements.

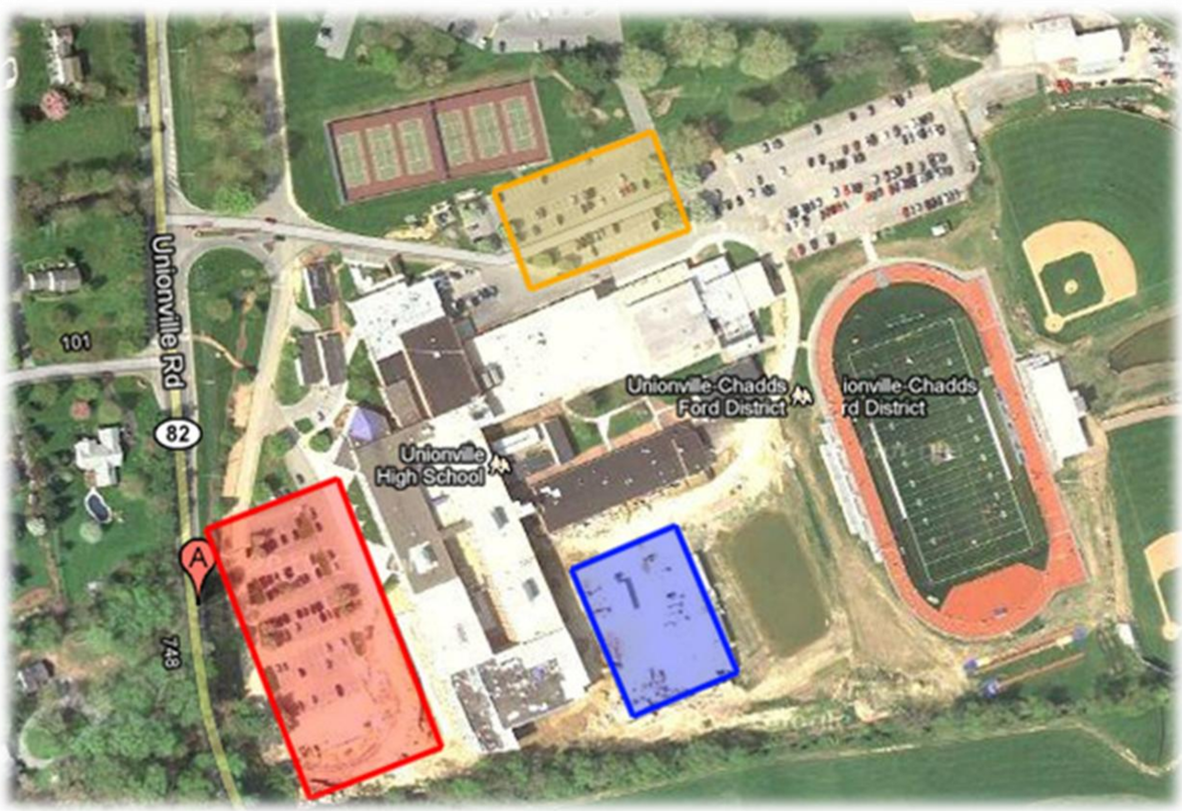


Figure 1: Aerial View of UHS Project Site

Parking is available for contractors in several locations depending on the current construction phase; the red region shows available contactor parking for phases 1, 2, and part of phase 3, the orange region is available for parking during phase 3, and the blue region shows available parking for phase 4. Parking availability varies throughout the project in order to accommodate both the phasing of the project as well as the UCFSD Administrative Staff; UCFSD Administrative Staff members will park in the blue region until phase 4, when their parking location moves to the red region and the contractors begin to occupy the blue region. Wohlsen on-site staff members are permitted to park in the southwest corner of the blue region at all times, as jobsite trailer are located here. No specific permitting issues have been identified for this public education project.

Existing Conditions

Although there is a middle school in close proximity, this project will deal only with the Unionville High School building. Initally, the project site was home to only the Unionville High School. As a result of this project, the site will now house both the Unionville High School as well as the Unionville-Chadds Ford School District Administration Building. As a result of the construction project, several multi-purpose fields were removed near the north east of the site and in their place went a new parking lot. The parking lot in the front of the existing building was expanded slightly and a one-way vehicular entrance to the parking lot was added from Unionville Willowdale Road.

Site utilities come from both the (magnetic) east and west, with several different branches feeding either the High School or the adjacent middle school depending on specific utilities. A few small access roads links both schools' parking areas and vehicular access paths. No covered pathways or temporary lighting are to be used at any point for students or staff members during the project as there was no need to reroute any pedestrian traffic using the exterior of the building. Several parking areas are shown on the site plan with most belonging to the high school. Throughout the project, contractor parking locations and UCFSD parking locations will vary depending on where construction is occuring during the different phases. An existing condition site plan for all phases can be found in APPENDIX B.

Client Information

Unionville-Chadds Ford School District is a public school district in Pennsylvania, including several other schools besides Unionville High School including Charles F. Patton Middle School and Unionville, Chadds Ford, Hillendale, and Pocopson Elementary Schools. The map below illustrates the layout of the Unionville-Chadds Ford School District and the location of each educational facilitiy, including the Unionville High School Building. Figure 2 shows the entire school dsitrict, with Unionville High School located near the center of the district.

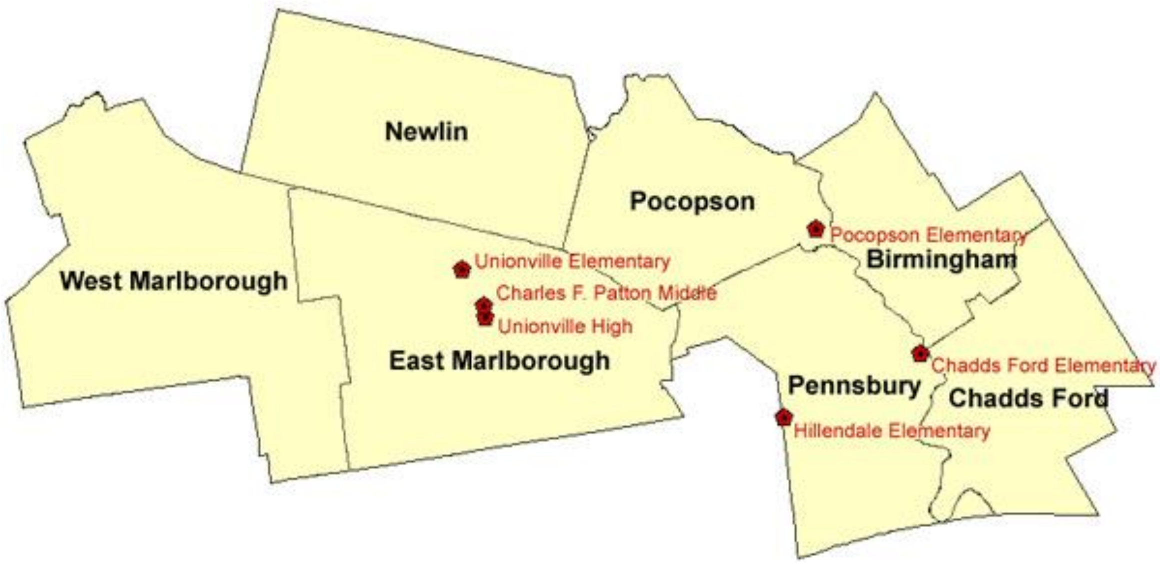


Figure 2: Unionville-Chadds Ford School District

A growing population within the school district led to the need to expand the school district's only high school. In addition to the new building accommodating the growing needs of Unionville High School it would also be the new home to the Unionville-Chadds Ford School District Administrative Offices. While increasing the space of Unionville High School is a key factor, many spaces and features within the high school were well outdated and the old administrative office was well overdue for an upgrade.

Among the outdated facilities within the old building included classrooms, art rooms, lockers rooms, the gymnasium, and namely, the auditorium. Renovations to classroom space will not only improve the look of these spaces but also the functionality and energy efficiency. The new Auditorium will sport hi-tech audio, video, and lighting equipment and an expanded seating capacity, leading to a space that better suit students involved in arts programs throughout the district. Several spaces including the new gymnasium, wrestling area, and locker rooms will improve the portions of the building that directly affect the student athletes and members of the athletic programs for the school.

Cost, while not completely unimportant, is the not the focus of this project. The schedule, on the other hand, is of great importance. As with most educational projects, construction disrupts the flow of everyday life. With a project such as this that includes both new construction and renovation, seamless phasing is even more important. 4 phases and 17 sub phases are to be utilized in order to minimize the construction process' effect on the students, faculty, and other inhabitants of Unionville High School. As a site note, the school required that no smoking occur on site, inside or outside of any structure, at any time.

Project Delivery System

The chart on the next page (figure 3) shows the breakdown of the project from a contractual standpoint. As the Unionville High School Additions and Renovations project is in the public sector, a hard bid method was used during the design phase and a Single Prime Delivery method was used for this particular project. The Owner, Unionville-Chadds Ford School District, is contracted directly with both MM Architects, Inc. and Wohlsen Construction, both of which are Lump Sum contracts. MM Architects has Lump Sum contracts with all engineers for this project, including Gipe Associates, Inc., ELA Group, Inc., and Joseph Barbato Associates, LLC. Wohlsen Construction is acting as the General Contractor and was awarded the Unionville High School Building project after submitting the lowest bid. As the GC for the project Wohlsen owns all contracts (also Lump Sum) with subcontractors, who are prequalified and selected based on the lowest bid. All subcontractors are required to be completely bonded, a key part of the contract in terms of keeping work moving. In addition to managing the contracts of all on-site contractors, Wohlsen is also self-performing some work such as portions of the on-site concrete work and interior carpentry work.

Utilizing a Single Prime project delivery method was the best option for this particular project. The owner has complete jurisdiction over the design and is able to speak directly with both the architect and the general contractor regarding the project. UCFSD has done similar educational construction projects in the past, so their knowledge of the construction industry is above average and although management of the entire project is not feasible, this previous experience allows for effective communication with both Wohlsen and the other parties involved throughout the project. Wohlsen's experience in the educational sector and on prior projects with the client made them an easy choice for UCFSD. Their knowledge of past works offers significant experience and makes them an ideal GC for the project. Despite the lack of a contract between parties, Wohlsen is able to communicate directly with MM Architects, Inc. and all Engineers contracted to them. Open lines of communication not only increase productivity but also help to solve issues as they arise in an efficient manner.

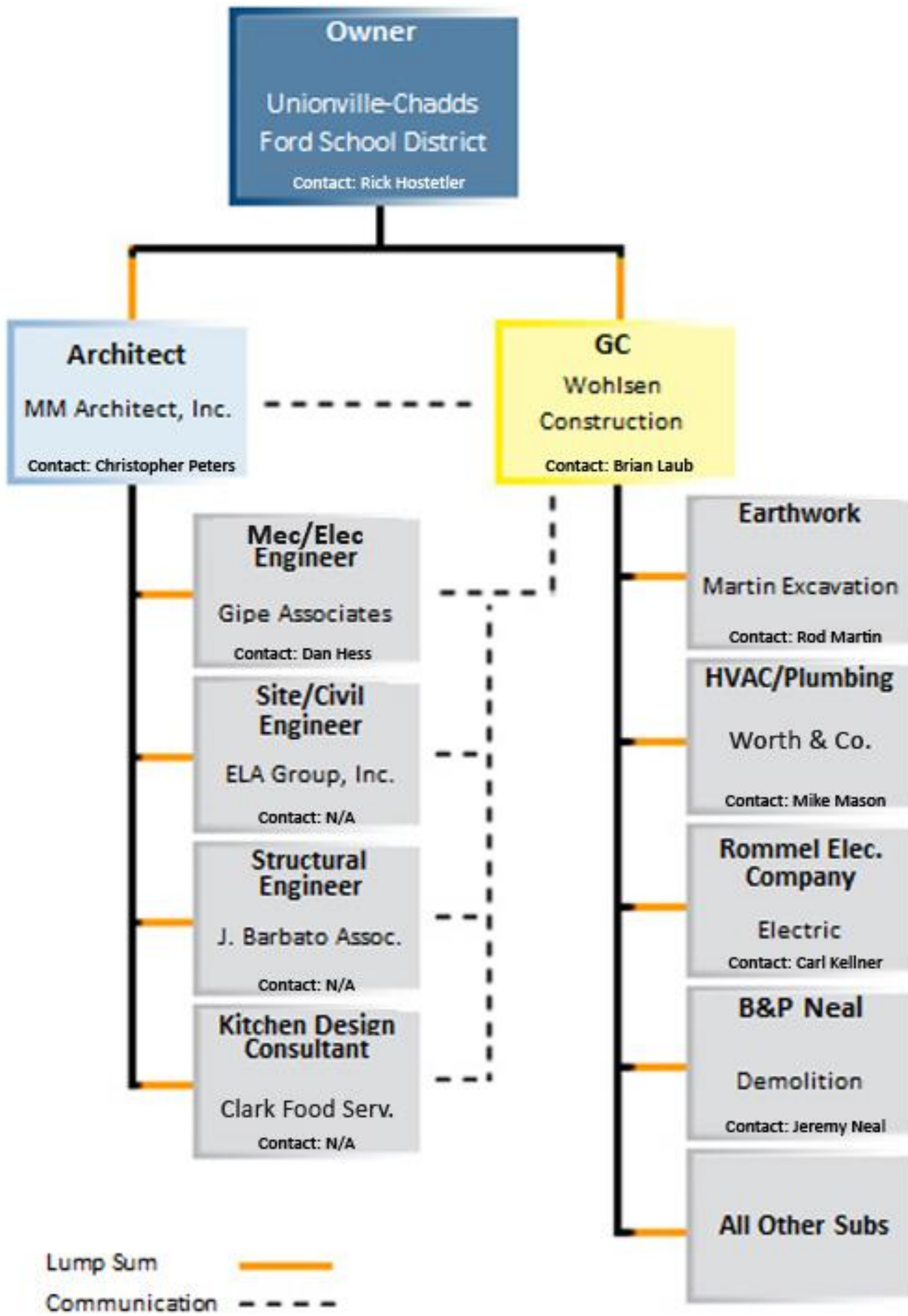


Figure 3: Project Delivery Method

Staffing Plan

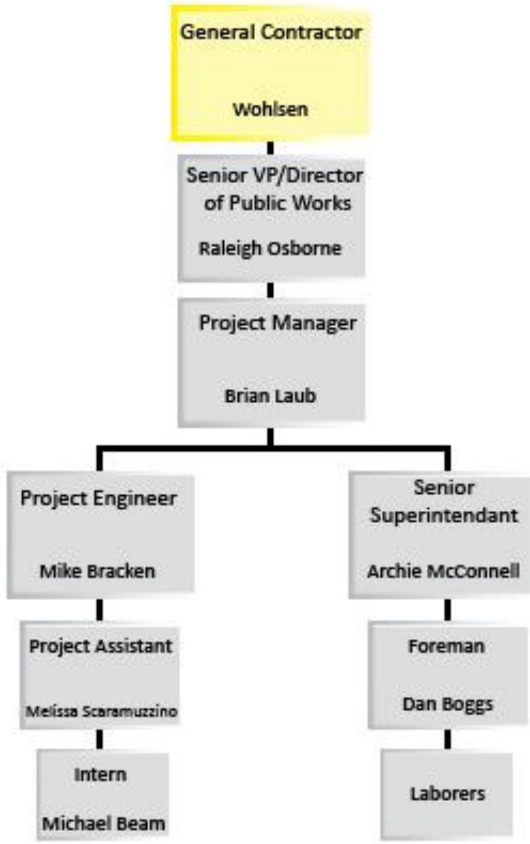


Figure 4: Staffing Plan

Wohlsen's staffing plan (figure 4) for the Unionville High School Building project can be seen above. The above plan is consistent with standard Wohlsen staffing plans, utilizing a Project Manager, Project Engineer, Project Assistant, Superintendent, and Foreman. The above staff includes the entire project team, however only the Project Engineer, Superintendent, Foreman, and Intern located on-site at all times. The Project Manager and Director of Public works visit the site as well, with the PM making trips at least once per week. Wohlsen's Director of Safety and other safety department members, although not a member of just this project team, oversees all Wohlsen projects. No safety coordinator was needed on-site for this particular project. Generally speaking, a Project Manager oversees between 2-3 projects and teams, while the Director of Public Works oversees all projects in the public sector. Project assistants generally work with the same PM on all projects, working on 2-3 projects at a time as well.

Building Systems

Demolition

Many new spaces are planned as part of this large public education project. In addition to the new construction on the building, demolition is required as many renovations are to take place during the project. Wrestling, physical education, and fitness and weight room space are set to replace half of the existing gymnasium once demolition of the existing facility have been demolished, and a new gymnasium is set to be constructed on the West side of the building. The existing auditorium is to be renovated into classroom space as a brand new 1,200-seat auditorium set to be built at the North end of the building, certain to become the new focal point of the building.

Figure 4: Demolition during Phase 4

Material to be removed includes structural CMU block, brick, windows, doors, structural steel, cast-in-place concrete, stage flooring, drywall, and roofing materials. Some items, such as acoustical wall panels from the existing auditorium, are to be saved and reused in other locations within the new building. All material is to be demoed by B&P Neal Demolition, who is also responsible for the proper removal of all materials. One exception is asbestos: the owner, Unionville-Chadds Ford School District, is responsible for all removal of asbestos. Once removed, B&P Neal is required to wait 10 calendar days before they are permitted to return to their demolition duties. During the process, several instances of asbestos occurred including readings from both ceiling and floor tiles. Figure 4 shows demolition during Phase 4 of construction during the Summer of 2011.

Structural

The primary foundation system uses several types and sizes of structural steel columns in tandem with reinforced concrete piers and footers, a 4” concrete slab on grade on top of 4” of crushed stone, and 16” CMU block for the foundation walls. Although primarily made up of W-flange columns, several locations throughout the foundation system utilize hollow structural steel members. HSS8x8x1/2 columns are used on the Western side of the building, while W10x33 and W14x90 are the two most prevalent w-flange sizes used in the foundation system. In most areas, the steel columns and CMU block walls run more than one story and make up the structure for exterior walls for the building. Reinforced concrete piers designed to carry the load of the columns range from 1’10” x 1’10” to 3’0” x 1’10” in size. There are several sizes of strip footings using primarily #5 rebar as well as various column spread footing sizes using #4, #6, and #8 rebar.

The steel erection on this project required the use of a 90-ton crawler crane. The need to move laterally along the portion of the building during each phase of construction made a crawler crane the best choice for this specific project. Structural steel erection is present in each phase, meaning the crane will be used at several points throughout the projects lifetime. Due to the many phases and sub phases during construction, crane location changes several times throughout the project.

The upper floors of the building utilize a structural steel skeleton system composed almost entirely of W-flange beams, primarily W10, W14, W18, and W21 members. In the instance of an elevator shaft, however, 8” CMU block is to make up the structure for the wall. Due to the multiple elevations of the land on site, several types of flooring systems have been designed. A 4” slab on grade on top of 4” crushed rock serves as the flooring system for the portion of the building sitting on soil, while a concrete on metal deck system is to be used when an area is above a preceding floor.

A variety of roofing systems are to be used throughout the building, depending on the area. Due to the large span and the barreled roof design, 48LH13 joists have been chosen as the

Figure 5: Barreled Auditorium Roof

structure for the auditorium roof (figure 5). Each joist has 8 foot wide bays, a curved top chord, and a 7 ½” height between the seat and the bottom chord. The new gymnasium will feature a similar roofing system, utilizing W10x39 truss with a curved top chord.

Cast-In-Place Concrete

All cast-in-place concrete used on the UHS Additions and Renovations project is to be designed per ACI 301. Items using CIP concrete include column piers, spread footings, strip footings, foundation walls, suspended slabs, stairs and access ramps, and retaining walls. All CIP concrete must meet minimum 28-day strength of 4000psi with a slump ranging from 2” to 4”.

Formwork and shoring is to be provided by the subcontractor and designed to meet ACI 301 standards. Formwork is to remain in place until the concrete in question has reached at least 90% of its 28 day compressive strength. Form-facing panels are to be used for any smooth-formed finished concrete. These panels are designed to provide continuous smooth concrete surfaces, suitable for an exposed finished face. Plywood, metal, or other materials approved by the owner are acceptable to meet this requirement. Rough-formed concrete will be used in most applications and can also be formed using the same materials listed above. Any cylindrical member, including columns and pedestals, is to be constructed from metal, glass-fiber-reinforced plastic, paper, or fiber tubes that produce minimal or no irregularities on the surface of the concrete.

Figure 6: Ongoing Concrete Pour

Reinforcement and formwork installation must be checked before any concrete placement can occur. Concrete is to be placed in layers such that no new concrete is placed on already hardened concrete, eliminating the possibility of seams or weak planes within the slab (figure 6). Construction joints are to be provided for any slab that cannot be poured continuously. A mechanical vibrator is to be used in order to ensure equal and should be used only on the newest layer of concrete. Over vibration can compromise the quality of the concrete, so care must be taken when consolidating.

Mechanical

With 319,000 square feet to condition, the Unionville High School Building utilizes 22 Air Handling Units, 4 existing and 18 new. The 4 existing units as well as 15 of the new AHU's are located on the roof, with the remaining 3 new units housed in mechanical rooms within the building. The mechanical rooms housing these units are located on the 2nd and 3rd floors, with AHU's 10 and 11 located in mechanical room 30.9A and AHU 17 located in mechanical room 201.1. All standard classrooms loads are handles by Innovent Laser Dedicated Outside Air Systems (DOAS), with supply fan loads ranging from 5,500 to 9,900 CFM. The auditorium is supplied completely by one unit, an Innovent RHXC Single Zone Heat Recovery VAV Unit with a max supply fan load of 26,000 CFM. Another single zone heat recovery system is used in the Gymnasium, with an Innovent 5000 VAV unit supplying a maximum of 32,000 CFM. In total 11 DOAS, 2 DOAS/VAV, 7 VAV, and 2 CAV units are to be used to service the building.

A total of 10 Blower Coil Units service the building as well, all of which are provided by Trane. Each 4 pipe BCU uses interlocks with a specific AHU and services multiple locations. The maximum loading capacity of the air sides of the units range from 300 to 2,770 CFM, while the cooling coil system loads range from 1.0 to 7.0 GPM and the heat coil loads range from 1.0 to 4.5 GPM. Finally, Vulcan DV-412 baseboard radiators have been used in several locations, generally some of the smaller spaces within the school including special education classrooms and personal offices. Each radiator is to be installed 4" from the top of the finished floor and is designed to handle a capacity of 5,400, 9,000, or 15,300 (corridor) BTU load depending on the space.

The new gymnasium and auditorium are to be fully sprinklered per NFPA 13 specifications. Sprinklers are required in all renovated spaces and every area within the newly built portion of the building, with renovated spaces remaining protected under the existing system. Pendant sprinklers are used in all spaces, most of which have covers. Sprinklers without covers are located in mechanical rooms, storage space, or other rooms with no ceiling.

Electrical

The Unionville High School utilizes a 35000 Volt service entrance into metal-enclosed switchgear provided by S&C Electric Company which feeds into a 2500KVA 34.5/19.9KV to 4.16/2.4KV Outdoor Oil Filled Transformer, through a metering station, and finally into a 1500KVA Oil Filled Transformer with a 4160 Volt, 3 Phase primary, and a 480/277V, 3 phase, 4 wire Y transformer secondary. Due to the varying uses throughout the building, both 480/277V and 280/120V service is used throughout the building. All of the lighting within the building is serviced by 480/277V, 3 phase power as well as all blower coil units (BCU) and air handling units (AHU). All equipment used in the shop is fed with 480/277V power, while kitchen equipment and other miscellaneous items run on 208/120V power.

Lighting

Figure 7: 2' x 4' Recessed Classroom Fixtures

Many different fixtures are used throughout the building based on which area they are serving. Classrooms are designed using a 2' x 4' recessed fixture with a fluorescent troffer and an acrylic diffuser, utilizing a 2, 3, or 4 lamp electronic ballasts (figure 7). 2' x 4' recessed fixtures are also used in the corridors of the buildings, although each fixture used in the corridor uses just two lamps. All 2'x'4 recessed fluorescent fixtures, classroom and corridor alike, utilize F32T8 lamps. Almost every classroom and restroom is designed with occupancy sensors in order to cut down on unnecessary use of electricity.

With a brand new auditorium comes a state of the art lighting system. The main lighting system for the auditorium uses a 9" diameter x 16" long metal cylindrical fixture. Both Metal Halide and Fluorescent lamps are used with this fixture type using Q500 T4 or 70W MH in the front and majority of the auditorium, or Q250 T4 or 50W MH lamps above the balcony towards the back of the balcony. Two different fixture types (research ongoing) are designed to be mounted on the three catwalks and will be utilized to illuminate the stage during use.

Masonry

Masonry is used on this project both as a load bearing material and an architectural veneer. CMU blocks are used in various locations throughout the building, as well as a portion of the foundation. 20" CMU units are used for the new gymnasium, 16" CMU blocks are used for foundation walls, and 12" CMU are used to construct the walls of the new auditorium. 6" 8" CMU units will be used to construct walls dividing standard classrooms and other standard spaces.

Figure 8: Rock Face Architectural Block

Rock face architectural block (figure 8) and standard red brick is to be used to make up the building façade. Structural CMU masonry units will sit on the structural steel frame and the façade veneer will be connected using masonry ties or adjustable anchors. Wire ties can be made of a number of materials and can come in the form of wire ties or corrugated metal ties. Adjustable anchors for units connected to steel framing are designed to allow horizontal or vertical adjustment but to resist tension and compression forces perpendicular to the wall.

Project Cost Evaluation

Construction Cost

The Construction Cost for the Unionville High School Additions and Renovations project is based on figures as of summer 2011. The following items have been excluded in order to arrive at the Construction Cost of the project.

- General Conditions
- Site Work
- Contingency
- Fee
- Controls
- Insurance

All cost data is provided by Wohlsen Construction; approved change orders to date have been included. A total project size of 319,000 is assumed.

Actual Building Construction Cost

Total Building Construction Cost	**$46,051,101.52**
Total Building Construction Cost/S.F.	**$150.30**

To calculate Total Building Cost, all line items have been totaled including the items that were excluded to obtain actual project cost.

Total Project Cost

Total Building Cost	**$52,744,833,02**
Total Building Cost/S.F.	**$165.34**

Major Building System Costs

	Total Cost	Cost/S.F.
Site Work	**$2,638,575.00**	**$8.27**
Substructure	**$2,073,459.00**	**$6.50**
Superstructure	**$3,710,829.32**	**$11.63**
Building Enclosure	**$5,562,196.13**	**$17.44**
Roofing	**$2,475,495.00**	**$7.76**
Fire Protection	**$360,366.25**	**$1.13**
Mechanical System	**$9,764,531.92**	**$30.61**
Plumbing System	**$2,610,852.54**	**$8.18**
Electrical System	**$5,931,113.41**	**$18.59**

RS Means Square Foot Cost Estimate

In order to develop a Square Foot estimate, the CostWorks software from RS Means was utilized. A square foot estimate was developed to compare to the actual project cost. Below is a chart showing all information used to develop the estimate.

Estimate Parameters

Building Type	School, High, 2-3 Story
Facade	Decorative Concrete Block
Structure	Steel Frame
Area	319,000 Square Feet
Perimeter	4,650 Linear Feet
Stories	3 Stories
Story Height	13.5 Feet

After entering the above information and running the analysis, RS Means CostWorks produced the following results for the Square Foot and Assembly analyses:

RS Means Square Foot Estimate Results

Total Building Cost	$38,878,000.00
Building Construction Cost/S.F.	$121.87

RS Means provides information based on general parameters (see above chart). These parameters included building type, size, and location. Also, renovation work costs are not provided by RS Means CostWorks therefore all work was estimated as new construction. Another reason for the lower total building cost and cost per square foot is due to RS Mean's lack of knowledge of what specific spaces are within the building. For example, the new auditorium is fit out with high end finishes. Further information provided by RS Means CostWorks on the square foot estimate can be found in APPENDIX C.

Cost Comparison

	Total Building Cost	Construction Cost/S.F.
Actual Building Cost	$46,051,101.52	$150.30
RS Means S.F. Estimate	$38,878,000.00	$121.87

General Conditions Estimate

Rather than estimating just one portion of the project (as was done with the structural estimate), the entire project has been accounted for in this general conditions estimate. The source for the information used to develop this general conditions estimate comes from *RS Means Building Construction Costs 2011.*

Several assumptions have been used to produce this estimate:

- Project Information
    - Project Duration:
        - 183 Weeks
        - 42 Months (original schedule)
    - Construction Site size
        - 900,000 Square Feet
        - 21 Acres
    - Construction Site Perimeter
        - Perimeter: 4,300 Linear Feet

- Field Personnel
    - 'Clerk' has been used to estimate the cost of a Project Assistant
    - 'Field Engineer' has been used to estimate the cost of a Project Engineer

- Temporary Utilities
    - The only temporary utilities accounted for in this estimate refer to the utilities providing power, electricity, HVAC, etc. to the trailer. All power and other utilities for the project are assumed to have been provided by existing portions of the building.

Construction fees and contingencies have been excluded from this estimate. Due to the lack of some 'Total Cost' information for certain items used in this estimate, all costs have been quantified using 'Total Cost including O&P' data. Final values include a *location factor of 108.9* and have been rounded to more easily interpret the cost data. Based on these assumptions, the following cost information has been derived.

General Conditions | Total Cost

Total Cost including O&P	**$4,020,000.00**
Total Cost with Location Factor	**$4,400,000.00**
Construction Cost	**$52,000,000.00**
General Conditions % of Total Cost	**$8.5%**

At 8.5%, this estimate is within a reasonable range in terms of price relative to the overall project cost. Most costs were calculated to be incurred for the entire duration of the project, but several costs were estimated based on their estimated duration on the project. Small variations may have altered the value of the estimate due to the exclusion of specific items from the estimate, namely items that RS Means did not have a specific value for. A further breakdown of the estimate can be seen below, with the entire project cost being divided into monthly costs for four main categories: Field Personnel, Insurance and Bonds, General Construction Costs, and Office and Storage Space. These values are derived from the General Conditions Cost with the location factor (108.9) applied.

General Conditions | Cost Per Month (including Location Factor)

Project Staff	**$41,500.00**
Insurance and Bonds	**$37,000.00**
General Construction Costs	**$25,000.00**
Office and Storage Space	**$1,000.00**
Total Cost	**$104,500.00**

With more than $100,000.00 per month in general conditions costs, it is clear that the schedule must be followed precisely. Not only would a delay produce direct costs, but liquidated damages (agreed upon in the contract) would be incurred as well. Note: Although some costs in the estimate are not incurred for the entire duration of the project, these values have been calculated as a division of the entire cost by the duration of the project in order to provide a rough estimate of monthly costs. This calculation allows for a quick view at which portions of the general condition contribute more to the job cost than others.

All General Conditions estimate information can be found in APPENDIX D.

Detailed Project Schedule

Projects including additions and renovations to a building require that some or most of the building remain in use during the construction process. As a result, the Unionville High School Building Additions and Renovations project follows a carefully designed phased construction schedule. The GMP contract was developed and agreed upon between UCFSD and Wohlsen Construction as a result of a hard bid publics work job. Overall, the project design spanned from June of 2008 until 2009, with construction initially slated to begin on June 22nd, 2009 and finish on December 28th, 2012. As of October 19th 2011 when this report was completed, the estimated finish for the project had moved up roughly three months and is expected to be completed on September 29th, 2012. With multiple phases during construction, the project team was able to develop a schedule in order to efficiently complete building construction while limiting the disruption of everyday life for students and faculty.

Each phase of construction focuses on one portion of construction, although some phases do incorporate multiple areas of the building. The first phase focuses on the addition of a new wing which will house District Offices and classroom space. Phase three focuses on the addition of the new Auditorium as well as the renovation of existing spaces within the building. The existing auditorium is renovated into Choral and Tech Ed rooms during phase three, and phase four sees the demolition of an existing portion of the building in order to make room for the new Gymnasium. Overall the project duration (as of this report) is set to span 39 months from June 15th 2009 until September 28th 2012. The phasing plan, as well as a map outlining the areas of the building, can be seen in APPENDIX A. Phase descriptions and phase timelines are listed below.

Phase Descriptions

- **Phase 1**: Construction of the New 3 story addition, set to house the Unionville-Chadds Ford School District Administrative Offices, Classrooms, and Science labs.
- **Phase 2**: Construction of the New Auditorium, Art rooms, and Family and Consumer Classrooms.
- **Phase 2A**: Renovation of existing Large Group Instruction, Library, Faculty Restrooms, Cafeteria, and Kitchen.
- **Phase 2B & 2C**: Renovation of existing District Administrative Offices into High School Offices, Science Labs, and Classrooms.
- **Phase 2D**: Renovation of existing High School Offices, Music Area, and Faculty Dining.
- **Phase 2E**: Renovation of existing Science Labs and Classrooms.
- **Phase 2F**: Renovation of existing Classrooms
- **Phase 2G**: Renovation of the existing Computer Applications Labs and Classrooms.
- **Phase 2H, 2I, 2J**: Renovation of existing Classrooms.
- **Phase 3**: Renovation of existing Auditorium into Choral Room and Tech Ed Classrooms.
- **Phase 4:** Demolition of existing Classroom and Tech Ed Wing and Weight Room.
- **Phase 4A**: Renovation of existing Gymnasium, Locker and Team Rooms.
- **Phase 4B**: Demolition of existing Auxiliary gym.

Phase Timelines

Design	**June 16th 2008 – June 12th 2009**
Phase 1	**June 15th, 2009 – June 25th, 2010**
Phase 2	**June 9th 2010 – June 23rd 2011**
Phase 2A	**June 2nd 2010 – July 28th 2011**
Phase 2B & 2C	**June 30th 2010 – December 31st 2010**
Phase 2D	**January 6th 2011 – June 27th 2011**
Phase 2E	**January 3rd 2011 – January 21st 2011**
Phase 2F	**January 24th 2011 – February 11th 2011**
Phase 2G	**February 14th 2011 – March 4th 2011**
Phase 2H	**March 14th 2011 – April 1st 2011**
Phase 2I & 2J	**April 4th 2011 – June 3rd 2011**
Phase 3	**June 9th 2011 – December 30th 2011**
Phase 4	**July 7th 2011 – April 27th 2012**
Phase 4A	**May 24th 2011 – September 28th 2012**
Phase 4B	**April 30th 2012 – June 29th 2011**

Overall, phased construction was easily the best choice for a project of this type. While working during school hours presents many challenges, phased construction allows for the careful planning of construction in order to manage the interaction between construction and everyday life. Thus far, construction has gone accordingly and the schedule has been met. As a result, normal school activities have gone uninterrupted while construction continues to be completed according to schedule. The detailed project schedule can be seen in APPENDIX E.

Analysis 1: Delivery Method Study

Problem Identification

The Separations Acts of 1913 dictates that all public education construction projects in Pennsylvania (among other states) be constructed using a Multiple Prime delivery method. On the Unionville High School Building Renovations and Additions project, however the project team did not feel comfortable using a multiple prime method and sought to employ a Single Prime delivery approach.

Research Goal

This analysis will outline both delivery methods: Multiple Prime and Single Prime. Each delivery method will be studied, outlined, and analyzed. One of the main goals of this analysis is to determine how the Unionville High School project team was able to bypass the Separations Act, why they chose to do this, and the benefits that a Single Prime delivery method has provided to the owner. In addition, both delivery methods will be compared to determine the best option for public education projects in Pennsylvania. Schedule and Cost impacts of each system will be highlighted to provide better insight regarding which of the two systems is superior.

Research Methods

- **Research UHS project team's reason for using Single Prime**
  - **Interview the project team and the owner to understand the reason for using an alternative delivery method.**
- **Study current delivery method**
  - **Research other projects using a Single Prime delivery method**
    - **Projects with similar scopes as well as alternate scopes**
- **Research Multiple Prime delivery method**
  - **Research other projects of similar scopes that were delivered using Multiple Primes**
  - **Research/study The Pennsylvania Separations Act of 1913**
- **Compare/Contrast both methods**
  - **Determine positives and negatives of each system for this application**
- **Determine best system for this project**
  - **Select delivery method that provides the most quality to the owner and also allows for the most efficient completion of this project**
  - **Cost, Schedule, and Quality to the Owner**

Owner Interview

The owner's representative, Rick Hostetler, was generous enough to take the time to provide me with in an interview regarding this very topic. As stated previously, the school district has past experience with public education construction projects. Rick explained that a multiple prime delivery method has caused issues on the projects that he has been a part of.

In order to receive the exception, Rick and the Unionville-Chadds Ford School District had to apply for a waiver in 2008 from the Pennsylvania Board of Education. The waiver application required sufficient information as to why the school district wanted to use a Single Prime delivery system as opposed to the Multiple Prime delivery system. Rick explained that the communication benefits offered by a Single Prime delivery method would aid the project and ultimately work more effectively for this specific project.

Coordination and collaboration using a multiple prime delivery method is far more difficult than when using a single prime. The main positive to using a single prime delivery method is the *single point of contact*. A single point of contact simplifies the communication process between the owner and the construction project team. Any question, request for information, or issue can be brought to one party who can then move forward to meet the request. With multiple prime contractors, communication becomes more difficult and information transparency is hard to keep.

Ultimately, Rick states in no uncertain terms a Single Prime delivery method has indeed been the right choice. Based on past experiences with a multiple prime system and the UHS' project results up to this point, a Single Prime delivery method has met all of UCFSD's expectation. In terms of logistics, quality, and cost, a Single Prime delivery method has provided the best value for projects.

(Hostetler, Rick)

Unionville High School Project – Use of a Single Prime Delivery Method

Due to the Separations Acts of 1913, all Pennsylvania public education construction projects exceeding $4,000 are required to use a Multiple Prime delivery method. On the Unionville High School Building Renovations and Additions project, however, a Single Prime Delivery Method was used. An interview with Project Manager Brian Laub of Wohlsen Construction provided useful insight into this specific project. The reasoning for using a Single Prime Delivery method and how the UHS project team went about requesting and receiving the exemption is a product of many factors.

The Unionville-Chadds Ford School District was the driving force behind use of a Single Prime delivery method. With past public education construction project experience, the school district knew from the inception of the project that a Single Prime delivery method was superior to a Multiple Prime delivery method, for their specific situation at least. For this reason, the school district applied for and was granted a waiver from the Pennsylvania Department of Education. Past experience with projects using a Multiple Prime delivery method was the main reason that the district applied for the waiver, as it created numerous issues and even law suits for UCFSD.

A Single Prime delivery method has proved effective for the school district. With one contractor to contact (rather than several) communication is more organized and it is easier for the owner to relay information to the construction team. A major benefit of using a Single Prime delivery method instead of a Multiple Prime delivery method is that the owner does not need to hire a Construction Manager to manage the prime contractors. With only one prime contractor, all information is relayed to that contractor and from there it is relayed to the subcontractors. Without the need for a CM, project costs can be lowered and communication can be increased.

Ultimately, UHS feels as though applying for the waiver to use a Single Prime delivery method was the right decision. Experience with Multiple Prime helped to push them away from that method. As of this report, the project and the delivery method have both been a success. The interview with PM Brian Laub can be seen in detail in APPENDIX F. (Laub, Brian)

Single Prime Delivery Method Background Information

A Single Prime delivery method, also known as Design-Bid-Build, is a project delivery method with one Prime Contractor. Every trade is a separate entity, although each trade reports directly to the prime contractor. The owner for the prospective project uses in-house staff or hires an outside resource to develop the design for the project. Based on this design, competitive bidding is held between interested contractors and the bid is awarded to the lowest responsible and qualified applicant. Depending on the details of the contract, the Prime Contractor that is awarded with the project is free to select the subcontractors that they prefer.

Under this system, the owner has just one point of contact, meaning information can be more easily transferred to the construction project team. All subcontractors are direct subordinates of the prime contractor, and all information is relayed through that prime contractor. This delivery method also allows the owner to maintain contact with the project team through constant communication. An organizational chart for the Single Prime Delivery Method can be found in APPENDIX G.

Case Study – Kennett Square, PA

As a part of their study, the Allegheny Conference performed several case studies. This case study refers to the Kennett Consolidated School District located in Kennett Square, PA. In 2001, the Kennett Consolidated School District had two public education construction projects preparing to begin. For one of them, the district applied for a waiver to use a Single Prime delivery method. The other project was completed using the Pennsylvania mandated Multiple Prime delivery method.

With two projects underway simultaneously, each using different delivery methods, the school distract was able to really see which delivery method was more effective. The Single Prime project was to be additions and renovations to an existing high school while the other project was a new middle school. Overall, the district much preferred the Single Prime approach.

Several key reasons behind this preference are outlined below.

- Schedule Acceleration
  - The Single Prime project completed two months ahead of schedule
- Communication
  - Communication was superior on the Single Prime project than the communication on the Multiple Prime project due to improved dispute resolution and fewer change orders.
- Cost difference
  - The Single Prime project experienced savings of nearly $300,000, while the multiple prime project came in over budget
- Higher Quality of Work
  - The Single Prime project was completed with work of a higher quality than that of the Multiple Prime project

This particular school district would choose to use Single Prime over Multiple Prime, given that the district had the choice. Increased quality, lower cost, schedule reduction, and communication are only some of the reasons that the Single Prime delivery method is preferred. Having one contractor in charge of the project proved to be more effective than spreading the work out between multiple prime contractors. The increased communication as a result of one prime contractor really benefits the project on the whole.

Multiple Prime Delivery Method Background Information

A delivery method gaining popularity in recent years, especially in the public sector, is the Multiple Prime Delivery Method. In this system, each construction subdivision is bid separately as opposed to all together to a lone prime contractor. Early on in the project's infancy, the owner hires a construction manager to oversee all construction practices throughout the project. Following the design phase, the resulting design documents will be handed over to the construction manager. At this point, the CM will produce specific bid packages for separate trades including structure, mechanical, electrical, and plumbing.

Each bid package is awarded to separate contractors, all of whom are on the same level of the organizational structure within the project team. These contractors are known as prime contractors and report directly to the owner under this system (as opposed to a Single Prime system, where the separate trades report to the lone prime contractor). Ideally, a Multiple Prime Delivery Method aims to produce a project faster than alternate delivery methods. An organizational chart for a Multiple Prime Delivery Method can be found in APPENDIX G.

Case Study

Like the Single Prime delivery method, the Allegheny Conference created a case study for a Multiple Prime Delivery Method for a Pennsylvania Public School. In this instance, the Troy Area School District reported that it had used exclusively a Multiple Prime delivery method for its construction projects. Based on their responses, several issues arose with this type of project delivery method. First, cost overruns were common. Each project experienced increased cost, at a minimum of 3 percent per project. Although this value does not seem overwhelming, on larger scale projects a 3 percent cost increase can create numerous issues. Another common issue was the volume of change orders. Change orders are timely and costly, meaning a large number of them can contribute to both cost and schedule increases, two huge issues in the construction industry. The districts final point against Multiple Prime systems is the increased stress; as a result of poor coordination, extra time needed to be allotted to the project to ensure better communication and coordination within the project team.

Pennsylvania Economy League – Review of The Pennsylvania Separations Act

My research on the debate between Multiple Prime and Single Prime delivery methods for Pennsylvania public school construction projects lead me to an extremely useful document developed by the Pennsylvania Economy League. Produced on November 8th 2007, the Pennsylvania Economy League produced a document titled "A Review of the Effects of the Pennsylvania Separations Act on School Districts" (The Allegheny Conference). This document will be referenced frequently, as the information therein is vitally important to my analysis and provides insight and information regarding this subject that I would otherwise be unable to attain.

Background and The Pennsylvania Separations Act of 1913

Still in effect today, the Pennsylvania Separations Act (PSA) of 1913 is legislation in place to dictate how contracts are structured for public construction projects. The PSA states that any public construction project exceeding $4,000 is to bid and award separate contracts for the primary trades including heating, ventilation, electrical, and plumbing. A project with multiple prime contractors each holding separate contracts, such as this, is referred to as a Multiple Prime Delivery method. The PSA has been removed in some areas including boroughs, townships, and counties, though the act remains in place regarding Public Education Projects.

The Pennsylvania School code also contains requirements regarding construction to public education buildings. Specifically, section 7-751 states that any construction, maintenance, or repair work performed on education buildings costing in excess of $10,000 requires separate contacts for each prime contractor (heating, ventilation, electrical, and plumbing) (The Allegheny Conference). The Mandate Waiver Program of the Education Empowerment Act was passed in 2000 and allowed school districts to apply to the Pennsylvania Department of Education (PDE) for a waiver to bypass certain Pennsylvania School Code requirements. As this mandate grants waivers pertaining only to the Pennsylvania School Code, PSA requirements demanding use of a Multiple Prime Delivery method still need to be met.

In 2005, Thomas Stevenson (Republican Representative, Allegheny) sponsored House Bill 2100 which would allow certain entities to select which type of project delivery method to use for construction project (The Allegheny Conference); unfortunately, this bill did not make it out of Committee. Another attempt to get around the PSA legislation came later in 2005. Joseph Petrarca (Democrat, Armstrong/Westmoreland) sponsored House Resolution No. 609. This piece of legislation requested information regarding cost overruns on the Peterson Events Center project located at the University of Pittsburgh. The University of Pittsburgh is a public entity and as such must abide by the requirements of the Pennsylvania Separations Act, meaning that multiple prime contractors and separate contracts must be used. The project reportedly "spent $28.5 in contract amendments, change orders, and claims settlements, resulting in a 34 percent (cost) overrun, a rate construction experts say is two to four times higher than normal." (The Allegheny Conference).

Education Empowerment Act - Section 751 Mandate Waiver Program

The report by the Allegheny Conference referenced ‘Section 751 Mandate Waivers’ when referring to alternative delivery methods for public school projects in Pennsylvania. As this piece of legislation relates directly to this Delivery Method discussion, research into the Mandate Waiver program was performed. The Education Empowerment Act was developed in May of 2000. This act, passed by the Pennsylvania General Assembly, aimed to help school districts with low test performance or a history of financial distress (Pennsylvania Department of Education). Every school district (501 districts) in Pennsylvania was eligible to receive aid from the Education Empowerment Act.

Pennsylvania School Code section 751 states that every public school district in the state must award bids to separate contractors for each primary trade, including electrical, ventilation, plumbing, etc. The Pennsylvania Department of Education Mandate Waiver program was established in 2000 and expanded in 2001. Specific to this analysis is Pennsylvania Department of Education Waiver Application Codes K, Construction and KS, Single Prime. These categories were created specifically to allow any of the 501 school districts in Pennsylvania to apply for an alternate to the Multiple Prime Delivery Method. This program was designed to accommodate all school districts in Pennsylvania regarding construction projects and how they are performed. A school districts school board may applied for a waiver in an attempt to “improve its instructional program or operate in a more effective, efficient or economical manner” (Pennsylvania Department of Education).

From 2000 to 2003, the program received a high level of interest. Many school districts applied for waivers during this time period, based on the Pennsylvania Department of Education's report data. The Pennsylvania Department of Education stopped accepting and processing new waiver requests in May of 2003, however, which obviously resulted in decreased inquiries from Pennsylvania School Districts. Based on data collected by the Mandate Waiver Annual Report, 61 schools applied for the Code KSP waiver between the years 2007 and 2009. However, Application Code K, Construction contained the Single-Prime waiver up until December of 2007.

From the program's inception in 2000 until application code KSP was created, 263 Code K – Construction waivers were requested. Although the Single-Prime exception was contained within Code K, there is not sufficient data to determine which of the 263 applications were made specifically for the Single-Prime exception. Of the 23 Code KSP requests made in 2009, 6 were withdrawn, 15 were approved, and just 2 were denied. Table 1 outlines the waiver application data for Code K and Code KSP from 2000 to 2009.

Table 1: Waiver Application Requests by Code (Pennsylvania Department of Education

Code	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total
K	*2*	*62*	*85*	*28*	*23*	*17*	*21*	25	13	24	300
KSP	0	0	0	0	0	0	0	*1*	*37*	*23*	*61*

Despite the program's success and the interest in mandate waivers, the program ended on June 30th 2010 when the Education Empowerment Act expired. At this point, the Pennsylvania Department of Education no longer has the jurisdiction to grant waiver requests. The program remains closed, and there are no plans to reinstate the program or develop another similar program.

Multiple Prime Delivery System Survey

As mentioned earlier, the Allegheny Conference produced a valuable document outlining the Pennsylvania Separations Act and how exactly it impacted public education construction projects in Pennsylvania. As a part of this document, a survey regarding the use of the Multiple Prime Delivery method yielded valuable and informative results.

Generally speaking, projects using multiple prime contractors caused problems for the school and/or owner in question. The disconnect between the parties leads to a breakdown in communication, which can snowball in to a myriad of other issues. Several school districts reported increased change orders due to the Multiple Prime Delivery Method, as well as an increase in the duration of the schedule and cost overruns.

Downfalls of Multiple Prime Delivery Method

The above survey shed light on several major issues with a Multiple Prime Delivery method for Pennsylvania public education projects. Some of the major issues are:

- Communication breakdown
  - Due to the increased number of contractors, communication between the contractors often insufficient, meaning that construction and facility managers must spend added time to ensure proper communication between the various parties.
- Multiple Parties Involved
  - With several contractors, any issue or change within the project must be relayed to multiple parties rather than just one; keeping in contact with each prime contractor at all times is difficult.
- Increased Error
  - Each contractor must have its own set of drawings, meaning the increased possibility of errors. Should a change occur that one prime contractor is unaware of, work could be put in to place that has actually been changed.
- Schedule Delays
  - With multiple prime contractors, the process of completing a change order must go through multiple contractors rather than one. Schedule delays can increase due to the lengthy process needed to complete a change order.
- Poor Coordination
  - Each contractor is responsible to complete its work on time and on budget. Should work be performed by one contractor that interferes with another contractor, there exists the possibility of repeated work.

Single Prime Delivery Method Waiver Survey

The Allegheny Conference on Community Development created a second extremely useful survey regarding this very topic; the survey was developed to determine which school districts attempted to receive permission to use a Single Prime Delivery method and the results of their efforts. The results of the survey are as follows, including a graphic developed by the Allegheny Conference:

Survey Results (figure 9)

- 61 out of 501 school districts in Pennsylvania were granted waivers to use a Single Prime Delivery method
  - Forty-two (42) of these Sixty-one (61) school districts constructed projects using a Single Prime delivery method
  - Roughly 70% of the 61 school districts estimated savings due to the use of Single Prime
- Nineteen (19) school districts applied for the waiver, were granted the wavier, but did not complete projects using a Single Prime delivery method
- Four (4) school districts applied for the waiver but were denied.
- 436 school districts did not apply for the waiver

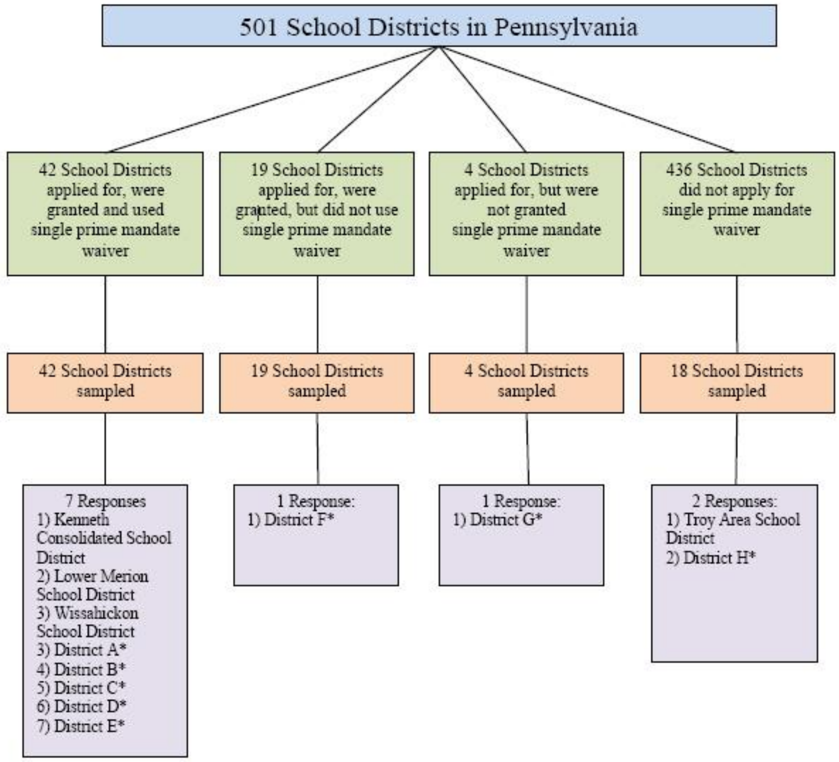


Figure 9: School District Survey, Allegheny Conference (The Allegheny Conference)

Pennsylvania Economy League Study Conclusions

Ultimately, the school districts approached for this study preferred a Single Prime delivery method to a Multiple Prime delivery method. The separation of work between multiple prime contracts caused many issues including schedule delays, cost increases, poor communication, and poor coordination. The ability to apply for a waiver in order to bypass the Separations Act Legislation proved useful for all those granted the exception, with savings on total project costs ranging from $8,000 to $2,500,000 (The Allegheny Conference).

Multiple Prime – Pros and Cons

The Multiple Prime Delivery Method is a project delivery system that has individual bid packages awarded to multiple prime contractors. The owner will frequently hire a Construction Manager to oversee the project, although the prime contractors are contracted directly to the owner. Pros and Cons for a Multiple Prime Delivery Method are outlined below:

Pros

- Direct Contact With owner
  - Contractors who are selected as Prime Contractors like the opportunity to work directly with the owner
- Increased Expertise
  - Each bid is trade specific, which can result in a Contractor with a higher competency in each area
  - Improved Work Ethic
- Economy of Scale
- No General Contractor
  - Without a GC, or Single Prime Contractor, the GC markup for each subcontract is removed
  - Fewer subcontracts, lowering overhead & profit costs
- Economy of Scale
- Awarding Bids Based on Sequencing
  - Specific contracts can be awarded only when that specific trade is beginning work

Cons

- Difficult on Complex Projects
  - Not an optimal delivery system for complex or specialized projects
- Increased Number of Contractors
  - The increase in prime contractors creates added stress on the owner/administration
  - Increased number of contracts increases cost
- No Definitive Price
- Scope Gap Issues
  - The CM creates bid packages, creating the possibility of scope gaps
  - Scope changes can create change orders
- Increased Error
  - Many sets of drawings, increased chance of error
- Change Orders
  - Frequent change orders can occur as a result of scope gaps
- Poor Coordination
  - Communication can break down, as each trade is contracted specifically to the owner and only worried about its specific tasks
- Cost Increase
  - A high number of change orders can inflate the project's price
  - Each contractor must have its own bond
- Schedule Increase
  - Coordination issues, change orders, and scope gap can all cause schedule delays

Single Prime – Pros and Cons

With only one prime contractor, a Single Prime Delivery Method offers one point of contact to the owner. Instead of prime contractors bidding on specific bid packages, all trades are bid as subcontracts to the lone prime contractor. Pros and Cons for a Single Prime Delivery Method are outlined below:

Pros

- One Point of Contact for Owner
  - The Owner has just one point of contact, the General Contractor
  - CM will act in the best interest of the Owner
- Competitive Bids
  - Price can decrease as a result of competitive bidding
- Easily Understood
  - Common delivery method, most contractors have experience with this delivery method
- Better Coordination
  - Subcontractors report to GC, who reports to Owner
- Complete Design
  - The project is designed fully prior to the start of construction

Cons

- No Design Input from Contractors
  - The GC is hired and subcontracts are purchased following design, meaning little to no contractor input on design
- Change Orders
  - Frequent change orders can occur as a result of scope gaps
- Contractors May Take Advantage of the Competitive Process
  - GC may select cheapest subcontractor, even if they are not of necessary quality/skill
  - Subcontractors may produce lower quality work in order to save on costs
    - Cheaper is better thought process
- Delay Claims
  - Delays can create claims, disputes, and other issues between subcontractors
- Redesign Disputes
  - Guidelines must clearly state who is responsible for
- Design Coordination
  - Design is developed by several separate parties, which may make the design process difficult to coordinate

Conclusion and Research Result

After compiling multiple sources of information as a result of research regarding Public Education construction projects in Pennsylvania, it is my opinion that a ***Single Prime Delivery Method is superior*** to a Multiple Prime Delivery Method. This type of project delivery system is well known by most contractors and easy to perform. In this case, Unionville-Chadds Ford School District has had past experience with Multiple Prime projects that created issues. Disputes and claims have pushed the school district away from this approach and towards a Single Prime Delivery Method.

With a Single Prime Delivery Method, the owner has just one point of contact. With only one prime contractor, the owner can be more confident that the work will be done as desired; the owner will relay desires to the General Contractor, who will then relay that same information to the subcontractors. The GC will most likely act in the best interest of the owner, rather than acting in their own best interest which may occur with a Multiple Prime Delivery Method.
Based on surveys and responses from those who have had experience with both systems, the majority of school districts experienced *cost savings, schedule reduction, and even increased quality* when using a Single Prime Delivery Method. As of this report, the Unionville High School Project is project to finish a full 3 months ahead of the initial schedule.

Unfortunately, the waiver program in Pennsylvania has expired. It is my opinion that the legislation requiring a Multiple Prime Delivery Method for public education construction projects in Pennsylvania needs to be amended. I believe that each school district, or owner, should be free to determine which Delivery Method works best for their project. It is in the best interest of each school to perform the work based on ***what will benefit their educational initiative most***. Although research for this analysis showed that a Single Prime Delivery Method was favored to a Multiple Prime Delivery Method, there are certainly owners who would prefer the latter for their specific project.

Analysis 2: 4D Safety and Phase Plan (Critical Industry Issue)

Problem Identification

Unionville High School is an existing building undergoing new additions as well as renovations, serving as home to both the Unionville-Chadds Ford School District Administrative Offices as well as Unionville High School. Construction is broken down in to four main phases and a total of 16 sub phases. The building is scheduled to remain in use throughout the entirety project, meaning that all staff and students will remain in the building during the project's construction. Although standard safety procedures were taken as part of the initial project logistics, a formal safety plan designed specifically for each phase could help to increase safety and decrease the likelihood of accidents.

Research Goal

The UHS project did not use Building Information Modeling in any fashion. In order to develop a safety plan, an adapted form of 4D Phase Planning will be implemented. A basic massing model of the building will be developed and individual models will be created for each phase of the project, showing which areas of the building are under construction during specific time periods. Using these models, a comprehensive safety plan will be developed for each phase; hazardous areas of the building, exits leading to ongoing construction, and streets and parking areas in use during construction will be highlighted and the information will be made available for the use of anyone who may be using the building.

This safety plan will be accessible by anyone via a specially developed website, which will be interactive and will allow anyone to view the safety plan and model for any specific phase of construction. Several kiosks will be placed throughout the school, in neutral locations, to allow quick access to this safety information. The safety planning website will also be available to anyone via a personal computer.

Research Methods

- **Outline current structure of construction phases**
- **Conduct research on similar projects**
  - **Study similarly phased educational projects, highlight potential dangers**
- **Develop basic 3D Model of the entire building**
- **Determine hazardous areas for individual phases**
  - **Study each phase to pinpoint hazardous areas as well as safe routes to avoid such areas**
- **Develop safety floor plan/diagram for each phase**
- **Create individual model for each phase**
  - **A basic model will show each phase, where construction is occurring, and hazardous areas related to that phase**
- **Study feasibility of Safety Plan**
  - **Cost, Implementation, and Value to the Owner**

Background Information

The BIM Execution Plan developed by a team at the Pennsylvania State University defines 4D Phase planning as a process using a 3D BIM (Building Information Modeling) model linked with time or the project schedule. This model, known as a 4D model, can be used to effectively plan the phased schedule of a construction project, namely for projects undergoing renovations and additions (Computer Integrated Construction Research Group). This tool is a useful application of BIM and can help an owner and project team visualize how the project is going to be completed.

Generally speaking, 4D BIM models are used to visualize the construction of a project. The main focus is on the actual construction of the project and the different areas of the building that must be completed. In this case, a 4D model is to be developed to provide a comprehensive, phase by phase safety plan. Due to the large number of phases, construction areas and safety hazards are shifting continuously throughout the project. A 4D model will help to visualize which areas of the building are under construction during each phase, which areas of the building are hazardous during each phase, and any other pertinent safety information regarding each specific phase.

For this analysis, the models to be developed will be massing models only. Specific knowledge of materials and finishes in each space is not necessarily essential. Ideally, Revit would be used but due to time constraints, Revit was not used for this study. An interactive website will be developed to illustrate the kiosks that would be used within the school. This BIM application offers numerous benefits to a project and its project team. For the Unionville High School building, the main aim of the 4D Phase and Safety Plan will be to:

- Provide a better understanding of the project schedule
- Provide a visual description of the phased schedule to all building inhabitants
- Provided phasing plans describing work to be done per phase and adjacent occupied areas
- Highlight potentially hazardous areas for each phase
- Identify any space, workspace, or phasing issues
- Provide a better understanding of parking and other site logistics for each phase

UHS Project Phasing Information

The Unionville High School project consists of both new additions and renovations to the existing building. During construction, all students and staff are to remain in the building during the school year. For this reason, the construction team decided that phasing the schedule was the most efficient way to construct the project.

Begging in 2009, the project consists of four main phases and has a total of 16 sub phases. The schedule and work breakdown for each phase is listed below.

Phase Descriptions

- **Phase 1**: Construction of the New 3 story addition, set to house the Unionville-Chadds Ford School District Administrative Offices, Classrooms, and Science labs.
- **Phase 2**: Construction of the New Auditorium, Art rooms, and Family and Consumer Classrooms.
- **Phase 2A**: Renovation of existing Large Group Instruction, Library, Faculty Restrooms, Cafeteria, and Kitchen.
- **Phase 2B & 2C**: Renovation of existing District Administrative Offices into High School Offices, Science Labs, and Classrooms.
- **Phase 2D**: Renovation of existing High School Offices, Music Area, and Faculty Dining.
- **Phase 2E**: Renovation of existing Science Labs and Classrooms.
- **Phase 2F**: Renovation of existing Classrooms
- **Phase 2G**: Renovation of the existing Computer Applications Labs and Classrooms.
- **Phase 2H, 2I, 2J**: Renovation of existing Classrooms.
- **Phase 3**: Renovation of existing Auditorium into Choral Room and Tech Ed Classrooms.
- **Phase 4:** Demolition of existing Classroom and Tech Ed Wing and Weight Room.
- **Phase 4A**: Renovation of existing Gymnasium, Locker and Team Rooms.
- **Phase 4B**: Demolition of existing Auxiliary gym.

Phase Timelines

Phase 1	**June 15th, 2009 – June 25th, 2010**
Phase 2	**June 9th 2010 – June 23rd 2011**
Phase 2A	**June 2nd 2010 – July 28th 2010**
Phase 2B & 2C	**June 30th 2010 – December 31st 2010**
Phase 2D	**January 6th 2011 – June 27th 2011**
Phase 2E	**January 3rd 2011 – January 21st 2011**
Phase 2F	**January 24th 2011 – February 11th 2011**
Phase 2G	**February 14th 2011 – March 4th 2011**
Phase 2H	**March 14th 2011 – April 1st 2011**
Phase 2I & 2J	**April 4th 2011 – June 3rd 2011**
Phase 3	**June 9th 2011 – December 30th 2011**
Phase 4	**July 7th 2011 – April 27th 2012**
Phase 4A	**May 24th 2011 – September 28th 2012**
Phase 4B	**April 30th 2012 – June 29th 2012**

Case Study – American School & University Magazine – Managing a School Construction Project

In 2002, The American School and University Magazine developed a document highlighting construction of educational facilities, with a specific focus on expansion of existing buildings. Many educational projects consist of additions and renovations, which can create a distraction and even safety hazards to building inhabitants. Demolition, a necessary step in a construction project involving and existing building, can be a major factor for any educational project.

In order to ensure safety during demolition, careful steps must be taken. First, swing space of machinery must be studied to determine if there is enough building space to perform demolition while an adjacent space is occupied. Providing temporary space during demotion for displaced building inhabitants will add cost and create discomfort for those who are displaced.

A key component of phasing a project of this type is to ensure that there is proper circulation within the building despite ongoing construction. When constructing an addition on a project, it is common practice to complete the addition portion of the project first. Creating this addition first can reduce rental costs, as building inhabitants who are displaced in future phases can then occupy the newly constructed addition.

Schedules can also vary greatly based on phased construction. Key academic schedule dates, like the first day of class and the final day of the school year, often drive the construction schedule. Other factors include staff and student holidays, providing opportunities for construction when the building is not occupied. For this reason, every educational construction project schedules a specific portion of the work during the summer when school is not currently in session. Another factor that may impact a project of this type is weather. Depending on the work being done, weather can create unsafe conditions. It is important to ensure that no students or staff be affected by unsafe conditions created due to adverse weather.

After scheduling parameters have been met, the actual construction of the project must be determined. Careful planning must occur to ensure that construction activities are safely disconnected from occupied areas of the building. Often times, educational projects are broken into different phases. The phases take numerous variables under consideration, including available utilities, temporary construction protection, signage and the age level of building occupants, air quality within the building, and disposal of construction waste. Each of these factors can pose dangers to building in habitants if not taken under careful consideration. (Rush)

Applications for the UHS project

Often times in today's construction industry a 3D Model is used for detecting clashes between multiple trades, such as MEP and Structure; this is not the case for the Unionville High School project. The original project used no BIM whatsoever, so there is no existing model of the project. Instead, this application will see a 3D model used more as a visual tool. As mentioned previously, ideally, Revit would be used for this application. With Revit, the model can be linked to the schedule and a linked visual can be created showing which areas are being constructed at which time. For this analysis, Google SketchUp was used to develop a simple 3D massing model. The 3D model will be linked to floor plans and the schedule to provide important information regarding the construction process.

Initially, a model of the entire finished building will be constructed. From this, a model for each phase will be extracted. From the uses described within the Penn State BIM Execution Planning guide, the use most closely related to this application is "Space Management and Tracking". By combining the 3D model with site and floors plans analyzed for hazards and dangerous areas, all information regarding safety during the construction process. Following completion, an integrated website will be developed in order to provide access to all information to all building inhabitants.

Using this interactive website, anyone entering the building will have construction information at their fingertips. Several kiosks will be implemented in the building at central locations. Ultimately, the new 4D Safety Plan will provide added value to the owner at little cost by increasing the availability of information regarding the construction process to those utilizing the building.

Note: Due to the time available to complete this analysis, only a sketch up model was used. Provided there was more time available, a Revit model could be constructed, and linked with the schedule to provide a true 4D model for the owner.

Hazardous Areas within each Phase

Each of the 16 phases during the project will be adjacent to a portion of the building that is still in use. The hazardous areas during each phase will be outlined, showing exactly where the work for that phase terminates, thee areas in which contractors will be parking and using vehicles, and any other areas that may present safety risks during that phase. This will provide a visual aid for building inhabitants, allowing them to see which areas of the school are being worked on at which times.

During construction, the existing building will remain in use. This means that areas within the existing building that are adjacent to ongoing construction are at an elevated safety risk do to the high volume of building inhabitants. Each of these areas within each phase will be highlighted on a 3D model, and floor plan. Finally, the front vehicle entrance of the school will always be considered a hazardous area. With just one entrance to the site, this area will be in use constantly due to normal use by staff and students, as well as contractors, delivery trucks, and other construction vehicles.

Ultimately, this phased safety plan will highlight hazardous areas for building occupants. The information within the safety plan will allow occupants to see which areas of the building are under construction at which times, providing a greater knowledge of the construction process. With constant use of the building, it is paramount that no one, contractors and building occupants alike, is put at risk of injury during the project. For this analysis, a phasing and safety plan for Area D will be developed. Due to time constraints, developing the plan for all 16 sub phases was not feasible.

Phase 1

Building Area	D
Construction Dates	June 16th 2009 – June 25th 2010
School in Session?	Yes

Phase one is the construction of a brand new wing of the building, located at the southernmost end of the building, and will be the main example of how BIM would be used to implement phase/transition and safety planning on the Unionville High School Project. This wing will be added to the existing building, and as such will create junctions between existing building that is still in use and adjacent construction areas. These areas are located at several points during the phase:

- Connection between new wing (Area D) and existing building (Area E)
- Stair tower at edge of Area E
- Rear Parking Lot

The connection between the two areas will pose the highest risk. The existing building is scheduled to remain in use throughout construction and as such, this area will see a high volume of students and staff during the phase. Next is the stair tower exit door; based on the existing building, school inhabitants are used to using this exit doorway. With construction going on in the location of the rear parking lot, a crane will be on site and material laydown will be occurring constantly. Keeping all building inhabitants out of these areas is of utmost importance in order to ensure project and civilian safety.

The diagrams on the next several pages show information and resources that will be available through the interactive 4D Phase and Safety plan.

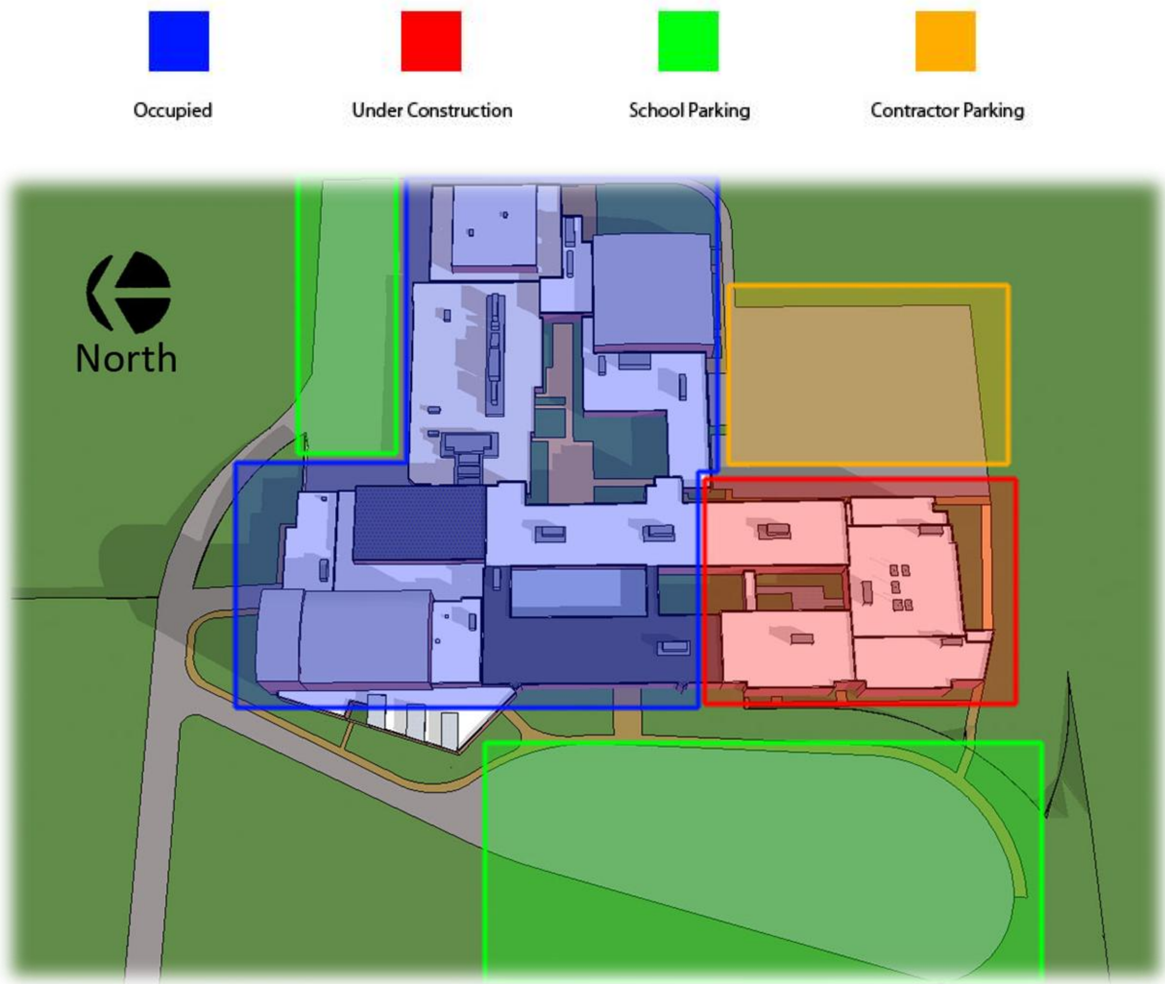


Figure 10: Phase 1 Building Breakdown

Figure 10 shows the entire building, highlighting which areas of the building are under construction and which areas are to remain in used during this phase. As you can see, the red area highlights all of Area D, which will be a new wing added to the existing building. During Phase 1, the entire existing building is to remain in use, shown here in blue. This means that a main area of concern is the intersection between area E and area D. Also shown here are parking areas; with students and staff parking on campus every day, it is important to keep construction vehicles and pedestrian vehicles separated. The green areas show parking lots where students and staff can park, while the orange lot shows contractor parking.

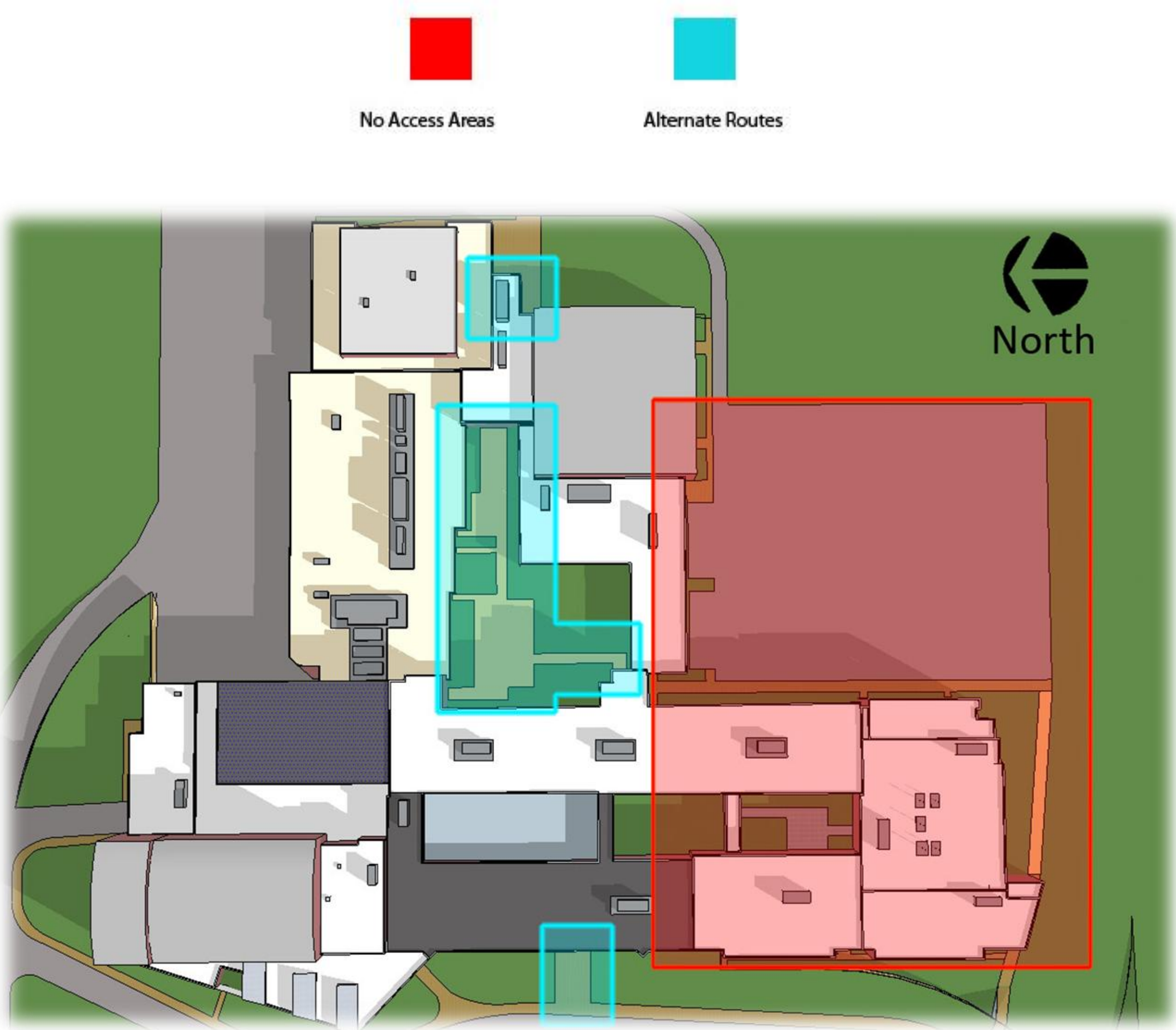


Figure 11: Phase 1 - No-Access Areas and Alternate Routes

In figure 11, the exterior of the building is highlighted. The red area shows the area of the project site that will be in use during the construction of Phase 1. Both Area D as well as the rear parking lot will be highly congested with construction workers and vehicles, and as such access is restricted to all building inhabitants. The light blue areas show exterior pathways that can be used as alternatives to those closed due to construction. By providing information regarding alternate routes, building inhabitants can avoid accidental contact with the construction team.

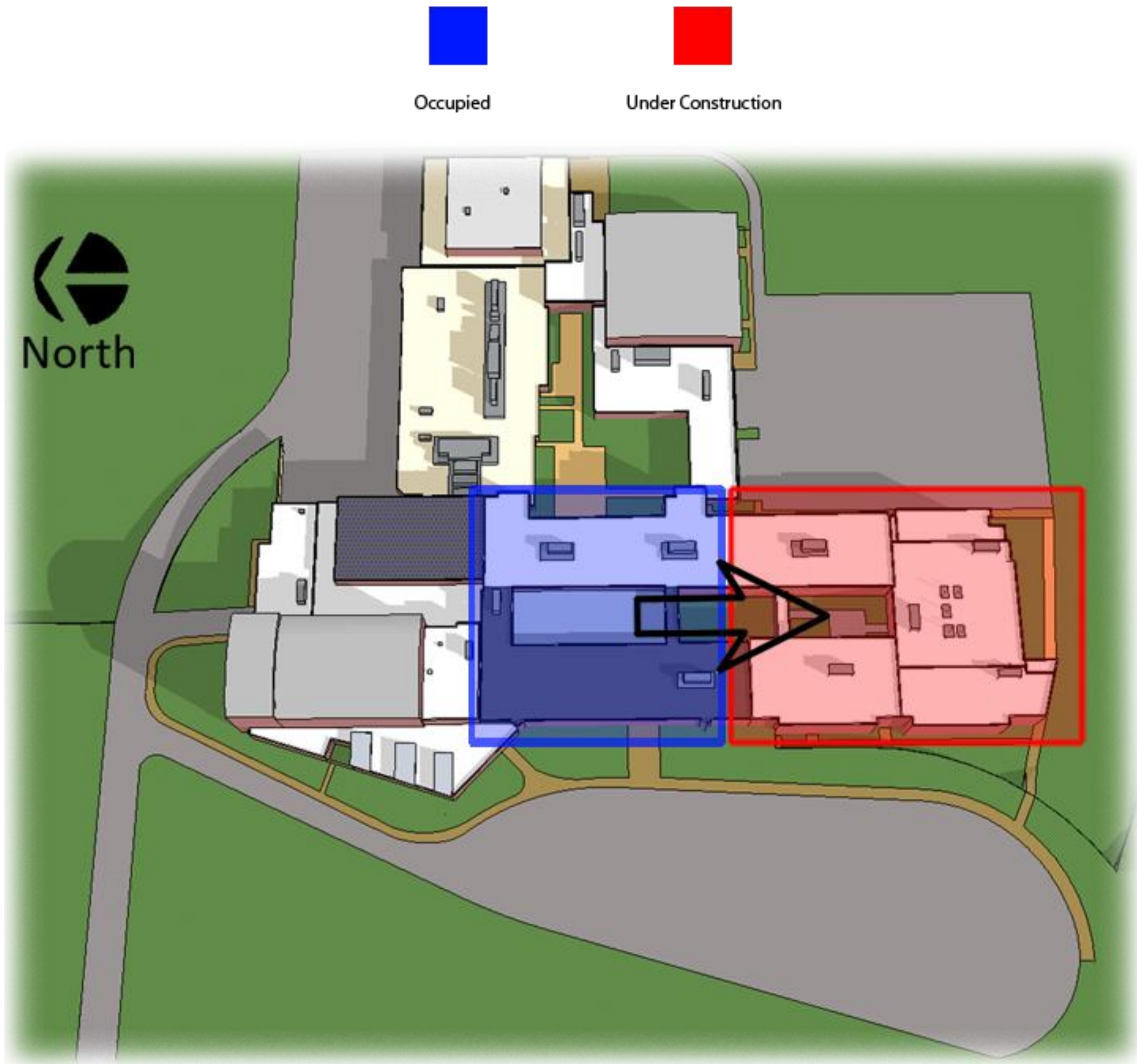


Figure 12: Transition Plan

Figure 12 shows the transition between Phases 1 and 2. Phase 2, which includes work being done in area E (the blue region), is set to begin shortly after the completion of Phase 1 (the red region). For this reason, a seamless transition between phases is extremely important. The first step will be to move all UCFSD Administrative personnel from the existing administrative offices (located in area E) into the new offices in area D. Next, any teachers set to move into a new classroom in area D will be moved. Moving the faculty and staff into new spaces efficiently is extremely important, as each phase is dependent on the phase before it.

Cost and Implementation

BIM software is no small investment, especially if the company in question plans to make BIM a focus in the future. Considerable training must occur in order to provide someone with enough knowledge to develop an effective, accurate BIM model. Additionally, the time needed to develop a phasing or safety plan of this size would be considerable. The cost and time associated beginning a BIM initiative within a company is certainly a major factor.

While no BIM was implemented on the project originally, I believe that integrating BIM into the project would be rather simple. Provided all parties involved have the software and knowledge available to produce BIM models, this application could easily be applied to the Unionville High School Building project. That being said, assuming that all parties involved do have the necessary requirements to implement BIM is a big step.

All things considered, I believe that it is well worth the time, money, and effort for any company involved in the construction industry to start using BIM software. The applications available using this software are vast and the value and even cost savings available are numerous.

Conclusions

Provided that the members of the construction team are able to obtain the software and training necessary to effectively use BIM software, I believe that ***this application would be beneficial if implemented***. On this project, the use of BIM to develop a 4D Phase plan which in turn can be developed into a safety plan can provide the owner with added value. On any construction project, especially a school, safety of building occupants is paramount. With student, staff, parents, and many other people frequenting the building constantly, keeping building occupants informed about the goings on throughout the construction project can lead to a lower likelihood of project related accidents and potentially cost savings. The website developed to showcase the proposed plan can be viewed from my CPEP website or directly at [http://www.engr.psu.edu/ae/thesis/portfolios/2012/MSB5153/4D%20Phasing%20and%20Safety%20Plan.html].

Analysis 3: Sustainability – On Site Renewable Energy Source

Problem Identification

The Unionville High School Building consists of new additions as well as renovations, both of which have been designed with state of the art technologies and top of the line finishes. The project has been designed with the goal of achieving LEED silver under the 2007 system; missing in the design, however, is the application of on-site renewable energy. Renewable energy is an area of construction growing in popularity that provides numerous benefits and would be a welcome addition to any project. Implementing a renewable energy system on this project can create savings and help the project and the school district to "go green".

Research Goal

This study will aim to identify which system, Wind or Solar, is the most feasible option for the Unionville High School Building. Incorporating a renewable energy system on the project can not only benefit the owner in the form of cost savings and may also help to improve the projects LEED rating. Each system will be analyzed to determine which of the two is a more appropriate system for this public education application. A system will be selected, designed, and analyzed to determine the constructability of the system. Finally, and a lifecycle cost calculation will be performed to show exactly how this addition would impact the project financially.

Research Methods

- **Research Solar and Wind Energy systems**
- **Check for case studies involving similar solar and wind energy applications**
  - **Research similar projects that have implemented this technology**
- **Research financial aid**
- **Determine which system to use and develop design for the proposed system**
- **Study any potential changes to structural system**
- **Update structural system if necessary**
- **Study feasibility of renewable energy system**
  - **Cost, Schedule impact, and Constructability**

Renewable Energy Background Information

As we all know, today's society is extremely dependent on fossil fuels to produce electricity. In recent years, however, alternative energy sources have become more efficient and have started to relieve some of the stress on fossil fuels. Some of the more prevalent sources of renewable energy include hydropower, biomass, biofuel, geothermal energy, solar energy, and wind energy. The latter two, solar and wind energy will be investigated during this study. As designed, the Unionville High School Building project did not incorporate any renewable energy. Background information, research, and calculations will be used to determine which of the two systems is more appropriate for the UHS project. Once completed, the new UHS building will remain in use for years to come which in turn suggests that there will be ample time to allow for a renewable energy system to pay itself off and even produce a profit.

Photovoltaic Solar Panels

Renewable energy sources are increasing in efficiency and popularity. While many systems remain highly inefficient, the progress made in recent years has been noticeable. Photovoltaic panels are one of the most popular forms of renewable energy available today. Each panel is made up of a collection of many smaller photovoltaic cells, which can range from a few millimeters to a few inches across. On average, photovoltaic solar panels covert roughly 15 percent of the energy retrieved through sunlight into usable electricity (PVPower). These panels are then grouped into arrays, which can be located on the earth's surface or on top of buildings or other structures.

PV arrays consist not only of these solar panels, but also of electrical connections, structural connections, and batteries that store the energy produced by the panels. There are two main types of systems in terms of electricity production, a system tied into the electrical grid (Grid tied and a system dedicated solely to one specific building or a specific portion of the building (Off grid). For the UHS project, a grid tied system would be more appropriate as the school has been in operation for years and is already tied into the electrical grid.

A photovoltaic panel can be one of three primary panel types: Monocrystalline, Polycrystalline, and Thin Film (Amorphous) (PVPower). Monocrystalline panels (figure 13) are made using the oldest form of solar cells, which are produced using pieces cut from a single crystal of silicon. Visually, the panels will have a smooth, flat finish similar to a piece of glass. As these panels produce best conversion efficiency of photovoltaic cells today and are the most expensive panel type.

Figure 13: Monocrystalline Solar Panel
Image: Courtesy of Atlantech Solar

The second type of photovoltaic panel, Polycrystalline (figure 14), is cut from more than one crystal of silicon. As a result of the cells coming from pieces of multiple crystals, the finish will appear more like a shattered piece of glass. Although not as efficient as Monocrystalline panels, Polycrystalline panels are the most common panel type. As the efficiency is lower, the cost is also lower than the first panel type.

Figure 14: Polycrystalline Solar Panel
Image Courtesy of Atlantech Solar

Finally, the third main type of solar panel is Thin Film (figure 15), or Amorphous Silicon. This type of panel is flexible and thinner than the first two types of panel. A thin film of amorphous silicon (meaning non crystalline) is installed over top of a preselected surface, which can be either rigid or flexible. Of the three, Thin Film panels have both the lowest costs as well as the lowest efficiency. One benefit to this type of panel, however, is that they are not hindered by shading like the other two types. Unfortunately, this type of panel is known to lose power output following installation, especially early on in the panel’s life.

Figure 15: Thin Film (Amorphous) Solar Panel
Image Courtesy of Atlantech Solar

Wind Power

Another free source of renewable energy exists in wind power. The wind power industry as we know it began in the late 1970's. In fact, wind energy is one of the world's fastest growing renewable energy sources. As of this report, the United States tops the list of countries producing the most wind generated electricity. Like Solar Power, Wind Power has become more efficient and more affordable in recent history as a result of government incentive programs. A New York Times article from January 27th 2012 states that by the year 2030, the United States will produce up to 20% of all its electricity using wind generated power ("Wind Power").

Caused by heat differences on the earth's surface, wind is a constant and free source of energy. Wind power is created by harvesting the energy produced by wind turbines. Wind turbines can range from hundreds of feet tall to just several feet. There are two main types of wind turbines, vertical axis and horizontal axis. Furthermore, there are three subtypes of vertical axis wind turbines, Darrieus Wind Turbine VAWT (vertical axis wind turbine) and Savonius VAWT. A *Darrieus wind turbine* (figure 16) has a vertical axis and spoke like vertical blades. The principle behind harvesting wind using this type of turbine is *lift*; as wind passes through the turbine, the blades create lift which in turn rotates the turbine. Sometimes referred to as 'eggbeater' turbines because of their appearance, Darrieus turbines provide high efficiency but are not extremely reliable; due to the design, the vertical shaft undergoes large amounts of stress during operation. Another downfall to this type of design is the fact that an external source is needed to provide initial rotation (Meyers, C. Bracken.). Several subtypes of this turbine type exist; the Gorlov Helical wind turbine (figure 17) and Giromill Darrieus wind turbine (figure 18).

Figure 16: Darrieus Wind Turbine
Image Courtesy of Winddose.com

Figure 17: Gorlov Helical Wind Turbine
Image Courtesy of WindDose.com

Figure 18: Giromill Wind Turbine
Image Courtesy of Winddose.com

The second type of vertical axis wind turbine is the *Savonius wind turbine* (figure 19). Unlike the Darrieus wind turbine, Savonius wind turbines are a drag-type turbine. Rather than using blade like vertical members, scoop like members are mounted on a vertical shaft and used to catch wind. Although they produce a lower efficiency than a Darrieus turbine, Savonius turbines are better in areas experiencing turbulent wind. This type of turbine can generate electricity even in the strongest of winds without sustaining considerable damaged and are a quieter alternative to Darrieus turbines.

Figure 19: Savonius Wind Turbine Image Courtesy of TheGreenTechnologyBlog.com

In addition to vertical axis wind turbines, horizontal wind turbines are also available. This turbine style is the turbine that most people associate with wind energy, consisting of a tall vertical shaft with a smaller vertical axis that is connected to the propeller attached at the top (figure 20). Because the electrical generator is attached to the propeller, this type of turbine must be pointed in the direction of the wind. Smaller horizontal axis turbines use a wind vane to determine the direction and point the turbine in the correct direction, while larger turbines use a sensor to achieve the correct position.

Figure 20: Horizontal Axis Wind Turbine
Image Courtesy of Centurion Energy

Financial Assistance

A large draw to incorporating a Photovoltaic system on a new project in recent years has been the financial aid provided by the government. Part of the American Recovery and Reinvestment Act, the Tax Incentives Assistance Project (TIAP), states that the federal government will provide a credit for up to 30% of the entire cost of the Photovoltaic System as a result of The Business Energy Investment Tax Credit (ITC) (IRS-1). Unfortunately, incentives in the state of Pennsylvania have diminished in the past several years. That being said, the program has not completely shut down and may return upon the government's receiving additional funding. Funding is provided based on when the system is completely installed and in place, ready for use. This means that even if the system installation begins when there are no incentives in place, the program could be providing financial aid again as the system is completed.

A government rebate was also available recently for small businesses looking to implement a Photovoltaic system. For the first 10kW, a rebate of $2.25 per watt is available. After 10kW, the next 90kW are valued at $2 per watt and the following 100kW receives $1.75 per watt. Another incentive program, the Pennsylvania Alternative Energy Credit program, provides incentive based on the amount of electricity produced. The Pennsylvania Alternative Energy Portfolio Standard (AEPS) requires that a certain percentage of electricity sold to customers in Pennsylvania be produced using alternative energy sources ("Pennsylvania AEPS Alternative Energy Credit Program"). For each 1000kWh of electricity, an Alternative Energy Credit is created which can be sold at a value of $325.00 (as of 2009/2010).

In Pennsylvania, the Solar Energy program dictates that "all or a portion of the construction work associated with the project may be subject to the Pennsylvania Prevailing Wage Act" (Pennsylvania Department of Community & Economic Development, 5). This means that some or all of the work must be done by union workers who are to be paid a prevailing hourly wage. Due to the higher rate of labor, installation costs for PV systems can increase significantly.

Like Solar Power, Wind Power has also decreased in cost in recent years. Thanks to decreased startup costs and government incentives, this renewable energy resource has become both more efficient and more affordable. The 2009 American Recovery and Reinvestment Act also provides a substantial financial incentive for new wind power systems. The Business Energy Investment Tax Credit (ITC) provides a 30% tax credit for new small wind turbine systems. This tax credit includes all expenditures and has no maximum monetary value, although the credit is only available for systems up to 100kW in size (IRS-1).

Another incentive available for wind energy systems is a rebate based on the electricity produced. The Renewable Electricity Production Tax Credit (PTC) is available for a multitude of alternative electricity production systems. For any wind power system completely installed and in service prior to December 31st 2012, \$0.022 (2.2 cents) can be earned per kilowatt-hour of electricity produced. This credit may be earned for up to 10 years following the systems in-service start date and has no limit to the amount of money that can be earned. That being said, if any other federal tax incentives are used by a project, the kWh credit value may be reduced (IRS-2).

Unfortunately, because the school is not a 'for-profit' entity, these federal incentives are unavailable for this project. There is, however, another way to take advantage of these financial incentives. A Power Purchase Agreement can be used to purchase energy at a reduced cost. Basically, the non-profit organization (the school district) will allow a third-party to procure, install, and operate a renewable energy system on its premises. In this case, Unionville High School and the Unionville-Chadds Ford School District would contract the system to a third party, who would completely own the system. This third party would incur all installation and equipment costs in return for the available space to locate the PV array or wind energy system. Once complete, UHS would purchase solar electricity from the third party at a reduced cost. While the incentives would not directly save the school money, the district would incur savings by purchasing solar electricity at a reduced cost. (National Renewable Energy Laboratory)

Solar Case Study 1 – West Sonoma County Union High School District, California

SunPower performed a case study on a project with a similar scope to that of UHS. The West Sonoma County Union High School District aimed to reduce energy cost and save money as a result of budget costs. Their solution was the implementation of a photovoltaic array renewable energy system, which would address both of their goals. (West Sonoma County Union High School District Goes Solar for General Fund Relief)

RGS Energy was awarded the contract from the school district, which included array installations on three high schools. Once completed, the three high schools had systems totaling a combined size of 834kW. The system is estimated to provide around 75% of the high school's energy needs and over the life of the system, the three high schools will save a total greater than $9 million. (SunPower Corp)

Solar Case Study 2 – Milpitas Unified School District, California

Another case study, performed by Chevron, highlights another similar application. Though a larger application, this system is still comparable to the system that would be installed at UHS. Milpitas Unified School District, located in Milpitas California, wanted to develop its own renewable energy initiative. In 2007, the school district contacted Chevron in order to make their initiative a reality.

The aim of the district's initiative was to develop a system that would have a long lasting impact for the school district. After meeting with Chevron, Milpitas decided to implement solar energy systems on 13 school sites and one district site. In total, the system was 3.4mW in size and was located on parking canopies throughout the school district. In fact, "this system is believed to be provide the largest percentage of solar power system for any K-12 school district in the United States" (Chevron Energy Solutions).

In addition to the cost savings, the new system provides educational opportunities for students within the district. Energy management software has also been implemented across the district to increase the ease with which users can interact with the system. The cost for the system was offset by the California Solar Initiative and in total, the system has lowered the district's cost by over 22% which translates roughly $12 million savings over the life of the system. (Case Study, Milpitas Unified School District)

Solar Case Study 3 – San Jose Unified School District, California

Chevron performed another case studying, describing the system installed by yet another high school in California. The San Jose Unified School District decided to develop a solar program in order to produce financial savings, educational opportunities, and leadership in the community. In 2007, the district reached out to Chevron and ultimately entered a partnership with Chevron and Bank of America to develop the solar system that it desired. ((Case Study, San Jose Unified School District)

The system is comprised of a 5.5mW installation spanning 14 district sites. Cost savings produced by the system are estimated to be greater than 30% of energy costs and would save the school district a total of more than $25 million over the life of the system. Financial incentives provide by the California Solar Initiative helped offset the project cost by more than $11 million. (Chevron Energy Solutions)

Solar Case Study 4 – Bald Eagle Area School District, Pennsylvania

Smart Energy Capital performed a case study on a project much closer in scope to the Unionville High School project. Bald Eagle Area School District, located in Pennsylvania, chose to implement a solar energy system on two of its schools. In 2010 the district entered a partnership with Tremco Roofing and Smart Energy Capitol.

With financial incentives totaling $1.4 from a Pennsylvania grant, the school district decided to enter a partnership with Tremco and Smart Energy in the form of a Purchase Power Agreement. This agreement, available to nonprofit government entities without access to tax credits and other government incentives, allows the school district to benefit from a solar system owned by a third party. In this case, the third party is SEC BESD Solar One LLC, who owns the solar system to be installed by Tremco and Smart Energy Capitol. (Smart Energy Capitol)

The system will span two schools, the Wingate Elementary School and the Bald Eagle Middle/High Schools. The elementary school system will produce roughly 300,000kWh of solar electricity, while the middle/high school system will produce 670,000kWh. As part of the agreement, the school district will purchase 100% of the electricity produced by the two systems, which should provide more than 50% of the schools' energy needs.

A Purchase Power agreement allows the school to incur no installation, equipment, or maintenance cost. Instead, Tremco roofing will install the systems and provide long term maintenance for all components of the systems while Smart Energy Capital will provide the financial investment. Ultimately, this agreement provides incentives for all three parties. (Smart Energy Capitol). Financially speaking, Bald Eagle High School will pay roughly $.049 per kWh to Duke Energy for the electricity produced by the PV array, as opposed to standard electric cost of $.078 per kWh, or a savings of more than 37% ($.029) per kWh.

Interview with Bald Eagle Area SD Project Manager Rick Vilello

After finding this Bald Eagle Area High School case study during my research, I attempted to reach out to the project team to learn a little bit more about the project. I was able get I contact with Rick Vilello's, who served as the project manager for Bald Eagle Area School District on this particular project.

Rick explained that Tremco Roofing and Smart Energy Capitol had already entered a partnership. Tremco, who was already contracted to install the new roof on a renovation of the high school, initiated contact with the school district regarding installation of a Photovoltaic array. Bald Eagle Area School district then contacted Smart Energy Capitol regarding the project, and the three parties agreed to move forward with the project.

The project began in December of 2010 and the final solar panel was turned on in March 2011. Due to the decreasing value of incentives at the time, the school district decided that this contract structure provided it with the best value. By contracting with Tremco and Smart Energy Capitol to install the array, Bald Eagle School District incurred absolutely no installation, equipment, or maintenance cost for the system. Instead, the district entered a 20 year agreement with a fixed utility rate; the school district would purchase all of the energy produced by the PV arrays for a fixed rate of $0.049 per kWh. Although this agreement included a fixed rate, Rick clarified that similar projects completed shortly after this one included clauses for inflation of utility prices.

After reviewing their options, Bald Eagle Area School District decided that without federal tax incentives, a project of this type would not be financially feasible. By letting another party own the array and purchasing power from it, the school district lines itself up to save significant money on utilities during the 20 year contract. At the completion of the 20 year contract, the school district will also gain ownership of the entire array and all included equipment.

(Vilello, Rick)

Wind Case Study 1 – Wind Powering America, Wind for Schools Project

In 2005, Wind Powering America launched the Wind for Schools Project, a project set to provide schools throughout the United States with clean, renewable wind energy. The Wind for Schools Project is available in 11 states, including Pennsylvania, and has contributed to more than 70 systems as of 2011. In Pennsylvania, nine projects were either operating, planned, or in the developmental stage as of this report. Of those nine, five were primary education projects and two were collegiate projects, one of which being the Pennsylvania Wind Application center located at The Pennsylvania State University.

For projects within this program, the primary wind energy source is a SkyStream 3.7, 2.4kW wind turbine. The SkyStream 3.7 is a small horizontal axis wind turbine and stands between 60 and 70 feet in height (Figure 21). Training and curricula are provided to any school taking part in the project in order to create education opportunities from this renewable energy resource. Project funding can be gained by several different avenues, including federal funding, partnerships, state funds, and even local utilities.

Figure 21: SkyStream 3.7 Turbine
Image Courtesy of Southwest Wind Power

Renewable Energy System Selection

After conducting research regarding the two renewable energy sources, Solar and Wind, I have decided to pursue the implementation of a **solar energy system** for the Unionville High School Project. While neither system has a clear cut advantage over the other in terms of federal financial aid, I was able to find more information regarding similar applications for photovoltaic systems. Wind energy is not as prevalent as solar energy, and information on applications for educational buildings is not as readily available.

In studying the Bald Eagle High School project, I learned that an application very similar to what I am targeting is in fact feasible. By utilizing a *Purchase Power Agreement*, Bald Eagle HS was able to benefit from the renewable energy resources despite limited financial aid. I believe that the Unionville High School Project can benefit from a similar agreement, where a third party would own the system while the school purchased power produced by it at a discounted rate.

For this specific project, I do not believe that the photovoltaic system will provide enough energy to fulfill the entire building's needs. For this reason, I aim to implement the largest system possible in order to produce as much electricity as possible. This way, a larger quantity of reduced-cost electricity can be purchased and thus a larger financial savings can be had.

Solar Design Parameters

For any renewable energy system, the project's location is of supreme importance. Unionville High School is located in the Unionville-Chadds Ford School District, which is located in Kennett Square Pennsylvania, which is located in the Southeast of the state (figure 22).

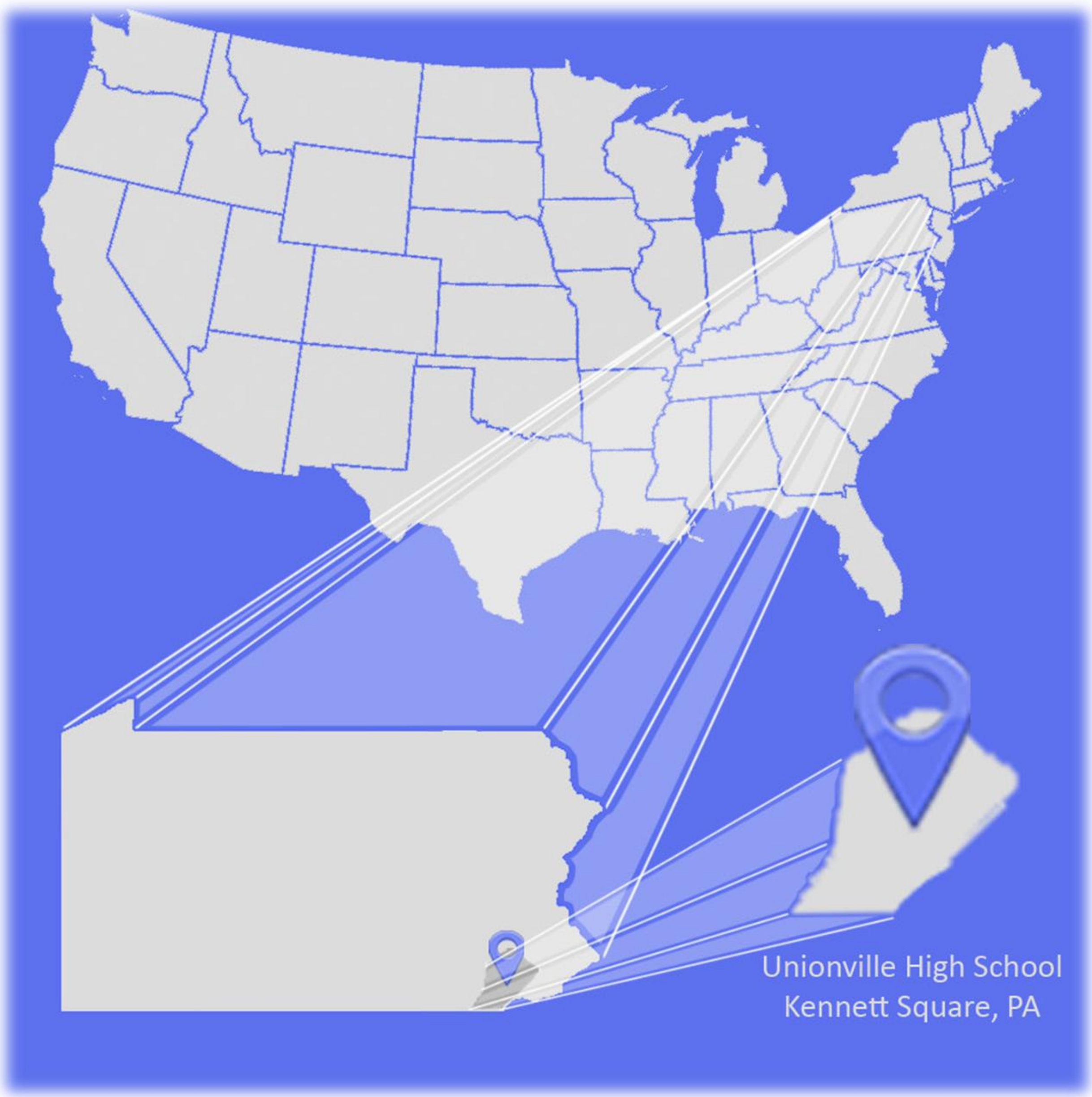


Figure 22: Unionville High School Location

The school sits on a plot of land completely free of adjacent obstructions. No trees, buildings, or other obstructions are close enough to the school to cast shadows on any roofs that may host solar panels. Unionville High School is located at latitude 39.84 N, longitude 75.71 W, and sits 310 feet above sea level (“City Data”). Kennett Square Pennsylvania averages about 4.6 sun hours per day, which will be the basis for all calculations (“Long Term Solar”). Figure 23 below shows all design parameters for the photovoltaic system.

Solar Design Parameters	
Building Type	Educational
Location	Kennett Square, Pennsylvania
Latitude	39.84° N
Longitude	75.71° W
Elevation	310 feet above sea level
Roof Orientation	Directly South
Sun Hours per day	4.6

Figure 23: Solar Design Parameters

After researching solar panel tilt angles, it appears as though the optimum tilt angle is very close to that of your location’s latitude. For this application, the panels will be installed at a tilt angle of **40° N.** Positioning the panels at this angle will provide the most efficient collection of the suns energy, as the panels will remain fixed in one position at all times.

The rooftops to be considered as locations for the PV arrays are all relatively flat roofs, with little to no slope. A number of rooftop mechanical units are spread across these roofs, although there are several locations that have ample room on which to place PV panels. Both roofs on the existing building as well as newly constructed areas will be considered for this analysis. Figure 24 is a map highlighting the potential rooftop areas to place PV panels; the blue areas show potential roof space and the red areas show roof obstructions. After determining the potential areas on which the photovoltaic panels could be placed and the roof obstructions on those areas, there is a total possible area of about **100,000 square feet**. A Google Sketch-Up model was then created and a shadow analysis was run to determine which roof areas are the best fits for solar panels. A larger image highlighting the potential roof areas for the PV array can be seen in APPENDIX H.

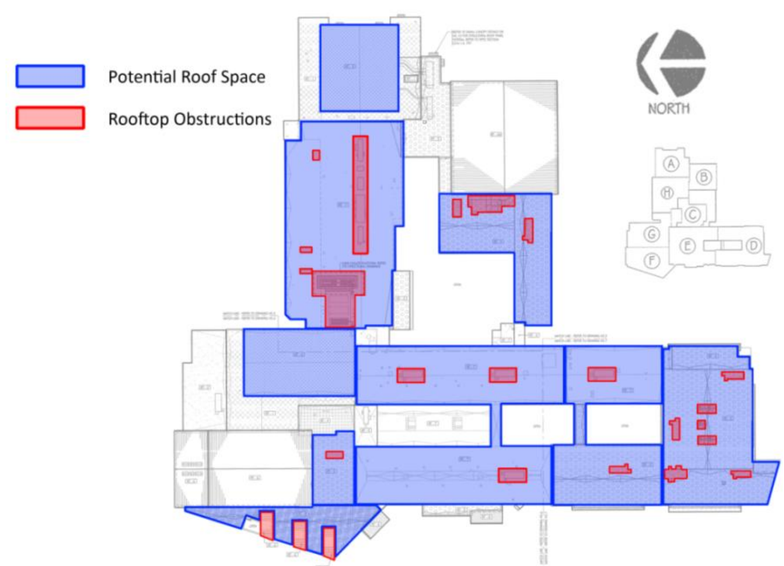


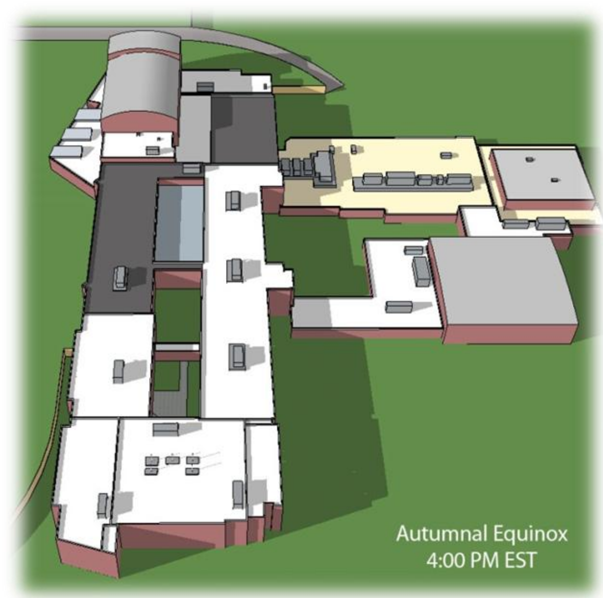
Figure 24: Potential Roof Space

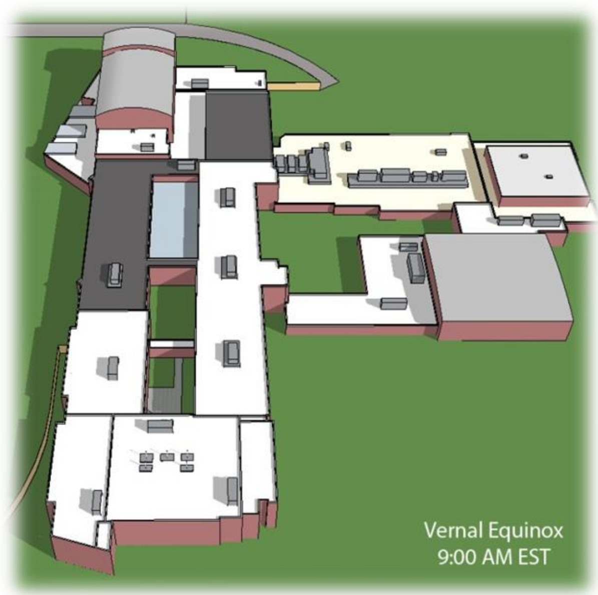
The following images detail the shading analysis performed on the Google Sketch-Up model. Each of the images displays the shadows cast by rooftop obstructions and adjacent portions of the building for a different time of year: The Summer Solstice (June 20th), the Autumnal Equinox (September 22nd), the Winter Solstice (December 21st), and Vernal Equinox (March 20th) at both 9:00AM and 4:00PM.

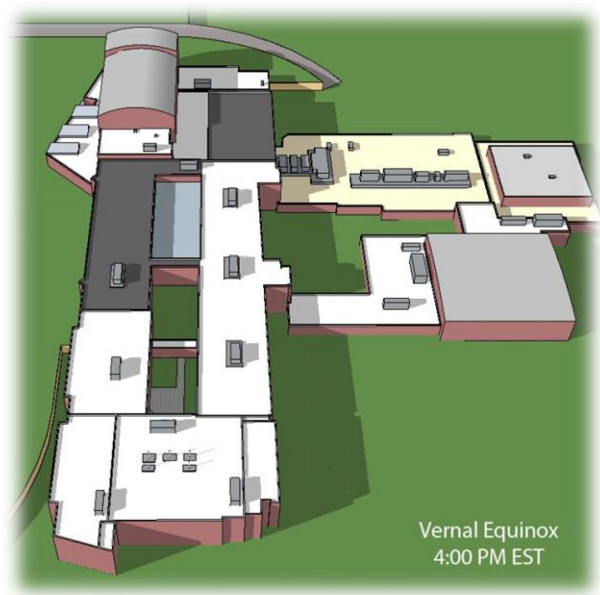

Summer Solstice
9:00 AM EST


Summer Solstice
4:00 PM EST


Autumnal Equinox
9:00 AM EST


Autumnal Equinox
4:00 PM EST





All images showing the shading from rooftop obstructions can also be seen in APPENDIX I.

Photovoltaic System Design

After determining which areas of the building are free of shading, it appears as though there is a total of about **50,000 square feet** of roof space available to place solar panels. The panels will be anchored on the roof, meaning there will be penetrations through the roof. Each connection will be water tight, as to ensure no damage due to the roof penetrations. An alternative would have been a Ballast-mounted system, where the panels are weighed down by heavy blocks; this system was not considered as it could have caused structural design changes and most likely an additional cost increase. The roof areas on which the PV array will be installed can be seen in APPENDIX J. As part of this analysis, several different types of photovoltaic cells were researched. Parameters for each panel are listed in table 2 below.

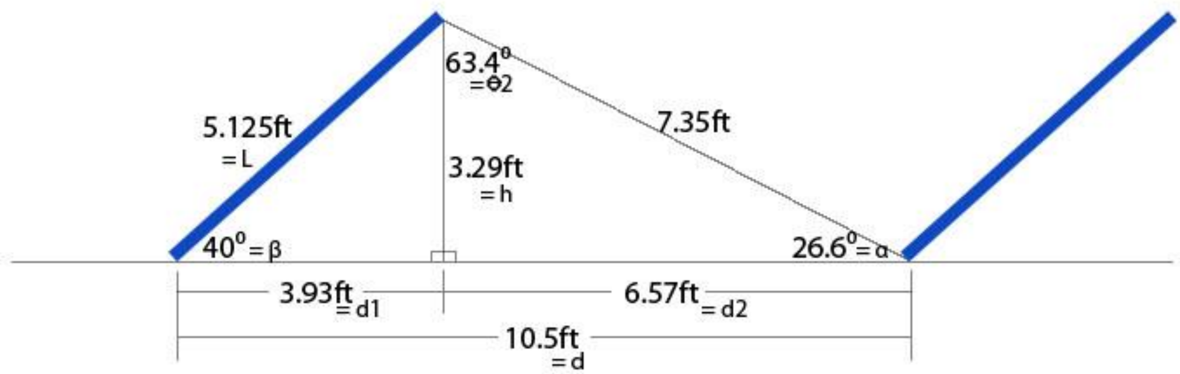
Table 2: PV Panel Specification Comparison

Manufacturer	PV Model	Cells	Power (W)	Efficiency (%)	Rated Voltage (V)	Rated Current (A)	Height (in)	Length (in)	Surface Area (Sq. In)	Weight (lb.)
Kyocera	KD320GX-LPB	80	320	-	39.8	7.92	65.5	52	3406	61
Mitsubishi	PV-MLT265HC	120	265	16.0	31.7	8.38	64.0	40	2560	44
BP Solar	BP Q235	60	245	14.1	29.6	7.94	65.5	39.5	2587.25	42
SunPower	**E19 / 320**	**96**	**320**	**19.6**	**54.7**	**5.86**	**61.5**	**41**	**2521.5**	**41**
Sharp	NU-Q250W2	60	250	-	37.6	8.26	64.5	38	2451	42
Trina Solar	TSM-PC14	72	290	14.9	36.4	7.97	50.25	32	1608	62
SunTech	STP290-24/Vd	72	290	14.9	35.6	8.15	77	39	3003	59.5

After researching the above panels, the **SunPower E19/320W** panel was selected for this application. To convert the system, a **Satcon 375kw PowerGate Plus inverter** was selected. Due to time restrictions, exact calculations were not performed to determine the exact characteristics of the electrical set up for the PV array. With many large AHU units on the roof already, this large inverter can be placed on top of the roof without taking away considerably from the aesthetics of the buildings. This *monocrystalline* panel provides the highest efficiency, lowest weight, and a high power to surface area ratio, meaning that the space taken up by the panel is producing electricity efficiently. Note: This panel will have a high initial cost; this analysis is assuming that UHS will enter into a Purchase Power Agreement with a third party, the initial cost will not be considered. Specifications for the SunPower E19/320W solar panel as well as the Satcon 375kW PowerGate Plus Inverter can be found in APPENDIX K.

Following the selection of the panel, the size of the system must be determined. The system size will be based off of the available roof space and the amount of solar panels that can be installed within the available roof space.

With several areas on the roof available, there will several different string sizes. Each area will be analyzed to determine the number of strings and the number of panels within each region. Firstly, the spacing of each row of panels must be determined. Using basic calculations, it has been determined that each row of panels must be spaced roughly **10.5 feet** from front to front. For added protection against shading, a 10% allowance has been included which will increase the spacing to **12 feet.** The diagram below shows a graphic representation of the panel spacing.



The below equations were used in determining the solar panel spacing.

$$\beta \cong altitude \rightarrow \boldsymbol{\beta = 40°}$$

$$\sin(\beta) = \left(\frac{h}{L}\right) \rightarrow \sin(40°) = \left(\frac{h}{5.125ft}\right) \rightarrow \boldsymbol{h = 3.29ft}$$

$$5.125^2 = 3.29^2 - d_{1^2} \rightarrow \boldsymbol{d_1 = 3.93ft}$$

$$\cos(26.6°) = \left(\frac{d_2}{7.35}\right) \rightarrow \boldsymbol{d_2 = 6.57ft}$$

$$d_1 + d_2 \rightarrow 3.93ft + 6.57ft \rightarrow \boldsymbol{d = 10.50\ ft}$$

$$\delta = -23.4$$

$$cos(\theta 2) = \cos(\beta)\cos(\delta) + \sin(\beta)\sin(\delta)$$

$$cost(\theta 2) = \cos(40)\cos(-23.4) + \sin(40)\sin(-23.4)$$

$$\cos(\theta 2) = -.25 \rightarrow \boldsymbol{\theta 2 = 63.4°}$$

During design, roughly 4 feet of space will be left around the perimeter of any roof on which panels are to be installed; this space if left in order to cut down on added wing load and to allow maintenance access to the roof (The German Energy Society 230, 231). Based on these parameters, the maximum amount of panels that can be placed on the available roof space can be calculated.

For the panel quantity calculations each individual roof space (figure 25) was calculated separately; these calculations are listed in the table below.

Figure 25: Roofs Selected for PV Array Installation

Givens:					
N-S Spacing: 12' from front to front					
# of Rows = (Length)/(12' spacing) + 1 (front edge)					
Panel width (E-W) = 3.42ft (Note will be installed edge to edge)					
Building Area	Length (N-S) ft	Width (E-W) ft	Number of Rows in Area	Number of Panels in row	Number of Panels in Area
A1	96	86	9.00	25.15	225
B1	34	75	3.83	21.93	63
D1	40	90	4.33	26.32	104
D2	40	50	4.33	14.62	56
D3	36	52	4.00	15.20	60
E1	140	40	12.67	11.70	132
E2	36	50	4.00	14.62	56
E3	50	42	5.17	12.28	60
E4	24	40	3.00	11.70	33
F1	26	36	3.17	10.53	30
G1	90	52	8.50	15.20	120
H1	36	88	4.00	25.73	100
Total					1039

After calculated each individual area, the system will consist of **1039 individual panels**. Based on the information provided by the manufacturer, the entire size of the system can be calculated as follows:

$$1039\ panels * 320W\ per\ panel \rightarrow \boldsymbol{Total\ System\ Power = 332,480\ W\ or\ 332.8kW}$$

Cost Analysis

As stated before, this system was designed to use under a Purchase Power Agreement. This means that a third party owns the system, while Unionville High School will purchase the power produced by the system, meaning that absolutely no up-front costs are incurred by the school.

The average electricity cost at the time that this report was completed in Pennsylvania is around **$0.96 per kWh**; this value will be used as the baseline for the cost savings analysis (United States Department of Labor). Based on the agreement, Unionville High School will contract with a third party; this contract will spell out exactly how much UHS will pay the third party per kWh. Based on information gathered through research, it is assumed that UHS will pay the third party 63% of today's electricity cost, or **$0.0605 per kWh**, for the energy produced by the photovoltaic system.

Using PVWatts (developed by the NREL) the yearly savings incurred as a result of the photovoltaic system can be calculated. The data output provided by PV Watts can be seen in APPENDIX L. After using the software to run the calculation, the results came back as follows:

$$\boldsymbol{Total\ System\ Power = 332{,}480\ W\ or\ 332.8kW}$$

$$Yearly\ AC\ Energy\ Produced\ by\ system = 401307\ kWh$$

$$Average\ Electricity\ Cost\ in\ PA = \$0.096\ per\ kWh$$

$$\boldsymbol{401307\ kWh * \$0.096\ per\ kwh = \$38{,}525.47\ energy\ value\ in\ year\ 1}$$

Assuming that UHS will pay just **63%** of the energy value in year one for energy produced by the solar energy system as a result of the PPA contract (based on the Bald Eagle Area High School case study), a savings analysis can be developed. With a typical PPA contract length of 25 years and inflation in energy prices of 1% per year, the savings over the life of the contract come out to be **roughly $402,590.56**. A spreadsheet detailing the energy savings analysis can be found in APPENDIX M.

Based on the "Tracking the Sun Report IV" document produced by the Berkeley Lab in California, the costs to install PV systems have been declining yearly. The cost to install PV systems in Pennsylvania is listed in table 3 below.

Table 3: Cost of PV Array Installation

State	Year	Size (kW_{dc})	Cost/W
Pennsylvania	2010	< $10kW_{dc}$	$6.8
		$10kW_{dc}$ – $100kW_{dc}$	$6.3
		> $100kW_{dc}$	**$5.6**

Because the system is over 100kW, it will be assumed the cost of the system will cost **$5.6 per Watt.** Given this information, the total cost of the system with no incentives will be as follows:

$$System\ Size: \mathbf{332,800\ watts}$$

$$332{,}800\ watt\ system * \$5.6\ per\ watt \rightarrow \boldsymbol{Up\ front\ cost} = \$\mathbf{1,863,680}$$

After finding the up-front cost, a lifecycle cost was developed to determine the initial investment for the Photovoltaic Array for the third party involved. Unlike the school district, the third party involved in the Power Purchase Agreement is eligible for government funding. The main sources of funding come from these sources:

Federal Tax Credit	30% of all expenditures, no limit
PA Sunshine Solar Rebate Program	Lesser of $52,500 or %35 of up-front costs
PA Renewable Energy Tax Credit	15% credit after all other incentives have been used

$$Total\ Initial\ System\ Cost: \$1{,}863{,}600$$

$$\$1{,}863{,}000 - (.30)(\$1{,}863{,}000) = \$1{,}304{,}576$$

$$\$1{,}304{,}576 - \$52{,}500 = \$1{,}252{,}076$$

$$\$1{,}247{,}076 - (.15)(\$1{,}247{,}076) = \$\mathbf{1,064,264}$$

After taking all of these incentives into account, the third party involved in the Purchase Power agreement would incur an up-front cost of: **$1,064,264.**

As a supplemental study to the cost savings due to reduced electricity costs as a result of a Purchase Power Agreement, an analysis was done to determine what the cost of the system would be if the school decided to incur all costs and own the system itself. With the cost of electricity in year one assumed to be $0.096 and a yearly inflation of 1%, the end result of this study saw a **40 year payback period for the school**; this is the main reason that a Purchase Power Agreement was the preferred option. Calculations for Unionville High Schools potential payback period can be seen in APPENDIX N.

Schedule Impact

Due to the contract structure of a Purchase Power Agreement, the system will not be a part of this projects budget; as a result, it will have no impact on the completion of the project. That being said, the system will take time to install. If the project team chooses to do so, the PV array could be installed in line with the UHS project phases. Depending on which roof the array is to be installed on, those panels can be installed following the completion of the necessary phase.

For example, Area D is the first phase. Following the completion of Phase 1, all PV panels located on the roof in area D can be installed. The final phase of the Unionville High School Building Renovations and Additions project is Phase 4B, which is the demolition of the existing auxiliary gym. With all other phases completing prior to the end of phase 4B, all roof areas will be completely finished. Based on this method, the entire array can be installed before the finish of the UHS project.

Constructability

This system will be installed following the completion of the necessary roof spaces. Structurally, the existing system is more than capable of handling the added load. The panels, which are roughly 41 pounds each (including the mounting hardware) will add less than 1.5 lb. per square foot. A sample calculation, provided for PV installation area D1, is shown below.

$$Area\ D1 \rightarrow 41\ lb\ per\ panel * 104\ panels = 4264\ lb$$

$$Area\ D1\ Area = 40\ feet * 90\ feet = 3600\ square\ feet$$

$$\frac{(4264\ lb\ )}{3600\ sf} = \boldsymbol{1.18\ lb/sf}$$

Based on the designed superimposed dead load of 20psf, this additional load is almost negligible and no structural changes will be needed to carry the added load of the PV panels.

LEED Implications

As originally designed, the Unionville High School Building Project was set to earn Silver Certification under the 2007 system. Under the 2009 system, the building qualifies only for LEED Certification. The addition of on-site renewable energy presents the opportunity for additional LEED credits under the Energy and Atmosphere category. EA Credit 2: On-Site Renewable Energy awards anywhere from 1 to 7 credits, depending on what percentage of the buildings overall energy use is produced by the renewable energy. The amount of energy used by Unionville High School was unable to be accurately determined, so the percentage of energy produced by the PV array cannot be calculated. It can be assumed, though, that additional LEED credits can be obtained through the implementation of a PV array on the project.

Findings and Conclusion

Should the school decide to front the entire cost of the system itself, the payback period for this system would be **40 year**, and as such would most likely not be feasible**.** However, because the school will enter a PPA with a third party, there will be no up-front costs incurred by the school. Assuming that the PPA will incur all initial costs and after performing all necessary research and calculations, it has been determined that the school will see a 25 year savings of roughly **$402,600.** These savings are the result of UHS purchasing electricity at a discounted rate, **63%** of the current rate, from the third party owner of the photovoltaic system. Ultimately, because no costs are incurred up front by the school, I believe that implementing this type of system ***would provide significant value*** to the owner and the project.

Analysis 4: Façade Redesign – Prefabricated Panel Façade System

Problem Identification

The original façade designed for the new additions to the Unionville High School building consist of rock-faced CMU blocks, bricks, and limestone lintels. Installation for this system is done piece by piece, known as a 'stick-built' façade. Installation of this system in this manner takes a significant amount of time and even adds time to the entire project schedule. Additionally, this type of system can lead to safety issues, unnecessary sight congestion, and decreased productivity.

Research Goal

A prefabricated façade system will be researched as an alternative to the originally designed system. Research will determine if using another system is feasible and would add value to the project. In order to make these determinations, a cost and schedule analysis will be performed highlighting the positives and negatives of implementing the new façade system. Any changes to the originally designed structural system will be studied, and any necessary additions or changes (including a connection for the new panels) will be designed. Mechanical properties for the new system will also be studied, determining any changes to mechanical loads and the potential for any changes to the existing system.

Research Methods

- **Study current façade assembly**
- **Determine duration and cost of installing the existing façade system**
- **Study potential prefabricated panel façade systems**
    - **Utilize past studies on implementation of prefabricated panels**
    - **Research and compare prefabricated panel manufacturers**
- **Determine which prefabricate panel façade system to use**
    - **Select system based on price, lead time, usage on similar projects**
- **Design Precast Panel**
    - **Determine installation cost and duration**
- **Mechanical Breadth:**
    - **Analyze effects on mechanical properties of the façade system (mechanical breadth)**
        - **Aim to improve thermal/mechanical properties with implementation of prefabricated façade panels**
        - **Compare existing façade with new façade to determine best option**
- **Structural Breadth:**
    - **Analyze resultant effects on existing structural system**
    - **Design any necessary additional structural connections (structural breadth)**
- **Study feasibility of prefabricated facade system**
    - **Cost, Schedule, Constructability, and Quality to the Owner**

Background Information

With a stick built façade as part of the original design, the Unionville High School project has dedicated a significant time within the project schedule to the construction of the façade. A prefabricated façade panel system would provide schedule relief, while also decreasing cost and potentially improving the systems mechanical properties. Prefabricated façade panels can be made of a variety of different sizes and incorporate a number of different building materials. For this reason, I felt that a prefabricated panel would be a suitable alternate to the originally designed façade system.

These panels can be manufactured off site and delivered to the project, decreasing the time that it takes to install the product. Aesthetically, prefabricated panels can be designed to meet almost any criteria. By producing the panels off site, on site labor can be reduced. Additionally, site congestion can be addressed as there is no need to store material as is the case with the original façade design. This analysis will aim to design a prefabricated panel with similar aesthetic qualities while decreasing the time that it takes to install the façade, improving the thermal properties, and lowering the cost.

Current Façade Assembly

The Unionville High School Building is a project undergoing renovations and construction on several new additions. These new additions have a slightly different architectural look than the existing building, with a stick built façade as part of the original design. The façade is to be built by hand, is not load bearing, and is made up of rock face CMU, brick, and limestone lintels. For this analysis, Phase 1 will be studied. Calculations for the entire project will be extrapolated from the information gathered during the analysis of Phase 1.

Rock face CMU units and red face bricks are the primary piece of the façade, making up the majority of the assembly. Also included are courses of darker bricks, located between every two rock face CMU or red brick courses. Limestone lintels rest above every door and both above and below each window (Figure 26). Some areas of the façade are strictly brick course, although the majority of the façade is the assembly as described above. The wall also includes an air cavity, rigid insulation, and CMU interior walls that sit on the steel structure. Although not exactly the same as, the colors and materials are similar to those used in the exiting building.

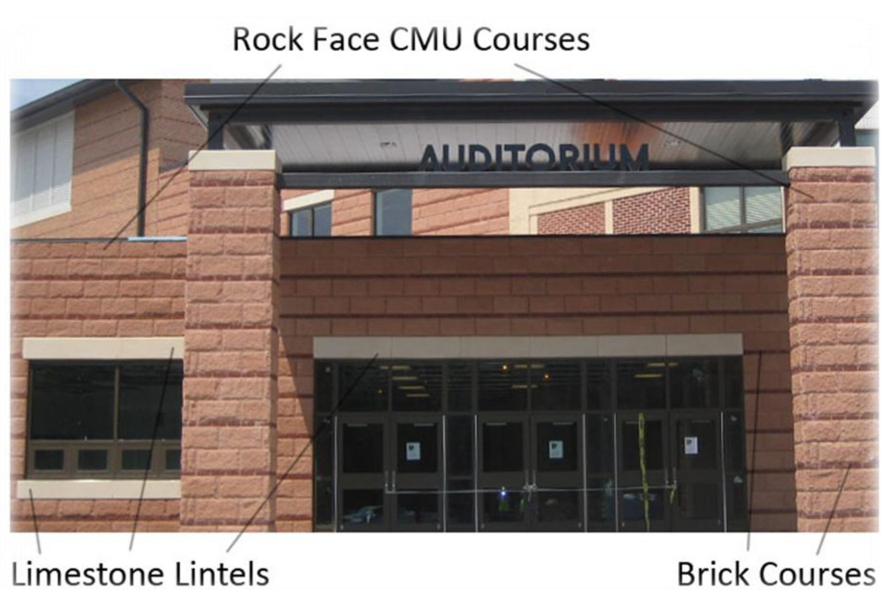


Figure 26: Original Facade

After consulting the specifications, all CMU and brick units are to be manufactured within 500 miles and made from material harvested within 500 miles of the project site, in Kennett Square Pennsylvania; as a result, an additional goal of this analysis will be to design a prefabricated façade panel that also meets this same 'regional materials' criterion.

Phase 1 has three elevations that this façade system will be installed on: East, South, and West; the North façade is connected to the existing building, and as such will have no facade. After totaling up the facades being studied for this analysis, there is a total of roughly **35,500 square feet** of façade to be redesigned. Based on the information provided by Wohlsen construction, the existing façade assembly will take **three months** from start to finish to completely erect, with a total of 64 working days excluding holidays and weekend days. Including all shipping, material, labor, and installation, the façade for this portion of the building will cost a total of **$2.2 million**. After subtracting the cost of the foundation **($699,000**), which will not be included for either system, and the total cost of all work involving windows and doors **($520,950**), which will be the same for both systems, the total cost of the original façade design comes to **$1.17 million.** One important factor to note is that the original façade does not require a crane, while the prefabricated panel system will. Based on these numbers, the original façade will cost approximately **$33.05 per square foot**.

Prefabricated Panel System Selection

Prefabricated façade panels have become more and more prevalent in the construction industry in recent years. With the actual production of these panels done in manufacturing warehouses, waste can be minimized and each panel can be produced in shorter time and engineered to exact specifications. As a result of the use of skilled labor, however, it is believed that the price of these prefabbed panels will be greater than the original façade system. The main goal of this façade redesign will be to shorten the project schedule.

Research on the topic revealed that there are a number of prefabricated façade panel manufacturers in the region that my building is in. After thoroughly studying the different options available, I decided to go with **Nitterhouse Concrete Products**. Located in Chambersburg PA, Nitterhouse services the entire state of Pennsylvania, as well as West Virginia, Virginia, Maryland, Delaware, New Jersey, and New York. As part of the requirements for the new Precast Panels, I wanted to ensure that the panels came from within 500 miles of Kennett Square, PA; Chambersburg is just 128 miles away, well within that limit. These panels will be strictly thin brick, but two colors of brick will be used in order to mimic the current architectural features of the rock face CMU façade.

Nitterhouse 9” Precast Sandwich Panel

Mark Taylor, President of Nitterhouse Concrete Products, was kind enough to provide me with all of the information that I needed for my research on precast façade panels. Mark provided me with information and panel specifications for a panel without an air cavity, which the originally designed façade system had. After speaking with him, he told me that the air panel was not necessary within the precast panel as the concretes density would not allow any moisture to pass through the assembly.

Each panel can be made a maximum of 12’ wide and a maximum of 40’ tall, and the order for this project would require 5 to 6 months of lead time. This is important because a system of this type would have to be decided upon early in the projects lifetime. The system would be 9” total in thickness, with a 3” inside concrete face, 2” of rigid insulation, and 4” of concrete for the outside face, which would be faced with thin brick to achieve a similar architectural finish.

With panels of this size, the installation crew could install 15-20 panels per day; for this analysis, the low end, **15 panels per day**, will be used as the norm. For this particular panel, the cost (including fabrication, delivery, and installation) would be roughly **$35 per square foot** of panel, or **$16,800 per 12’ x 40’ panel**. Based on this information, the total cost of the façade using this precast panel would be roughly **$1.24 million**, or slightly more expensive than the original system which came in at a total cost of **$1.17 million**.

$$\$35\ per\ square\ foot * 35{,}500\ square\ feet = \$\mathbf{1{,}242{,}500}$$

A visual comparison, developed in Google Sketch Up of the two façade systems and their makeups can be found in APPENDIX O.

Panel Implementation

Based on a simple calculation of 35,500 square feet of total façade divided by 480 square feet (12 feet by 40 feet) for panels, a total of **74 panels** would be needed to complete the façade if each panel were to be uniform. With 15 panels erected each day, the façade system would be completed in **5 working days**.

$$\frac{35{,}500\ square\ feet}{480\ square\frac{feet}{panel}} = \mathbf{74\ panels} \rightarrow \frac{74\ panels}{15\frac{panels}{day}} = \mathbf{5\ working\ days}$$

This calculation is *not accurate*, however, as the façade's design will not allow for 12' wide uniform panels all the way across the elevation. Instead, some panels will have to vary in width, which means the total number of panels will increase and ultimately, the time to erect the panels will increase. The façade's in question will be analyzed and the different size panels will be determined. Each panel will be designed with openings for both windows and doors already formed, and all windows and doors will remain the same as the original design.

Mark stated that the panels can come in sizes up to 12' x 40', or the largest size possible to fit on a flatbed truck. For several reasons, this size will not work for my building. For one, as mentioned above, the façade will not allow the panels to be designed at just one width. Secondly, the new addition tops out at 42' feet, 2' taller than the panel's maximum height. For this reason, the panels will be 1 story in height, and will vary in width. In total, there will be **37** different size panels, with just 4 different panel widths (6', 8, 10', and 12') and two different panel heights (13.5' and 28.5'). Although the panels vary in length, these widths allow a relatively uniform layout. Some panels are the same size, but due to window and door locations will have different opening. In total, there will be **132** panels to complete the façade. Assuming that 15 panels will be erected per day, the façade will take a total of 8.8 or **9** working days. Allowing 1 day for any learning curve, it will be assumed that the new façade will take **10** working days to complete. Images showing the panel layouts can be found in APPENDIX P.

$$\mathbf{132\ panels} \rightarrow \frac{132\ panels}{15\frac{panels}{day}} = \mathbf{8.8} \cong \mathbf{10\ working\ days}$$

While the new façade system installation duration breaks down to roughly 10 working days to install, integrating it with the other work within Phase 1 is not as simple as just plugging it in and assuming a 10 day duration. The current schedule splits the steel erection for Phase 1 into three parts, shown on figure 27 below.

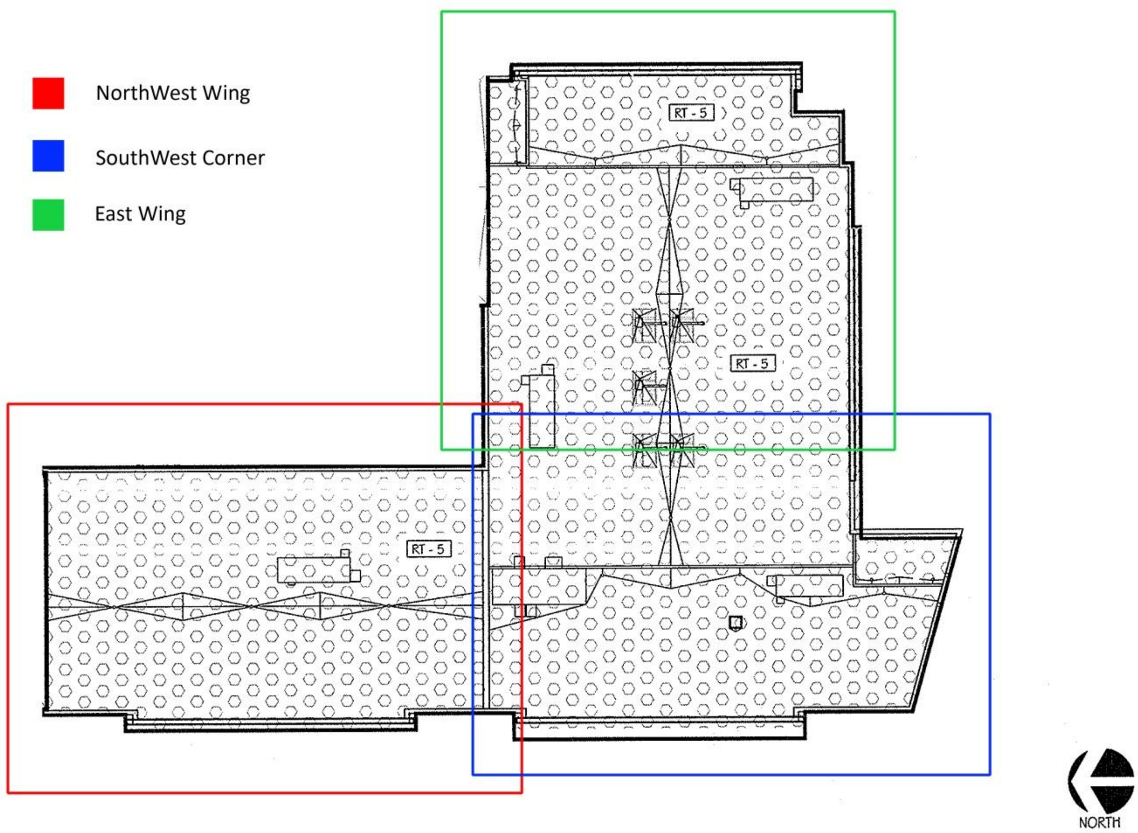


Figure 26: Structure Schedule Breakdown by Area

The schedule for the steel structure for the three areas is as follows:

Area	Start Date	Completion Date	Duration (work days)
Northwest Wing (Red)	July 20th 2009	November 13th 2009	82
Southwest Corner (Blue)	July 31st 2009	December 9th 2009	90
East Wing (Green)	August 25th	December 17th 2009	79

Within each of the three areas, the façade is split into several portions, depending on how many exposed elevations exist in each area. These facades are listed below.

Area	Start Date	Completion Date	Duration (work days)
North (Green)	February 11th 2010	March 15th 2010	15
East (Red)	December 1st 2009	December 20th 2009	15
East (Green)	February 2nd 2010	March 4th 2010	22
South (Blue)	January 12th 2010	February 12th 2010	29
South (Green)	January 22nd 2010	February 23rd 2010	22
West (Red)	December 10th 2009	January 11th 2010	21
West (Green)	December 31th 2009	February 2nd 2010	21

The facades within each of these areas are to be started following the completion of the steel for that particular area, meaning that it can be assumed that the precast façade panels can start at the same time as the originally designed façade. Based on this information, the installation of the new panels can be integrated into the original schedule to truthfully determine how much time can be saved.

Each area within Phase 1 has a different amount of panels. Information regarding how many panels is to be installed within each area is listed below.

Area	Amount of Panels	Days Needed to Complete
North (Green)	10	1
East (Red)	17	2
East (Green)	18	2
South (Blue)	24	2
South (Green)	21	2
West (Red)	18	2
West (Green)	24	2

With an assumed quantity of 15 panels erected each day, the total duration for all of the panels to be installed is actually **13 working days**, or roughly **3 working weeks**. Compared to the original façade, this is a difference of **51 working days** of total duration.

Based on those durations, the new schedule for the installation of the façade will be as follows:

Area	Start Date	Completion Date	Duration (work days)
North (Green)	February 11th 2010	February 11th 2010	1
East (Red)	December 1st 2009	December 2nd 2009	2
East (Green)	February 2nd 2010	February 3rd 2010	2
South (Blue)	January 12th 2010	January 13th 2010	2
South (Green)	January 22nd 2010	January 25th 2010	2
West (Red)	December 10th 2009	December 13th 2009	2
West (Green)	December 31st 2009	January 4th 2010	2

Based on these calculations, a total of **132 working days** can be saved when considering each elevation within the phase; this means that the cost of labor to install the original façade would be decreased significantly. As a result of the project being phased so tightly, it is difficult to determine exactly which activities would be altered as a result of the more rapid façade installation, and exactly how many days could be shaved off of the schedule. It is clear, however, that the precast façade panel system ***would save time*** on the project schedule, and as a result, potentially money.

As a result of the crane having to be on site additional days in order to erect the panels, an added cost will be incurred. Assuming that the same 15 ton crane will be used to erect the panels (the largest of which is 15 tons), a simple calculation was done to determine that added cost of having the crane on site to erect the panels. After integrating the panel erection into the current schedule and merging it with the structural steel erection, which will be entirely complete before any of the facades are installed, it has been determined that the crane will have to remain on site for an additional **13 working days**, or **roughly 3 weeks**. It was decided to install the entire façade after all of the structure was complete for phase one in order to allow the erection of steel to progress as originally scheduled.

Based on this duration, and a cost of **$1200** per day for the cane to be on site, a total added cost of **$15,600** will be accrued as a result of using the crane to install the precast wall panels. (Crane Rental Rates)

Cost

After compiling all of the data related to the two systems, I do not believe that it would be beneficial to implement the precast façade panels. With the precast façade panels, the system would be more expensive in terms of initial cost; the material, labor, and shipping total for the original façade comes in at around **$1.17 million**, while the precast façade system would cost **$1.24 million**. In addition to this **cost increase of $700,000** for the initial cost of the façade, an **added $15,600** in crane costs will be added should the precast panel system be implemented. Overall, the precast panel façade system clearly costs more than the original stick build façade system.

Schedule Impact

As previously stated, the original stick built façade has a much longer installation time than the proposed precast façade panel system: the original façade is scheduled to take roughly 3 months to complete, while the precast panel façade system will take about 3 working weeks to complete. With such a massive difference, it is clear that implementing the precast panels on this project would be a benefit to the schedule.

Constructability

Regarding installation of the panels, the implementation of this system would not cause an issue. With a crane on site (which is large enough to pick the heaviest panel), I believe that installing this precast façade panel system would have worked seamlessly. That being said, a much greater lead time is associated with a precast panel façade system; for this particular system, the lead time would range from 4 to 5 months, meaning that the decision to used precast panels would have to occur at an early stage of the project's lifecycle. Additionally, the precast panels would eliminate the varying architecture seen in the original façade.

Conclusion

The information obtained as a result of the mechanical breadth comparing the two façade assembly’s shows that the panel façade system would be inferior to the original façade assembly as well. When comparing the heat loss for the two assemblies using DesignBuilder, the original façade saw an annual heat loss of around **160 kBTU x 10^3**, while the new panel façade system experienced greater losses, with a value around **195 kBTU x 10^3**; in total, the original façade is roughly %18 more effective thermally. Should the new façade be implemented, additional costs would likely be incurred as a result of the need for increased thermal loads.

Ultimately*, **I would not advocate*** the implementation of these precast panels for the Unionville High School Building. Based on the information obtained through the research and analyses done regarding the panels shows that the increased cost, change in architectural look, and decreased thermal properties outweigh the savings in schedule. While schedule reduction is of great importance, the other features regarding the implementation of this new precast panel façade system dictate that the original system is in fact a better option.

Mechanical Breadth

As previously mentioned, the current façade system is not load-bearing. Instead, a structural steel frame makes up the superstructure of the building, with CMU interior walls. The façade itself sits on the foundation, while the CMU interior walls rest on beams at each floor level. Following the erection of steel for all new construction phases, the facade will then be installed. Because each piece of the façade assembly much be placed individually, installation for the façade can take up a fair amount of time. At UHS, the façade for Phase 1 (The New Administrative Office addition) took a total of three months (November 9th 2009 to February 10th 2010).

In terms of thermal properties, each piece of the assembly has different characteristics. Each item has a unique R-Value, a measure of thermal resistance. Depending on the combination of materials, a wall assembly will have certain thermal properties. For this particular building, the façade is made up of four primary layers: Veneer, air cavity, insulation, and CMU interior wall. Based on the elevation of the wall, three materials have been used for the façade: Rock Face CMU block, Limestone, and Face Brick. Each piece of both the existing assembly as well as the precast façade panels is listed below, with the corresponding R-values taken from the HAM Toolbox software developed by PSU. Calculations from the HAM Toolbox can be seen in APPENDIX Q. Note: Only Brick and Rock Faced CMU were analyzed using this software, as the Limestone made up a small percentage of all façade area.

Table 4: Original Facade Materials R Values

Construction Material	R Value (per thickness hr*ft^2*BTU)
4" Face CMU Block	0.69
4" Face Brick	0.64
4" Cast Limestone	0.19
2" Air Cavity	0.98
2" Rigid Insulation	7.90
8" CMU Block	1.03

Table 5: Original Façade Assembly R Values

Construction Material	R Value (per thickness hr*ft^2*°F/BTU)
4” Face Brick Layer	0.64
2” Air Cavity	0.98
2” Rigid Insulation	7.90
8” CMU Block layer	1.03
Total	**10.56**

Table 6: Precast Facade Panel Assembly R Values

Construction Material	R Value (per thickness hr*ft^2*°F/BTU)
3” Concrete Layer	0.44
2” Rigid Insulation	7.90
4” Concrete Layer	0.58
Total: 9”	**8.92**

As you can see, the precast façade panels are one layer smaller than the original façade, with the elimination of the air cavity. Based on information received while speaking with Mark Taylor of Nitterhouse Concrete products, the air cavity can be removed due to the density of the concrete; there is no danger of moisture reaching the insulation and as such, the cavity can be removed.

After a quick comparison of the two façade assemblies, it is clear that the original façade assembly has a higher R value than the precast façade panels, **10.56 hr*ft^2*°F/BTU** compared to **8.92 hr*ft^2*°F/BTU**.

In order to get a better understanding of the thermal properties of the two systems, and the differences that these façade assemblies would have on the building, a simple energy model was developed using the software program DesignBuilder.

A simple model of Area D, or Phase 1, of the Unionville High School was created within the software in order to compare the two façade systems. The model was developed by creating the building and specifying materials for all floors, walls, roofs, and interior spaces. Other than the façade assembly itself, no other features of the building changed between the two analyses. Two types of reports were generated from each analysis: an annual ventilation report and a monthly ventilation report.

Each report analyzed the building to determine how effective the thermal properties of each façade system are. The effective heat gain for the building was the main target output, showing which of the two systems would provide better insulation for the building. After running both tests, the Original Façade tested favorably, as the numbers from HAM toolbox suggested it would.

When studying *monthly* heat loss comparisons, the original façade clearly outperformed the precast façade panels. For each month, the original façade provided better insulation for the building, resulting in the better overall performance of the original façade.

Table 4: Monthly heat gain comparison (in kBTU)

System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Original	-47000	-34000	-18500	-17000	-3000	4500	14500	15100	3500	-4000	-20500	-32000
Panels	-60000	-46000	-27000	-21000	-5000	8000	18000	19000	3500	-10000	-28000	-455000

Based on a comparison of the *annual* heat gain values for both assemblies (table 4), the original façade experiences a net loss of roughly **160 kBTU x 10^3**. The newly designed precast panel façade, on the other hand, experienced a net loss of roughly **195 kBTU x 10^3**. Comparatively, the original façade system was 18% more effective in terms of its thermal properties. Graphs taken from the DesignBuilder showing this information can be found in APPENDIX R.

Conclusions

Based on the information provided by both the HAM toolbox and DesignBuilder software, it is clear that the original façade assembly provided a higher quality of thermal properties for the building as opposed to the precast panel façade system. With greater losses after applying the new precast panel façade system, it can be assumed that heating and cooling loads necessary for the building would have to increase. As a result of this mechanical load increase, it can also be assumed that **costs increases** would be incurred based on these needs for increased mechanical loads within the building.

Structural Breadth

Research into prefabricated precast façade panels brought up questions regarding the existing structural system and whether or not the original design would be capable of supporting the increased load. This breadth was performed in order to compare the two systems' effects on the originally designed structural system and to ultimately determine whether any changes would need to be made to the structural system.

For this breadth, one specific beam in Area D will be analyzed; located on the second floor between column lines BB and CC and on column line 51, this beam will carry the entire load of two of the largest panels to be installed on the facade. As a **W21x44 at 24'-4" in length**, this specific beam is one of the smaller beams on the exterior of the building and should some of the most dramatic loading differences as a result of the façade change. Figure 28 below shows the location of the beam. The allowable limits for the W21x44 beam are listed below:

Beam Type	Length	Max Allowable Moment ΦM_n	Max Allowable Deflection	Max Allowable Deflection due to Live Load
W21x44	24'-4"	331 kip-ft.	1.2"	.81"

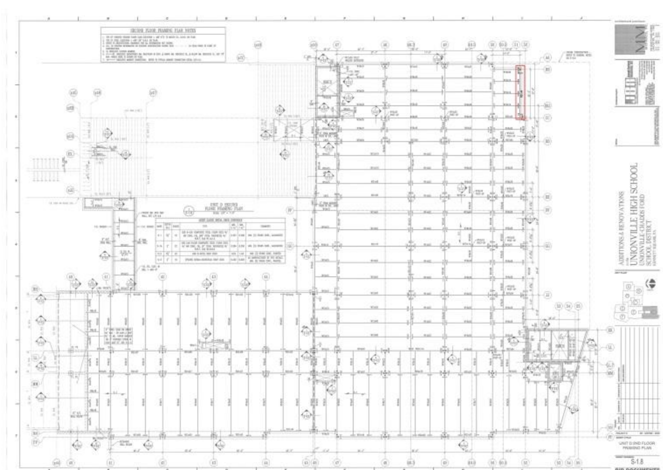


Figure 27: Sample Beam Location

Calculations to determine the loading from the original façade were done to set the baseline to compare the new system to. The original façade system is made up primarily of face brick, with an air gap, insulation, and CMU backup wall; only the CMU backup wall is supported by the steel structure, the brick veneer is supported by the foundation and as such was not included in these calculations. Note: the only load that the façade placed on this beam is a one story tall CMU backup wall. Figure 29 below shows the original façade's connection to the structure.

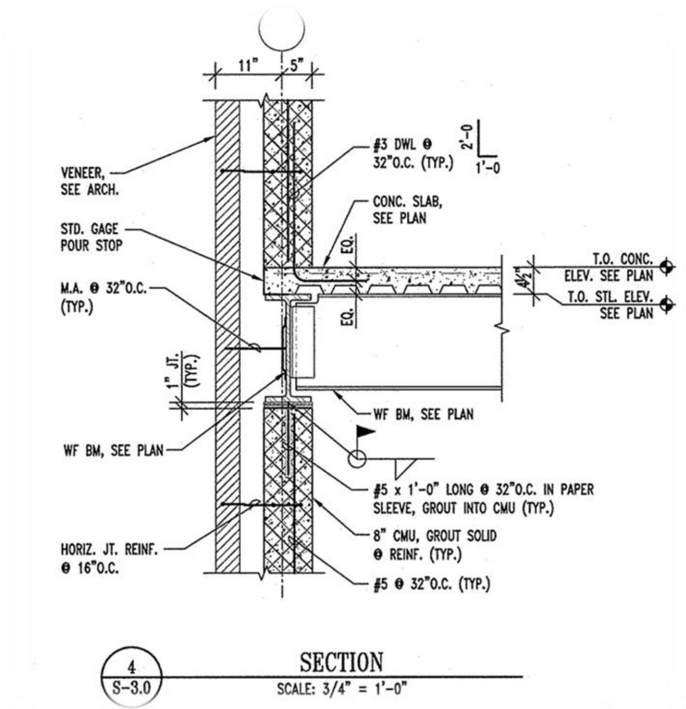


Figure 28: Original Facade Structural Connection

Hand calculations were used to determine the loading, moments, deflections, and results of the two façade assemblies; these calculations are available in APPENDIX #. After performing some calculations on the existing façade, the following information was obtained:

Total Load w (klf)	Total Moment M_u (k-ft.)	Total Deflection (in)	Live Load Deflection (in)
2.46	182.02	0.53"	0.17"

Upon checking these results against the member's acceptable values, each check showed that the member was **acceptable** as designed. Now, knowing how the structural member performed under the loading from the original façade, the new precast panel façade was analyzed.

The precast façade is expected to produce increased loading, moments, and deflections as a result of the increased weight. In addition this steel member, located on the second floor, will carry the weight of a panel spanning both the second and third floor, while the original façade required this same member only to support one story of CMU block wall. Made up of 3" of exterior concrete, 2" of rigid insulation, and 4" of interior concrete, each façade panel will weigh 88 pounds per square foot. The structural connection chosen to hang the precast panels was selected from several options from the manufacturer; Figure 30 below shows this detail.

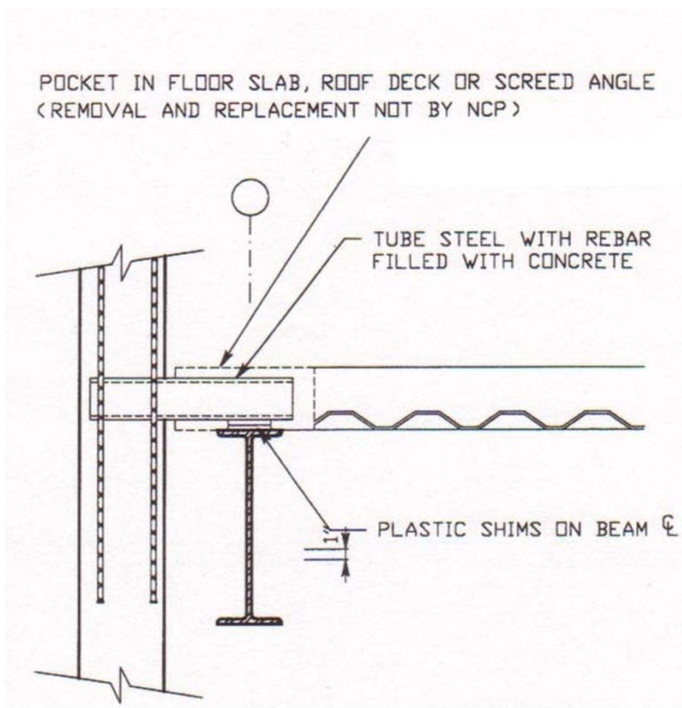


Figure 30: Precast Facade Panel Connection Detail

Again, the same loading calculations were performed to determine how the structural steel member would react when loaded with the new precast panel façade system. It is assumed that two panels will be supported by this single beam, with each panel having one support at each corner; with two panels meeting at the center of the beam, a single point load will be assumed at the center of the beam which will likely contribute to a significantly increased moment. After running the calculations, the following information was obtained:

Total Load w (klf)	Point Load (kip)	Total Moment M_u (k-ft.)	Total Deflection (in)	Live Load Deflection (in)
1.57	30.51	301.75	1.15”	0.17”

Compared to the original façade system, the precast panel façade system does in fact produce much greater loads, moments, and deflections. That being said, the existing W21x44 beam still **provides sufficient support** to carry the increased load. For a better comparison, the effects of each façade assembly on the beam are listed below.

	Total Load (klf)	Point Load (kip)	Tot Moment (M_u)	Tot Deflection (in)	LL Deflection (in)
Original Facade	2.46	-	182.02	.53	.17
Precast Facade	1.57	30.51	301.75	1.15	.17

For comparison sake, the 30.51 kip point load due to the precast façade can be converted into a distributed load and combined with the existing distributed, bringing the total distributed load due to the precast façade to 2.82 klf.

Ultimately, the new façade system had the following effects on the structural system:

Total Load Increase (%)	Total Moment Increase (%)	Total Deflection Increase (%)
14.63	65.78	116.98

Hand calculations can be found in APPENDIX S.

Conclusions

As mentioned before, despite these increases, the existing structural member at this location **will support the added load**. That being said, due to the large increases in loading, moment, and deflection, it can be assumed that upsizing of some structural members as a result of the increased load may occur.

Sources

The Allegheny Conference, The Pennsylvania Economy League of Southwestern Pennsylvania. "A Review of the Effects of the Pennsylvania Separations Act on School Districts." *AlleghenyConference.org*. N.p., November 8th, 2007. Web. 1 Feb 2012. <http://www.alleghenyconference.org/PEL/PDFs/PASeparationsActReport1107.pdf>.

"Case Study, Milpitas Unified School District." Chevron Energy Solutions. N.p., 2009. Web. 13 Feb 2012. <http://www.chevronenergy.com/case_studies/musd.asp>.

"Case Study, San Jose Unified School District." Chevron Energy Solutions. N.p., 2009. Web. 13 Feb 2012. <http://www.chevronenergy.com/case_studies/sjusd.asp>.

Computer Integrated Construction Research Group, . "BIM Execution Planning." *BIM Execution Planning*. The Pennsylvania State University, 2011. Web. 14 Feb 2012. <http://bim.psu.edu/>.

"Energy Benchmarking Report fo Bound Brook High School." *NJCleanEnergy.com*. N.p., November 2009. Web. 20 Feb 2012. <www.njcleanenergy.com/.../BBHS Energy Benchmarking Report.pdf>.

The German Energy Society, . *Planning & Installing Photovoltaic Systems*. Second. London, England: Earthscan, 2009. 230,231.

Hostetler, Rick. Unionville-Chadds Ford School District. Personal Interview. February 28th, 2012.

IRS. "Business Energy Investment Tax Credit (ITC)." *Database of State Incentives for Renewables and Efficiency*. U.S. Internal Revenue Service (IRS-2), June3rd 2011. Web. 12 Feb 2012. <http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=0>. IRS, . "Renewable

IRS. “Electricity Production Tax Credit (PTC)." *Database of State Incentives for Renewables and Efficiency*. U.S. Internal Revenue Service (IRS-1), June3rd 2011. Web. 12 Feb 2012. <http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=US13F&State=federal¤tpageid=1&ee=1&re=1>.

"Kennett Square, Pennsylvania." *City Data*. N.p., January 1st 2011. Web. 12 Feb 2012. <http://www.city-data.com/city/Kennett-Square-Pennsylvania.html>.

Laub, Brian. Wohlsen Construction. Personal Interview. February 15th, 2012.

"Managing Energy Costs in Schools." *TouchStoneEnergy.com*. E Source, 2008. Web. 20 Feb 2012. <www.touchstoneenergy.com/efficiency/bea/Documents/Schools.pdf>.

Meyers, C. Bracken. "Types of Wind Turbines." *Centurion Energy*. N.p., February 21st, 2010. Web. 9 Feb 2012. <http://centurionenergy.net/types-of-wind-turbines>.

National Renewable Energy Laboratory, . United States Government. U.S. Department of Energy. *Power Purchase Agreement Checklist for State and Local Governments*. 2009. Web.

<*www.nrel.gov/docs/fy10osti/46668.pdf*>

Pennsylvania Department of Community & Economic Development, . State of Pennsylvania. Pennsylvania Department of Community & Economic Development. *Solar Energy Program*. 2009. Web. <http://www.newpa.com/webfm_send/1389>.

Pennsylvania Department of Education, . "Education Empowerment Annual Report." *Pennsylvania Department of Education Bureau of Teaching and Learning Support*. N.p., 2007-2008. Web. 6 Feb 2012. <http://www.portal.state.pa.us/portal/server.pt/community/education_empowerment_act/7403/education_empowerment_annual_report/510189>.

"Pennsylvania AEPS Alternative Energy Credit Program." *The Pennsylvania AEPS Alternative Energy Credit Program*. Pa.Gov, n.d. Web. 8 Feb 2012. <http://paaeps.com/credit/index.do>.

PVPower, Inc. "How Efficient is Solar Energy?." *PVPower.com*. N.p., 2012. Web. 7 Feb 2012.

<http://www.pvpower.com/howefficientissolarenergy.html>

Rush, Richard D.. "Managing a School Construction Project." *American School & University Magazine*. N.p., August 1st, 2002. Web. 14 Feb 2012.

<http://asumag.com/mag/university_construction_mix/>.

Smart Energy Capitol, . "Bald Eagle Area School District (PA) selects rooftop photovoltaic system from Tremco Roofing and Building Maintenance, and Smart Energy Capital." *Smart Energy Capitol*. N.p., May 12th, 2010. Web. 13 Feb 2012. <http://www.smartenergycapital.com/news/news-room/bald-eagle-area-school-district-pa-selects-rooftop-photovoltaic-system-from-tremco-roofing-and-building-maintenance-and-smart-energy-capital>.

"Solar Sunlight Hours." *Long Term Solar*. N.p., September 28th, 2011. Web. 12 Feb 2012. <http://www.longtermsolar.com/solar-sunlight-hours/>.

Taylor, Mark. Nitterhouse Concrete. Personal Interview. January 12th, 2012.

United States. Environmental Protection Agency. *Putting Energy Into Profits*. 2000. Web. <seco.cpa.state.tx.us/TEP.../c/EPAEnergyStarSmallBusinessGuide.pdf>.

United States Department of Energy, . "Photovoltaic Cells." *Energy Efficiency and Renewable Energy*. U.S. Department of Energy, 08/12/2011. Web. 7 Feb 2012. <http://www.eere.energy.gov/basics/renewable_energy/pv_cells.html>.

United States Department of Labor. Bureau of Labor Statistics. *Average Energy Prices in the Philadelphia Area*. November 2011. Web. <http://www.bls.gov/ro3/apphl.htm>.

Vilello, Rick. Bald Eagle Area SD. Personal Interview. Jaunary 24th, 2012.

"West Sonoma County Union High School District Goes Solar for General Fund Relief" SunPower Corp. N.p., 2010. Web. 13 Feb 2012. <http://us.sunpowercorp.com/cs/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobheadername3=Content-Disposition&blobheadervalue3=attachment%3B+filename%3D11_701_sp_dealer_wscuhsd_cs_en_ltr.pdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1300271294088&ssbinary=true>.

Wind Power." *New York Times* [New York] 27th January 2012, n. pag. Web. 9 Feb. 2012. <http://topics.nytimes.com/top/news/business/energy-environment/wind-power/index.html>.

Acknowledgements

This report is the product of countless hours of research and a vast number of resources. Without the help that I have received, this Thesis would have been impossible to assemble.

Thank you to Unionville High School staff. You were always open to helping me throughout the process and provided my building for this project.

Thank you to Wohlsen Construction, especially Project Manager Brian Laub and Project Manager Mike Bracken. You helped me greatly during the summer when I was on site, as well as during the two semesters following.

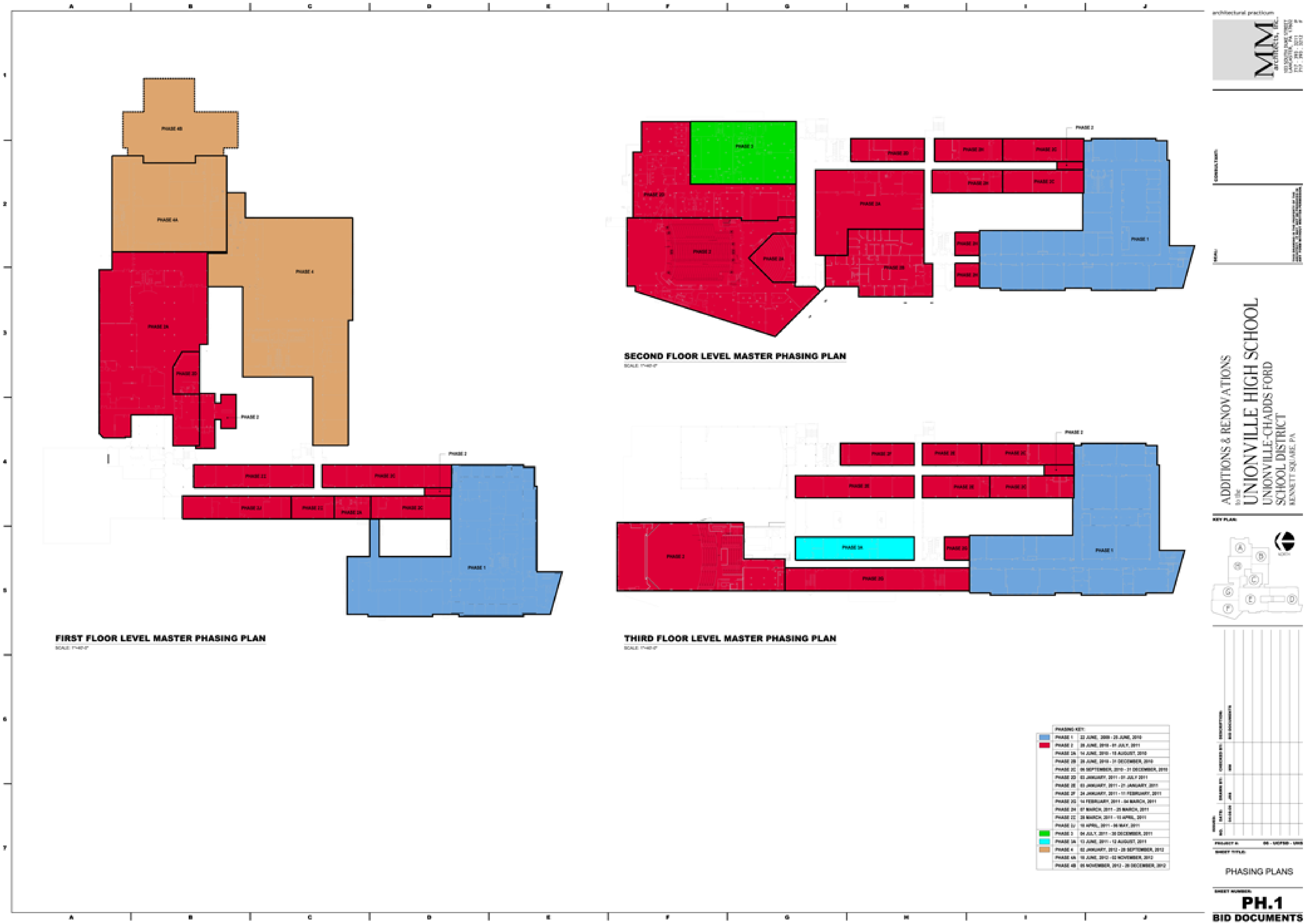
Thank you to MM Architects for providing access to drawings of the project, as well as other resources.

Finally, thank you to the AE Staff and my fellow students. Our staff is second to none, and no staff member (whether I had met them prior to this year or not) hesitated to provide assistance.

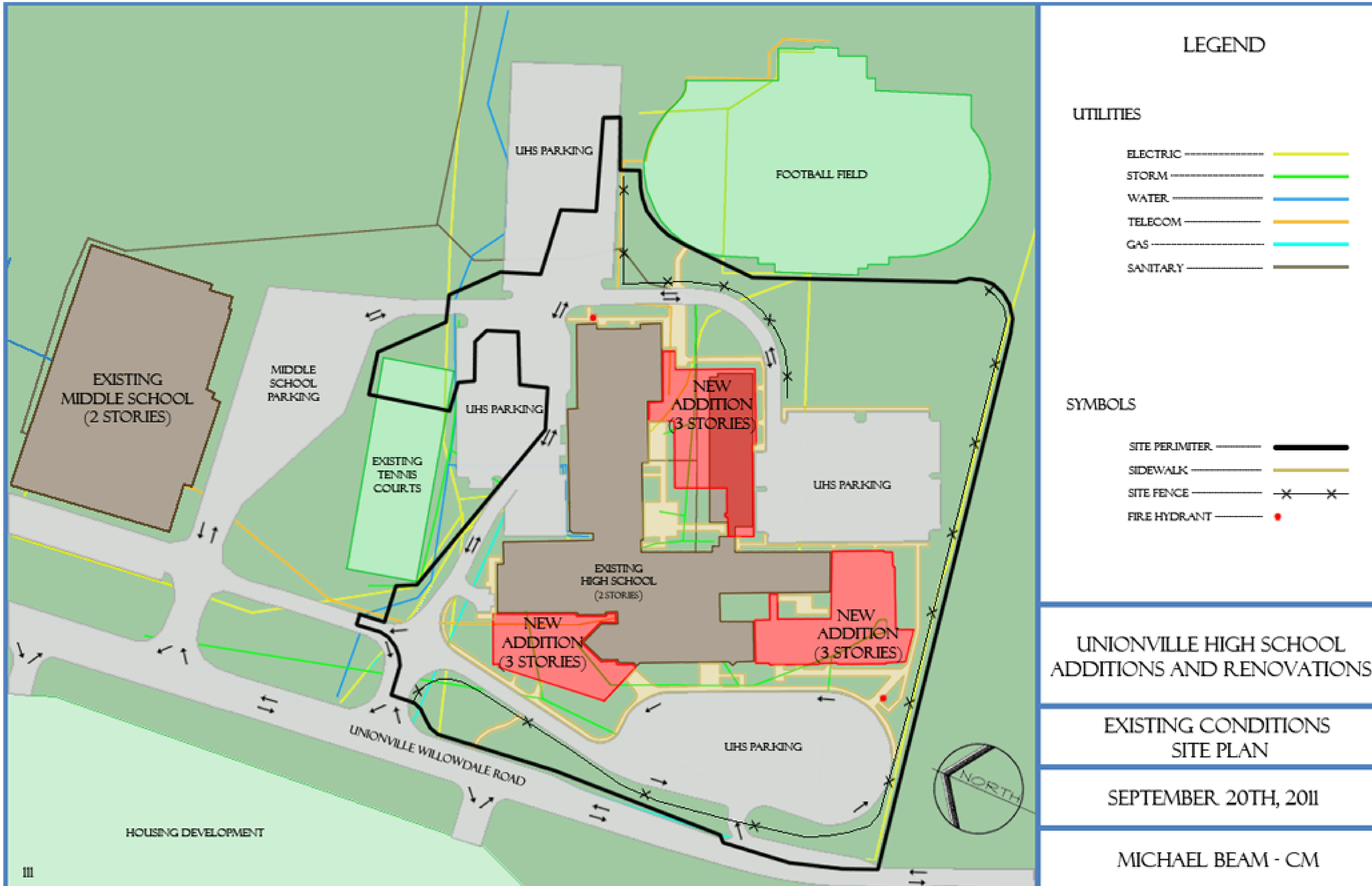
Thank you to all who helped me throughout the process, your experience, knowledge, and resources have helped me to produce this document.

APPENDIX A – Phasing Plan and Area Key

Building Phasing Plan and Building Area Key



APPENDIX B – Existing Conditions Site Plan

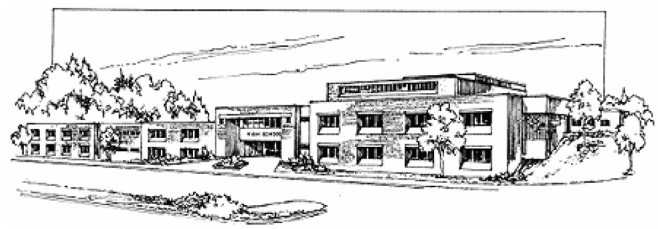


LEGEND
UTILITIES
ELECTRIC
STORM
WATER
TELECOM
GAS
SANITARY
SYMBOLS
SITE PERIMITER
SIDEWALK
SITE FENCE
FIRE HYDRANT
UNIONVILLE HIGH SCHOOL ADDITIONS AND RENOVATIONS
EXISTING CONDITIONS SITE PLAN
SEPTEMBER 20TH, 2011
MICHAEL BEAM - CM
EXISTING MIDDLE SCHOOL (2 STORIES)
MIDDLE SCHOOL PARKING
EXISTING TENNIS COURTS
UHS PARKING
UHS PARKING
UHS PARKING
UHS PARKING
FOOTBALL FIELD
NEW ADDITION (3 STORIES)
EXISTING HIGH SCHOOL (2 STORIES)
NEW ADDITION (3 STORIES)
NEW ADDITION (3 STORIES)
UNIONVILLE WILLOWDALE ROAD
HOUSING DEVELOPMENT
NORTH

APPENDIX C – Square Foot Estimate Calculations

Square Foot Cost Estimate Report

Estimate Name:	**Unionville SF**
	Kennett Square
	Pennysylvania
Building Type:	**School, High, 2-3 Story with Decorative Concrete Block / Steel Frame**
Location:	WESTCHESTER, PA
Stories Count (L.F.):	**3.00**
Stories Height	**13.50**
Floor Area (S.F.):	**319,000.00**
LaborType	**Open Shop**
Basement Included:	No
Data Release:	**Year 2011 Quarter 3**
Cost Per Square Foot	**$121.87**
Total Building Cost	**$38,878,000**



Costs are derived from a building model with basic components. Scope differences and market conditions can cause costs to vary significantly.
Parameters are not within the ranges recommended byRSMeans.

		% of Total	Cost Per SF	Cost
A Substructure		**3.2%**	**3.86**	**$1,231,000**
A1010	**Standard Foundations**		**1.08**	**$345,500**
	Strip footing, concrete, reinforced, load 5.1 KLF, soil bearing capacity 3 KSF, 12" deep x 24" wide			
	Spread footings, 3000 PSI concrete, load 100K, soil bearing capacity 6 KSF, 4' - 6" square x 15" deep			
	Spread footings, 3000 PSI concrete, load 150K, soil bearing capacity 6 KSF, 5' - 6" square x 18" deep			
A1030	**Slab on Grade**		**1.65**	**$525,000**
	Slab on grade, 4" thick, non industrial, reinforced			
A2010	**Basement Excavation**		**0.06**	**$19,500**
	Excavate and fill, 30,000 SF, 4' deep, sand, gravel, or common earth, on site storage			
A2020	**Basement Walls**		**1.07**	**$341,000**
	Foundation wall, CIP, 4' wall height, direct chute, .148 CY/LF, 7.2 PLF, 12" thick			
B Shell		**33.4%**	**40.71**	**$12,987,500**
B1010	**Floor Construction**		**14.08**	**$4,492,000**
	Steel column, W8, 100 KIPS, 16' unsupported height, 31 PLF			
	Steel column, W10, 150 KIPS, 16' unsupported height, 45 PLF			
	Floor, concrete, slab form, open web bar joist @ 2' OC, on W beam and column, 25'x25' bay, 29" deep, 100 PSF su			
	Fireproofing, gypsum board, fire rated, 2 layers, 1" thick, 8" steel column, 3 hour rating, 14 PLF			
B1020	**Roof Construction**		**2.47**	**$786,500**
	Floor, steel joists, beams, 1.5" 22 ga metal deck, on columns, 25'x25' bay, 20" deep, 40 PSF superimposed load, 60			
B2010	**Exterior Walls**		**8.75**	**$2,791,000**
	Concrete block (CMU) wall, split rib, 8 ribs, hollow, regular weight, 12x8x16, reinforced, vertical #5@32", grouted			
B2020	**Exterior Windows**		**10.77**	**$3,435,000**
	Aluminum flush tube frame, thermo-break frame, 2.25" x 4.5", 5'x6' opening, 2 intermediate horizontals			
	Glazing panel, insulating, 1/2" thick, 2 lites 1/8" float glass, tinted			
B2030	**Exterior Doors**		**0.49**	**$157,500**
	Door, aluminum & glass, with transom, narrow stile, double door, hardware, 6'-0" x 10'-0" opening			
	Door, steel 18 gauge, hollow metal, 1 door with frame, no label, 3'-0" x 7'-0" opening			
	Door, steel 24 gauge, overhead, sectional, manual operation, 8'-0" x 8'-0" opening			

		% of Total	Cost Per SF	Cost
B3010	**Roof Coverings**		4.13	$1,318,500
	Roofing, single ply membrane, EPDM, 60 mils, fully adhered			
	Formed roofing, zinc-copper alloy, standing seam, 2-1/2" min slope, .020" thick, 0.87 PSF			
	Insulation, rigid, roof deck, polyisocyanurate, 2#/CF, 2" thick			
	Insulation, rigid, roof deck, polyisocyanurate, tapered for drainage			
	Base flashing, aluminum, .016" thick, fabric 2 sides, .025" aluminum reglet, .032" counter flashing			
	Roof edges, aluminum, duranodic, .050" thick, 6" face			
B3020	**Roof Openings**		0.02	$7,000
	Roof hatch, with curb, 1" fiberglass insulation, 2'-6" x 3'-0", galvanized steel, 165 lbs			
C Interiors		22.2%	27.03	$8,624,000
C1010	**Partitions**		6.62	$2,112,000
	Concrere block (CMU) partition, light weight, hollow, 6" thick, no finish			
	1/2" fire ratedgypsum board, taped & finished, painted on metal furring			
C1020	**Interior Doors**		1.48	$471,000
	Door, single leaf, kd steel frame, hollow metal, commercial quality, flush, 3'-0" x 7'-0" x 1-3/8"			
C1030	**Fittings**		1.15	$365,500
	Toilet partitions, cubicles, ceiling hung, stainless steel			
	Chalkboards, liquid chalk type, aluminum frame & chalktrough			
C2010	**Stair Construction**		0.56	$179,000
	Stairs, steel, cement filled metal pan & picket rail, 16 risers, with landing			
C3010	**Wall Finishes**		3.45	$1,099,500
	Painting, masonry or concrete, latex, brushwork, primer & 2 coats			
	Painting, masonry or concrete, latex, brushwork, addition for block filler			
	Wall coatings, acrylic glazed coatings, maximum			
	Ceramic tile, thin set, 4-1/4" x 4-1/4"			
C3020	**Floor Finishes**		6.79	$2,166,500
	Carpet, tufted, nylon, roll goods, 12' wide, 36 oz			
	Carpet, padding, add to above, minimum			
	Terrazzo, maximum			
	Vinyl, composition tile, maximum			
C3030	**Ceiling Finishes**		6.99	$2,230,500
	Acoustic ceilings, 3/4"mineral fiber, 12" x 12" tile, concealed 2" bar & channel grid, suspended support			
D Services		37.3%	45.40	$14,481,500
D1010	**Elevators and Lifts**		1.01	$323,500
	2 - Hydraulic, passenger elevator, 2500 lb, 2 floors, 100 FPM			
	Hydraulic passenger elevator, 2500 lb., 2 floor, 125 FPM			
D2010	**Plumbing Fixtures**		4.92	$1,570,000
	Water closet, vitreous china, bowl only with flush valve, floor mount			
	Urinal, vitreous china, wall hung			
	Lavatory w/trim, wall hung, PE on CI, 20" x 18"			
	Kitchen sink w/trim, countertop, stainless steel, 44" x 22" triple bowl			
	Lab sink w/trim, polyethylene, single bowl, flanged, 23-1/2" x 20-1/2" OD			
	Service sink w/trim, PE on CI, corner floor, 28" x 28", w/rim guard			
	Service sink w/trim, PE on CI,wall hung w/rim guard, 24" x 20"			
	Group wash fountain, stainless steel, circular, 54" diam			
	Shower, stall, baked enamel, terrazzo receptor, 36" square			
	Water cooler, electric, wall hung, wheelchair type, 7.5 GPH			
D2020	**Domestic Water Distribution**		0.36	$116,000
	Gas fired water heater, commercial, 100< F rise, 600 MBH input, 576 GPH			
D2040	**Rain Water Drainage**		0.66	$209,500

		% of Total	Cost Per SF	Cost
	Roof drain, CI, soil,single hub, 4" diam, 10' high			
	Roof drain, CI, soil,single hub, 4" diam, for each additional foot add			
	Roof drain, CI, soil,single hub, 5" diam, 10' high			
	Roof drain, CI, soil,single hub, 5" diam, for each additional foot add			
D3010	**Energy Supply**		**4.78**	**$1,523,500**
	Commercial building heating system, fin tube radiation, forced hot water, 100,000 SF, 1mil CF, total 3 floors			
D3030	**Cooling Generating Systems**		**15.65**	**$4,992,500**
	Packaged chiller, water cooled, with fan coil unit, schools and colleges, 60,000 SF, 230.00 ton			
D4010	**Sprinklers**		**2.53**	**$806,500**
	Wet pipe sprinkler systems, steel, light hazard, 1 floor, 50,000 SF			
	Wet pipe sprinkler systems, steel, light hazard, each additional floor, 50,000 SF			
D4020	**Standpipes**		**0.29**	**$92,000**
	Wet standpipe risers, class III, steel, black, sch 40, 6" diam pipe, 1 floor			
	Wet standpipe risers, class III, steel, black, sch 40, 6" diam pipe, additional floors			
D5010	**Electrical Service/Distribution**		**0.57**	**$181,000**
	Service installation, includes breakers, metering, 20' conduit & wire, 3 phase, 4 wire, 120/208 V, 2000 A			
	Feeder installation 600 V, including RGS conduit and XHHW wire, 2000 A			
	Switchgear installation, incl switchboard, panels & circuit breaker, 2000 A			
D5020	**Lighting and Branch Wiring**		**10.01**	**$3,193,500**
	Receptacles incl plate, box, conduit, wire, 8 per 1000 SF, .9 W per SF, with transformer			
	Wall switches, 2.0 per 1000 SF			
	Miscellaneous power, 1.2 watts			
	Central air conditioning power, 4 watts			
	Motor installation, three phase, 460 V, 15 HP motor size			
	Motor feeder systems, three phase, feed to 200 V 5 HP, 230 V 7.5 HP, 460 V 15 HP, 575 V 20 HP			
	Fluorescent fixtures recess mounted in ceiling, 1.6 watt per SF, 40 FC, 10 fixtures @32watt per 1000 SF			
D5030	**Communications and Security**		**4.06**	**$1,295,500**
	Communication and alarm systems, includes outlets, boxes, conduit and wire, sound systems, 100 outlets			
	Communication and alarm systems, fire detection, addressable, 100 detectors, includes outlets, boxes, conduit and			
	Fire alarm command center, addressable with voice, excl. wire & conduit			
	Communication and alarm systems, includes outlets, boxes, conduit and wire, master clock systems, 50 rooms			
	Communication and alarm systems, includes outlets, boxes, conduit and wire, master TV antenna systems,100 outle			
	Internet wiring, 2 data/voice outlets per 1000 S.F.			
D5090	**Other Electrical Systems**		**0.56**	**$178,000**
	Generator sets, w/battery, charger, muffler and transfer switch, diesel engine with fuel tank, 250 kW			
E Equipment & Furnishings		**4.0%**	**4.82**	**$1,538,000**
E1020	**Institutional Equipment**		**1.90**	**$606,500**
	Architectural equipment, laboratory equipment, counter tops, acid proof, economy			
	Architectural equipment, laboratory equipment, counter tops, stainless steel			
	Architectural equipment, laboratory equipment, cabinets, wall, open			
	Architectural equipment, laboratory equipment, cabinets, base, drawer units			
E1090	**Other Equipment**		**2.92**	**$931,500**
	1200 - Auditorium chair, fully upholstered, spring seat			
	1500 - Lockers, steel, baked enamel, single tier, 60" or 72", minimum			
	1 - Flagpoles, aluminum, tapered, ground set, 20' high, excludes base or foundation			
	1 - Master time clock system, master controller, clocks & bells, 20 room, excl. wires & conduits			
	Architectural equipment, school equipment basketball backstops, suspended type, electrically operated			
	Architectural equipment, school equipment bleachers-telescoping, manual operation, 15 tier, economy (per seat)			
	Architectural equipment, school equipment, weight lifting gym, universal, economy			
F Special Construction		**0.0%**	**0.00**	**$0**

		% of Total	Cost Per SF	Cost
G Building Sitework		0.0%	0.05	$16,000
G2040	**Site Development**		0.05	$16,000
	Specialties, flagpole, on grade, aluminum, tapered, 59' high			
Sub Total		**100%**	**$121.87**	**$38,878,000**
Contractor's Overhead & Profit		**0.0%**	**$0.00**	**$0**
Architectural Fees		**0.0%**	**$0.00**	**$0**
User Fees		**0.0%**	**$0.00**	**$0**
Total Building Cost			**$121.87**	**$38,878,000**

APPENDIX D – General Conditions Estimate Calculations

General Conditions Estimate | Total Costs (w/ Monthly Costs)#

CSI Division	Item	Type	Unit	Unit Cost			Total	Total Including O&P		Quantity	Total Cost Including O&P	Total Cost Per Month
				Material	Labor	Equipment						
General Requirements												
Summary of Work												
01 11 31.20 0350	Construction Management Fees	$50M job, min	Project				4%	4%			$ 2,080,000.00	$ 49,523.81
Project Management and Coordination												
01 31 13.20 20	Field Personnel	Clerk, average	Week		410		410	630		183	$ 115,290.00	$ 2,745.00
01 31 13.20 120	Field Personnel	Field Engineer, average	Week		1265		1265	1950		183	$ 356,850.00	$ 8,496.43
01 31 13.20 200	Field Personnel	Project Manager, average	Week		2075		2075	3175		183	$ 581,025.00	$ 13,833.93
01 31 13.20 260	Field Personnel	Superintendent, average	Week		1925		1925	2950		183	$ 539,850.00	$ 12,853.57
01 31 13.30 20	Insurance	Builder's risk, standard, minimum	Job					0.24%			$ 124,800.00	$ 2,971.43
01 31 13.90 20	Performance Bond	For buildings, minimum	Job					2.50%			$ 1,300,000.00	$ 30,952.38
Construction Progress Documentation												
01 32 13.50 650	Scheduling	Rule of Thumb, CPM, Large job ($50M +)	Job					0.03%			$ 156,000.00	$ 3,714.29
Regulatory Requirements												
01 41 26.50 20	Permits	Rule of Thumb, most cities, minimum	Job					0.50%			$ 2,600.00	$ 61.90
Quality Control												
01 45 23.50 50	Testing	Steel building, minimum	Job					5200		1	$ 5,200.00	$ 123.81
Construction Facilities												
01 15 13.80 1000	Temporary Facilities	Temporary toilets, rent portable toilet, chemical	Each	0.11	18.65	56	168	180.1		294	$ 52,949.40	$ 1,260.70
01 52 13.20 400	Office and Storage Space	Trailer, furnished, no hookups, 50'x10', buy	Each	23,300	1175		24475	27500		1	$ 27,500.00	$ 654.76
01 52 13.30 1200	Office and Storage Space	Storage Box, 40'x8' rent per month	Each	94			94	103		2	$ 206.00	$ 4.90
01 52 13.20 140	Field Office Expense	Telephone bill: avg bill/month inc. long dist.	Month	81			81	89		42	$ 3,738.00	$ 89.00
01 52 13.20 160	Field Office Expense	Lights and HVAC	Month	152			152	167		42	$ 7,014.00	$ 167.00
Construction Aids												
0154 09.60 6220	Safety	Safety Supplies and First Aid Kits	Month	24.5			24.5	27		42	$ 1,134.00	$ 27.00
Equipment Mobilization												
01 54 36.50 20	Mobilization	Doze, loader, backhoe, excav., grader, paver, roller	Each		69	116	185	233		1	$ 233.00	$ 5.55
01 54 36.50 2100	Mobilization	Crane, truck-mounted, over 75 ton	Each		259	46.5	305.5	440		1	$ 440.00	$ 10.48
Temporary Barriers and Enclosures												
01 55 23.50 50	Roads and Sidewalks	Roads, gravel fill, no surfaceing, 4" gravel depth	S.Y.	4	2.43	0.45	6.88	8.6		100	$ 860.00	$ 20.48
Temporary Barriers and Enclosures												
01 56 26.50 250	Temporary Fencing	Rented chain link, 6' high, over 1000' (up to 12 mo.)	L.F.	10.45	9		19.45	25		4300	$ 107,500.00	$ 2,559.52
Project Identification												
01 56 13.50 20	Signs	High intensity reflectorized, no posts, buy	S.F.	26.5			26.5	29.5		25	$ 737.50	$ 17.56
Examination and Preparation												
01 71 23.13 1100	Construction Layout	Crew for layout of bldg, trenching, 2 person crew	Day		690	69.5	759.5	1125		16	$ 18,000.00	$ 428.57
Cleaning and Waste Management												
01 76 13.20 20	Cleaning Up	After job completion, minimum	Job				0.30%	0.30%			$ 156,000.00	$ 3,714.29
Commisioning												
01 91 13.50 150	Building Commisioning	Basic building commissioning, maximum	%				0.50%	0.50%			$ 260,000.00	$ 6,190.48
Existing Condtions												
Surveys												
02 21 13.09 20	Topographical Surveys	Topographical Surveying, conventional, minimum	Acre	18.2	340	21	379.2	565		21	$ 11,865.00	$ 282.50
02 21 13.13 320	Boundary and Survey Markers	Lot location and lines, large quantities, average	Acre	51.5	900	55.5	1007	1500		21	$ 31,500.00	$ 750.00
Selective Demolition												
02 41 19.23 800	Selective Demolition, Rubbish Handling	Dumpster, weekly rental, 1 dump/wk, 30 C.Y. capacity	Week	750			750	825		183	$ 150,975.00	$ 3,594.64
Erosion and Sedimentation Controls												
31 25 14.16 1000	Rolled Erosion Control Mats and Blankets	Silt fence, polypropylene, 3' high, ideal conditions	L.F.	0.41	0.58		0.99	1.34		4300	$ 5,762.00	$ 137.19
										Total Cost	$ 4,018,028.90	$ 95,667.35
										Total Cost with Location Factor	$ 4,375,633.47	$ 104,181.75

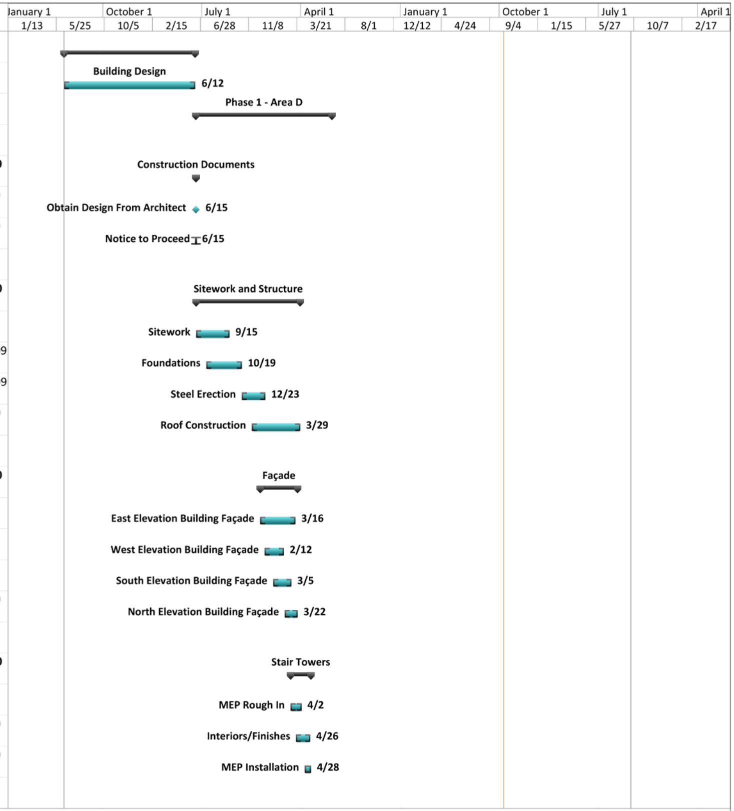
General Conditions Estimate | Sub Category Monthly Costs

Item	Type	Total Cost Including O&P		Monthly Cost		Monthly Cost W/ Location Factor
Field Personnel		$	1,593,015.00	$	37,928.93	$ 41,304.60
Insurance and Bonds		$	1,424,800.00	$	33,923.81	$ 36,943.03
General Construction Costs		$	961,755.90	$	22,898.95	$ 24,936.96
Office and Storage Space		$	38,458.00	$	915.67	$ 997.16
	Total Cost	**$**	**4,018,028.90**	**$**	**95,667.35**	**$ 104,181.75**
	Total Cost with Location Factor	**$**	**4,375,633.47**	**$**	**104,181.75**	**$ 113,453.93**

Note: These categories have been developed in order to best summarize the items used in the general conditions estimate. Lumping of specific items gives a quick snapshot of which items contributed what quantity of the total cost.

APPENDIX E – Detailed Project Schedule

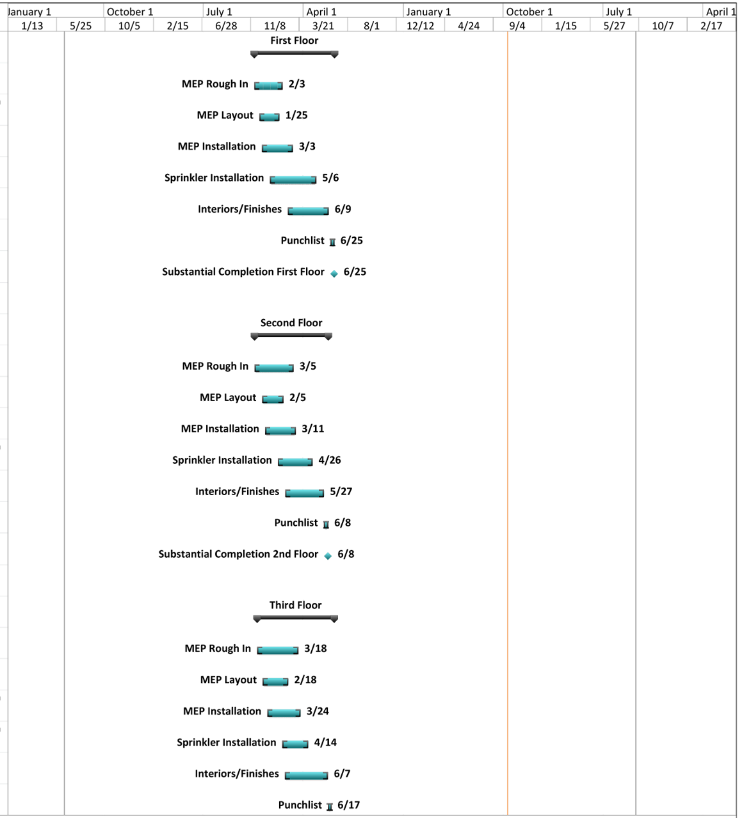
ID		Task Mode	Task Name	Duration	Start	Finish
1			**Design Development**	**260 days**	**Mon 6/16/08**	**Fri 6/12/09**
2			Building Design	260 days	Mon 6/16/08	Fri 6/12/09
3			**Phase 1 - Area D**	**270 days?**	**Mon 6/15/09**	**Fri 6/25/10**
4			<New Task>			
5			**Construction Documents**	**1 day?**	**Mon 6/15/09**	**Mon 6/15/09**
6			Obtain Design From Architect	0 days	Mon 6/15/09	Mon 6/15/09
7			Notice to Proceed	1 day	Mon 6/15/09	Mon 6/15/09
8			<New Task>			
9			**Sitework and Structure**	**205 days?**	**Tue 6/16/09**	**Mon 3/29/10**
10			Sitework	66 days	Tue 6/16/09	Tue 9/15/09
11			Foundations	70 days	Tue 7/14/09	Mon 10/19/09
12			Steel Erection	47 days	Tue 10/20/09	Wed 12/23/09
13			Roof Construction	95 days	Tue 11/17/09	Mon 3/29/10
14			<New Task>			
15			**Façade**	**73 days?**	**Thu 12/10/09**	**Mon 3/22/10**
16			East Elevation Building Façade	69 days	Thu 12/10/09	Tue 3/16/10
17			West Elevation Building Façade	39 days	Tue 12/22/09	Fri 2/12/10
18			South Elevation Building Façade	36 days	Fri 1/15/10	Fri 3/5/10
19			North Elevation Building Façade	25 days	Tue 2/16/10	Mon 3/22/10
20			<New Task>			
21			**Stair Towers**	**40 days?**	**Thu 3/4/10**	**Wed 4/28/10**
22			MEP Rough In	22 days	Thu 3/4/10	Fri 4/2/10
23			Interiors/Finishes	27 days	Fri 3/19/10	Mon 4/26/10
24			MEP Installation	13 days	Mon 4/12/10	Wed 4/28/10
25			<New Task>			



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

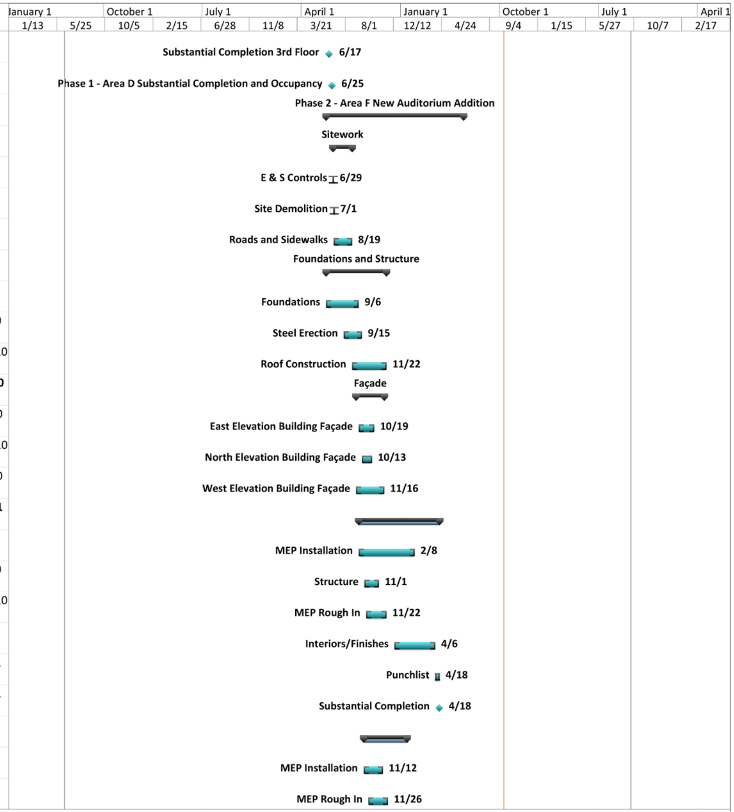
ID		Task Mode	Task Name	Duration	Start	Finish
26			**First Floor**	**158 days?**	**Wed 11/18/09**	**Fri 6/25/10**
27			MEP Rough In	56 days	Wed 11/18/09	Wed 2/3/10
28			MEP Layout	39 days	Wed 12/2/09	Mon 1/25/10
29			MEP Installation	61 days	Wed 12/9/09	Wed 3/3/10
30			Sprinkler Installation	91 days	Thu 12/31/09	Thu 5/6/10
31			Interiors/Finishes	80 days	Thu 2/18/10	Wed 6/9/10
32			Punchlist	9 days	Tue 6/15/10	Fri 6/25/10
33			Substantial Completion First Floor	0 days	Fri 6/25/10	Fri 6/25/10
34			<New Task>			
35			**Second Floor**	**144 days?**	**Thu 11/19/09**	**Tue 6/8/10**
36			MEP Rough In	77 days	Thu 11/19/09	Fri 3/5/10
37			MEP Layout	42 days	Thu 12/10/09	Fri 2/5/10
38			MEP Installation	60 days	Fri 12/18/09	Thu 3/11/10
39			Sprinkler Installation	67 days	Fri 1/22/10	Mon 4/26/10
40			Interiors/Finishes	76 days	Thu 2/11/10	Thu 5/27/10
41			Punchlist	8 days	Fri 5/28/10	Tue 6/8/10
42			Substantial Completion 2nd Floor	0 days	Tue 6/8/10	Tue 6/8/10
43			<New Task>			
44			**Third Floor**	**151 days**	**Thu 11/26/09**	**Fri 6/25/10**
45			MEP Rough In	81 days	Thu 11/26/09	Thu 3/18/10
46			MEP Layout	50 days	Fri 12/11/09	Thu 2/18/10
47			MEP Installation	65 days	Thu 12/24/09	Wed 3/24/10
48			Sprinkler Installation	51 days	Wed 2/3/10	Wed 4/14/10
49			Interiors/Finishes	84 days	Wed 2/10/10	Mon 6/7/10
50			Punchlist	8 days	Tue 6/8/10	Thu 6/17/10



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

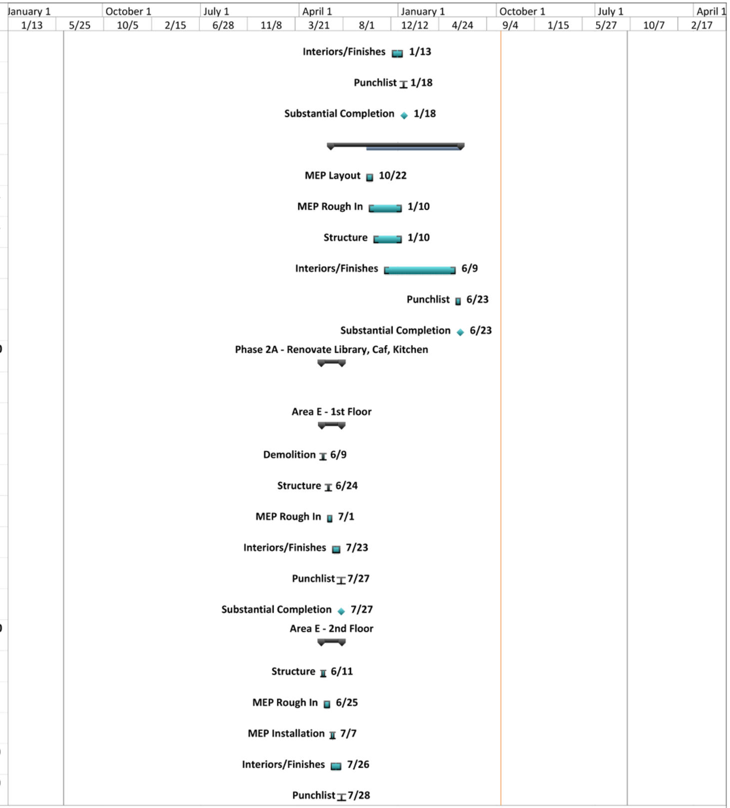
ID		Task Mode	Task Name	Duration	Start	Finish
51			Substantial Completion 3rd Floor	0 days	Thu 6/17/10	Thu 6/17/10
52			Phase 1 - Area D Substantial Completion and Occupancy	0 days	Fri 6/25/10	Fri 6/25/10
53			**Phase 2 - Area F New Auditorium Addition**	**272 days**	**Wed 6/9/10**	**Thu 6/23/11**
54			**Sitework**	**39 days**	**Mon 6/28/10**	**Thu 8/19/10**
55			E & S Controls	2 days	Mon 6/28/10	Tue 6/29/10
56			Site Demolition	2 days	Wed 6/30/10	Thu 7/1/10
57			Roads and Sidewalks	37 days	Wed 6/30/10	Thu 8/19/10
58			**Foundations and Structure**	**119 days**	**Wed 6/9/10**	**Mon 11/22/10**
59			Foundations	64 days	Wed 6/9/10	Mon 9/6/10
60			Steel Erection	36 days	Wed 7/28/10	Wed 9/15/10
61			Roof Construction	67 days	Fri 8/20/10	Mon 11/22/10
62			**Façade**	**56 days**	**Tue 8/31/10**	**Tue 11/16/10**
63			East Elevation Building Façade	31 days	Tue 9/7/10	Tue 10/19/10
64			North Elevation Building Façade	20 days	Thu 9/16/10	Wed 10/13/10
65			West Elevation Building Façade	56 days	Tue 8/31/10	Tue 11/16/10
66			**2nd Floor**	**160 days**	**Tue 9/7/10**	**Mon 4/18/11**
67			MEP Installation	111 days	Tue 9/7/10	Tue 2/8/11
68			Structure	28 days	Thu 9/23/10	Mon 11/1/10
69			MEP Rough In	40 days	Tue 9/28/10	Mon 11/22/10
70			Interiors/Finishes	81 days	Wed 12/15/10	Wed 4/6/11
71			Punchlist	8 days	Thu 4/7/11	Mon 4/18/11
72			Substantial Completion	0 days	Mon 4/18/11	Mon 4/18/11
73			**3rd Floor**	**86 days**	**Tue 9/21/10**	**Tue 1/18/11**
74			MEP Installation	39 days	Tue 9/21/10	Fri 11/12/10
75			MEP Rough In	40 days	Mon 10/4/10	Fri 11/26/10



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

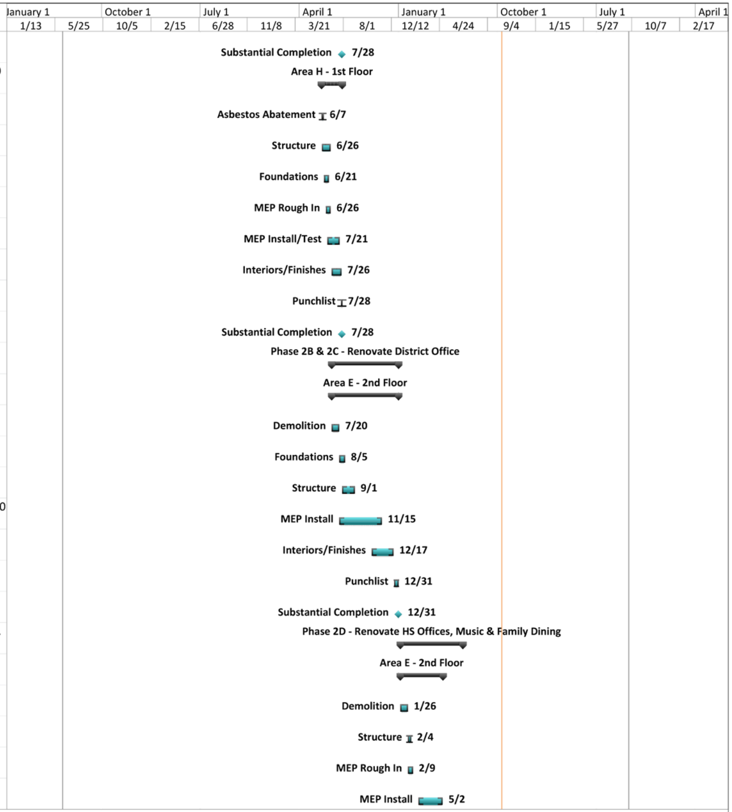
ID		Task Mode	Task Name	Duration	Start	Finish
76			Interiors/Finishes	22 days	Wed 12/15/10	Thu 1/13/11
77			Punchlist	3 days	Fri 1/14/11	Tue 1/18/11
78			Substantial Completion	0 days	Tue 1/18/11	Tue 1/18/11
79			**Auditorium/Stage/Balcony**	**259 days**	**Mon 6/28/10**	**Thu 6/23/11**
80			MEP Layout	14 days	Tue 10/5/10	Fri 10/22/10
81			MEP Rough In	65 days	Tue 10/12/10	Mon 1/10/11
82			Structure	56 days	Mon 10/25/10	Mon 1/10/11
83			Interiors/Finishes	143 days	Tue 11/23/10	Thu 6/9/11
84			Punchlist	10 days	Fri 6/10/11	Thu 6/23/11
85			Substantial Completion	0 days	Thu 6/23/11	Thu 6/23/11
86			**Phase 2A - Renovate Library, Caf, Kitchen**	**41 days**	**Wed 6/2/10**	**Wed 7/28/10**
87			<New Task>			
88			**Area E - 1st Floor**	**39 days**	**Thu 6/3/10**	**Tue 7/27/10**
89			Demolition	5 days	Thu 6/3/10	Wed 6/9/10
90			Structure	5 days	Fri 6/18/10	Thu 6/24/10
91			MEP Rough In	10 days	Fri 6/18/10	Thu 7/1/10
92			Interiors/Finishes	16 days	Fri 7/2/10	Fri 7/23/10
93			Punchlist	2 days	Mon 7/26/10	Tue 7/27/10
94			Substantial Completion	0 days	Tue 7/27/10	Tue 7/27/10
95			**Area E - 2nd Floor**	**41 days**	**Wed 6/2/10**	**Wed 7/28/10**
96			Structure	8 days	Wed 6/2/10	Fri 6/11/10
97			MEP Rough In	13 days	Wed 6/9/10	Fri 6/25/10
98			MEP Installation	8 days	Mon 6/28/10	Wed 7/7/10
99			Interiors/Finishes	21 days	Mon 6/28/10	Mon 7/26/10
100			Punchlist	2 days	Tue 7/27/10	Wed 7/28/10



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

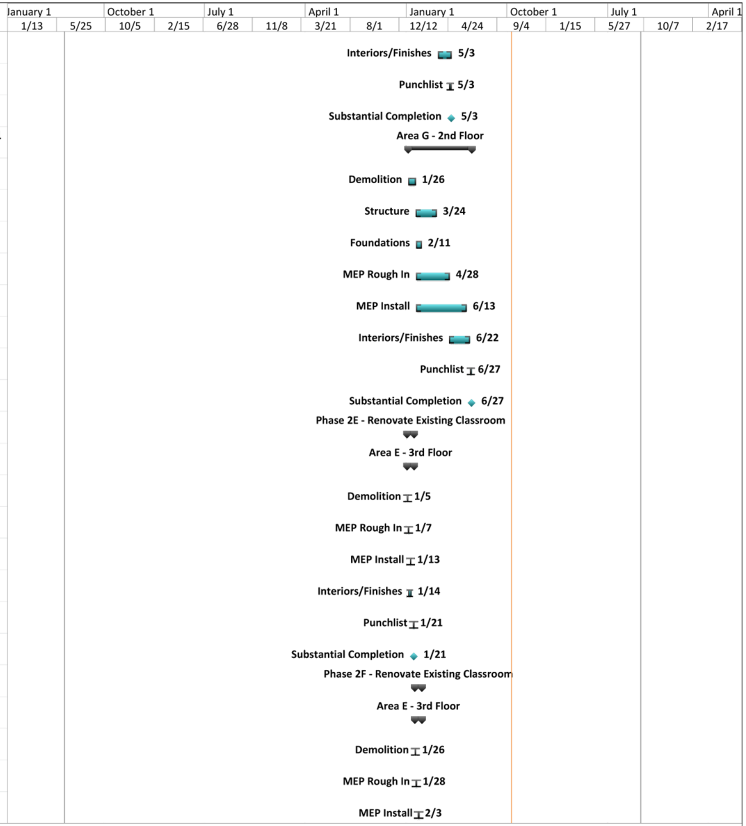
ID		Task Mode	Task Name	Duration	Start	Finish
101			Substantial Completion	0 days	Wed 7/28/10	Wed 7/28/10
102			**Area H - 1st Floor**	**41 days**	**Wed 6/2/10**	**Wed 7/28/10**
103			Asbestos Abatement	4 days	Wed 6/2/10	Mon 6/7/10
104			Structure	18 days	Thu 6/3/10	Sat 6/26/10
105			Foundations	9 days	Wed 6/9/10	Mon 6/21/10
106			MEP Rough In	11 days	Mon 6/14/10	Sat 6/26/10
107			MEP Install/Test	24 days	Fri 6/18/10	Wed 7/21/10
108			Interiors/Finishes	19 days	Wed 6/30/10	Mon 7/26/10
109			Punchlist	2 days	Tue 7/27/10	Wed 7/28/10
110			Substantial Completion	0 days	Wed 7/28/10	Wed 7/28/10
111			**Phase 2B & 2C - Renovate District Office**	**133 days**	**Wed 6/30/10**	**Fri 12/31/10**
112			**Area E - 2nd Floor**	**133 days**	**Wed 6/30/10**	**Fri 12/31/10**
113			Demolition	15 days	Wed 6/30/10	Tue 7/20/10
114			Foundations	12 days	Wed 7/21/10	Thu 8/5/10
115			Structure	25 days	Thu 7/29/10	Wed 9/1/10
116			MEP Install	84 days	Wed 7/21/10	Mon 11/15/10
117			Interiors/Finishes	44 days	Tue 10/19/10	Fri 12/17/10
118			Punchlist	10 days	Mon 12/20/10	Fri 12/31/10
119			Substantial Completion	0 days	Fri 12/31/10	Fri 12/31/10
120			**Phase 2D - Renovate HS Offices, Music & Family Dining**	**123 days**	**Thu 1/6/11**	**Mon 6/27/11**
121			**Area E - 2nd Floor**	**84 days**	**Thu 1/6/11**	**Tue 5/3/11**
122			Demolition	15 days	Thu 1/6/11	Wed 1/26/11
123			Structure	7 days	Thu 1/27/11	Fri 2/4/11
124			MEP Rough In	10 days	Thu 1/27/11	Wed 2/9/11
125			MEP Install	47 days	Fri 2/25/11	Mon 5/2/11



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

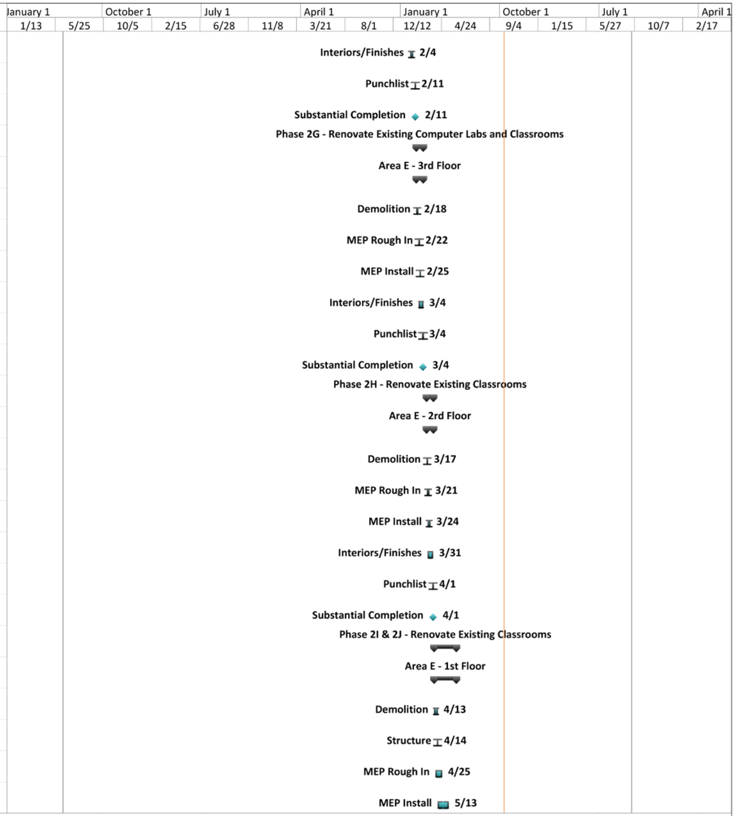
ID		Task Mode	Task Name	Duration	Start	Finish
126			Interiors/Finishes	27 days	Mon 3/28/11	Tue 5/3/11
127			Punchlist	5 days	Wed 4/27/11	Tue 5/3/11
128			Substantial Completion	0 days	Tue 5/3/11	Tue 5/3/11
129			**Area G - 2nd Floor**	**123 days**	**Thu 1/6/11**	**Mon 6/27/11**
130			Demolition	15 days	Thu 1/6/11	Wed 1/26/11
131			Structure	42 days	Wed 1/26/11	Thu 3/24/11
132			Foundations	12 days	Thu 1/27/11	Fri 2/11/11
133			MEP Rough In	66 days	Thu 1/27/11	Thu 4/28/11
134			MEP Install	98 days	Thu 1/27/11	Mon 6/13/11
135			Interiors/Finishes	41 days	Wed 4/27/11	Wed 6/22/11
136			Punchlist	3 days	Thu 6/23/11	Mon 6/27/11
137			Substantial Completion	0 days	Mon 6/27/11	Mon 6/27/11
138			**Phase 2E - Renovate Existing Classroom**	**15 days**	**Mon 1/3/11**	**Fri 1/21/11**
139			**Area E - 3rd Floor**	**15 days**	**Mon 1/3/11**	**Fri 1/21/11**
140			Demolition	3 days	Mon 1/3/11	Wed 1/5/11
141			MEP Rough In	2 days	Thu 1/6/11	Fri 1/7/11
142			MEP Install	3 days	Tue 1/11/11	Thu 1/13/11
143			Interiors/Finishes	7 days	Thu 1/6/11	Fri 1/14/11
144			Punchlist	2 days	Thu 1/20/11	Fri 1/21/11
145			Substantial Completion	0 days	Fri 1/21/11	Fri 1/21/11
146			**Phase 2F - Renovate Existing Classroom**	**15 days**	**Mon 1/24/11**	**Fri 2/11/11**
147			**Area E - 3rd Floor**	**15 days**	**Mon 1/24/11**	**Fri 2/11/11**
148			Demolition	3 days	Mon 1/24/11	Wed 1/26/11
149			MEP Rough In	2 days	Thu 1/27/11	Fri 1/28/11
150			MEP Install	1 day	Thu 2/3/11	Thu 2/3/11



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

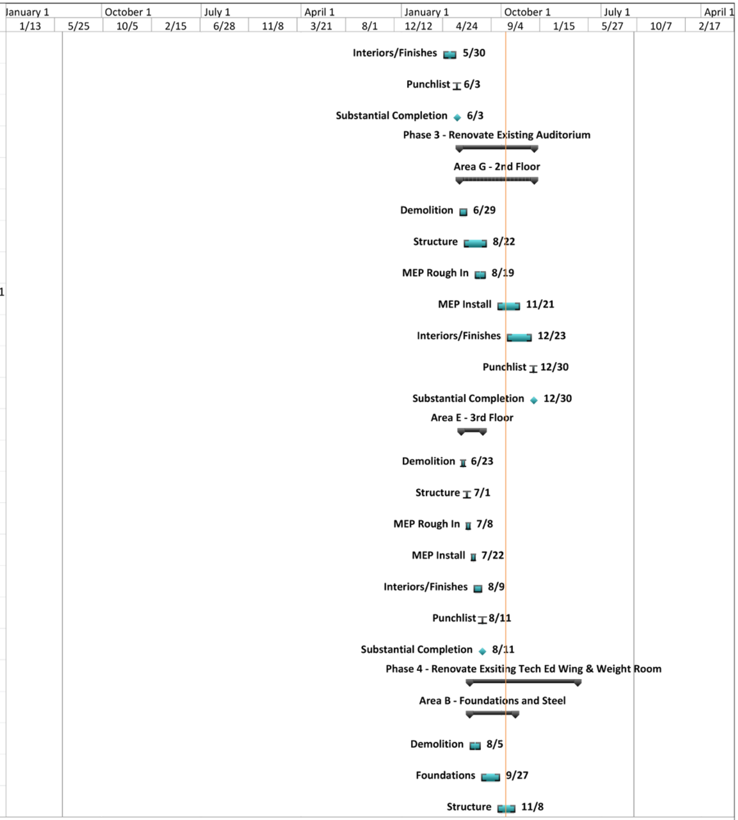
ID	Task Mode	Task Name	Duration	Start	Finish
151		Interiors/Finishes	6 days	Fri 1/28/11	Fri 2/4/11
152		Punchlist	2 days	Thu 2/10/11	Fri 2/11/11
153		Substantial Completion	0 days	Fri 2/11/11	Fri 2/11/11
154		**Phase 2G - Renovate Existing Computer Labs and Classrooms**	**15 days**	**Mon 2/14/11**	**Fri 3/4/11**
155		**Area E - 3rd Floor**	**15 days**	**Mon 2/14/11**	**Fri 3/4/11**
156		Demolition	5 days	Mon 2/14/11	Fri 2/18/11
157		MEP Rough In	2 days	Mon 2/21/11	Tue 2/22/11
158		MEP Install	3 days	Wed 2/23/11	Fri 2/25/11
159		Interiors/Finishes	10 days	Mon 2/21/11	Fri 3/4/11
160		Punchlist	1 day	Fri 3/4/11	Fri 3/4/11
161		Substantial Completion	0 days	Fri 3/4/11	Fri 3/4/11
162		**Phase 2H - Renovate Existing Classrooms**	**15 days**	**Mon 3/14/11**	**Fri 4/1/11**
163		**Area E - 2rd Floor**	**15 days**	**Mon 3/14/11**	**Fri 4/1/11**
164		Demolition	4 days	Mon 3/14/11	Thu 3/17/11
165		MEP Rough In	5 days	Tue 3/15/11	Mon 3/21/11
166		MEP Install	6 days	Thu 3/17/11	Thu 3/24/11
167		Interiors/Finishes	11 days	Thu 3/17/11	Thu 3/31/11
168		Punchlist	2 days	Thu 3/31/11	Fri 4/1/11
169		Substantial Completion	0 days	Fri 4/1/11	Fri 4/1/11
170		**Phase 2I & 2J - Renovate Existing Classrooms**	**45 days**	**Mon 4/4/11**	**Fri 6/3/11**
171		**Area E - 1st Floor**	**45 days**	**Mon 4/4/11**	**Fri 6/3/11**
172		Demolition	8 days	Mon 4/4/11	Wed 4/13/11
173		Structure	3 days	Tue 4/12/11	Thu 4/14/11
174		MEP Rough In	12 days	Fri 4/8/11	Mon 4/25/11
175		MEP Install	22 days	Thu 4/14/11	Fri 5/13/11



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

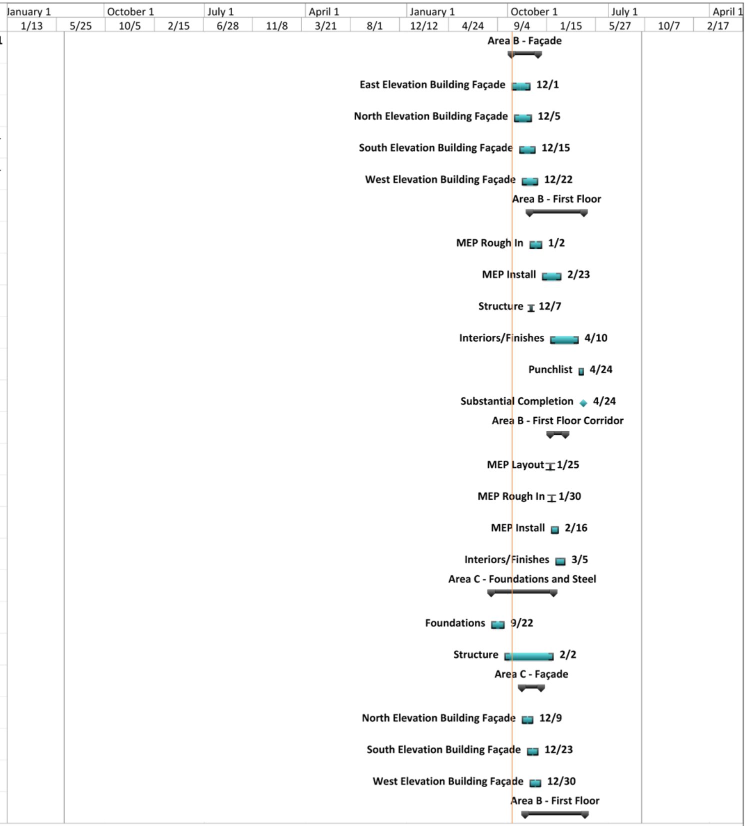
ID		Task Mode	Task Name	Duration	Start	Finish
176			Interiors/Finishes	25 days	Tue 4/26/11	Mon 5/30/11
177			Punchlist	4 days	Tue 5/31/11	Fri 6/3/11
178			Substantial Completion	0 days	Fri 6/3/11	Fri 6/3/11
179			**Phase 3 - Renovate Existing Auditorium**	**147 days**	**Thu 6/9/11**	**Fri 12/30/11**
180			**Area G - 2nd Floor**	**147 days**	**Thu 6/9/11**	**Fri 12/30/11**
181			Demolition	15 days	Thu 6/9/11	Wed 6/29/11
182			Structure	45 days	Tue 6/21/11	Mon 8/22/11
183			MEP Rough In	22 days	Thu 7/21/11	Fri 8/19/11
184			MEP Install	44 days	Wed 9/21/11	Mon 11/21/11
185			Interiors/Finishes	50 days	Mon 10/17/11	Fri 12/23/11
186			Punchlist	5 days	Mon 12/26/11	Fri 12/30/11
187			Substantial Completion	0 days	Fri 12/30/11	Fri 12/30/11
188			**Area E - 3rd Floor**	**43 days**	**Tue 6/14/11**	**Thu 8/11/11**
189			Demolition	8 days	Tue 6/14/11	Thu 6/23/11
190			Structure	5 days	Mon 6/27/11	Fri 7/1/11
191			MEP Rough In	10 days	Mon 6/27/11	Fri 7/8/11
192			MEP Install	10 days	Mon 7/11/11	Fri 7/22/11
193			Interiors/Finishes	17 days	Mon 7/18/11	Tue 8/9/11
194			Punchlist	2 days	Wed 8/10/11	Thu 8/11/11
195			Substantial Completion	0 days	Thu 8/11/11	Thu 8/11/11
196			**Phase 4 - Renovate Exsiting Tech Ed Wing & Weight Room**	**212 days**	**Thu 7/7/11**	**Fri 4/27/12**
197			**Area B - Foundations and Steel**	**89 days**	**Thu 7/7/11**	**Tue 11/8/11**
198			Demolition	22 days	Thu 7/7/11	Fri 8/5/11
199			Foundations	37 days	Mon 8/8/11	Tue 9/27/11
200			Structure	35 days	Wed 9/21/11	Tue 11/8/11



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

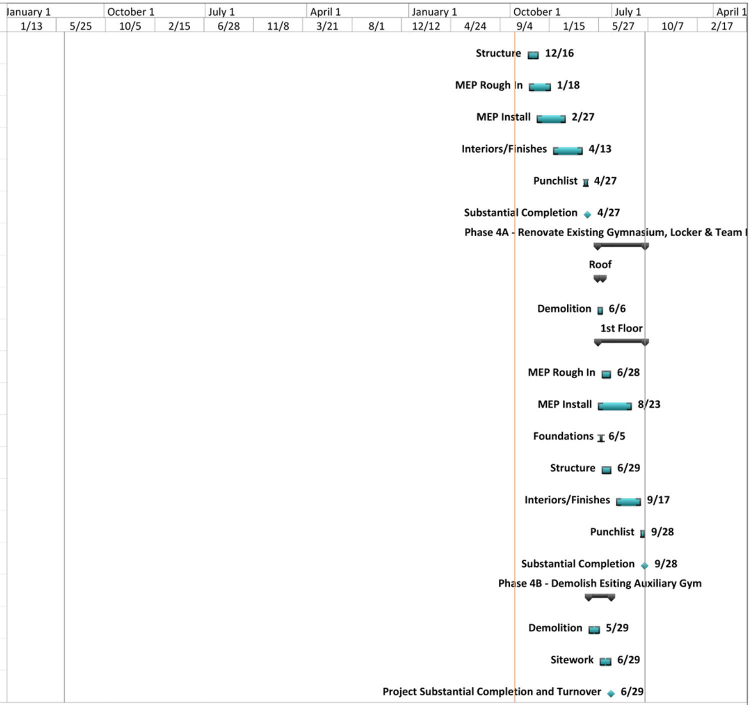
ID		Task Mode	Task Name	Duration	Start	Finish
201			**Area B - Façade**	**52 days**	**Wed 10/12/11**	**Thu 12/22/11**
202			East Elevation Building Façade	37 days	Wed 10/12/11	Thu 12/1/11
203			North Elevation Building Façade	34 days	Wed 10/19/11	Mon 12/5/11
204			South Elevation Building Façade	32 days	Wed 11/2/11	Thu 12/15/11
205			West Elevation Building Façade	32 days	Wed 11/9/11	Thu 12/22/11
206			**Area B - First Floor**	**105 days**	**Wed 11/30/11**	**Tue 4/24/12**
207			MEP Rough In	24 days	Wed 11/30/11	Mon 1/2/12
208			MEP Install	38 days	Tue 1/3/12	Thu 2/23/12
209			Structure	6 days	Wed 11/30/11	Wed 12/7/11
210			Interiors/Finishes	55 days	Wed 1/25/12	Tue 4/10/12
211			Punchlist	10 days	Wed 4/11/12	Tue 4/24/12
212			Substantial Completion	0 days	Tue 4/24/12	Tue 4/24/12
213			**Area B - First Floor Corridor**	**29 days**	**Tue 1/24/12**	**Mon 3/5/12**
214			MEP Layout	1 day	Tue 1/24/12	Wed 1/25/12
215			MEP Rough In	2 days	Fri 1/27/12	Mon 1/30/12
216			MEP Install	15 days	Fri 1/27/12	Thu 2/16/12
217			Interiors/Finishes	19 days	Wed 2/8/12	Mon 3/5/12
218			**Area C - Foundations and Steel**	**121 days**	**Thu 8/18/11**	**Thu 2/2/12**
219			Foundations	26 days	Thu 8/18/11	Thu 9/22/11
220			Structure	95 days	Fri 9/23/11	Thu 2/2/12
221			**Area C - Façade**	**38 days**	**Wed 11/9/11**	**Fri 12/30/11**
222			North Elevation Building Façade	23 days	Wed 11/9/11	Fri 12/9/11
223			South Elevation Building Façade	23 days	Wed 11/23/11	Fri 12/23/11
224			West Elevation Building Façade	23 days	Wed 11/30/11	Fri 12/30/11
225			**Area B - First Floor**	**116 days**	**Fri 11/18/11**	**Fri 4/27/12**



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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 Mode	Task Name	Duration	Start	Finish
226		Structure	21 days	Fri 11/18/11	Fri 12/16/11
227		MEP Rough In	43 days	Mon 11/21/11	Wed 1/18/12
228		MEP Install	56 days	Mon 12/12/11	Mon 2/27/12
229		Interiors/Finishes	58 days	Wed 1/25/12	Fri 4/13/12
230		Punchlist	9 days	Tue 4/17/12	Fri 4/27/12
231		Substantial Completion	0 days	Fri 4/27/12	Fri 4/27/12
232		**Phase 4A - Renovate Existing Gymnasium, Locker & Team Rooms**	**92 days**	**Thu 5/24/12**	**Fri 9/28/12**
233		**Roof**	**10 days**	**Thu 5/24/12**	**Wed 6/6/12**
234		Demolition	10 days	Thu 5/24/12	Wed 6/6/12
235		**1st Floor**	**91 days**	**Fri 5/25/12**	**Fri 9/28/12**
236		MEP Rough In	19 days	Mon 6/4/12	Thu 6/28/12
237		MEP Install	65 days	Fri 5/25/12	Thu 8/23/12
238		Foundations	5 days	Wed 5/30/12	Tue 6/5/12
239		Structure	20 days	Mon 6/4/12	Fri 6/29/12
240		Interiors/Finishes	47 days	Fri 7/13/12	Mon 9/17/12
241		Punchlist	10 days	Mon 9/17/12	Fri 9/28/12
242		Substantial Completion	0 days	Fri 9/28/12	Fri 9/28/12
243		**Phase 4B - Demolish Esiting Auxiliary Gym**	**45 days**	**Mon 4/30/12**	**Fri 6/29/12**
244		Demolition	22 days	Mon 4/30/12	Tue 5/29/12
245		Sitework	23 days	Wed 5/30/12	Fri 6/29/12
246		Project Substantial Completion and Turnover	0 days	Fri 6/29/12	Fri 6/29/12



Project: Tech 2 Detailed Schedule
Date: Fri 10/14/11

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

APPENDIX F – Interview with Wohlsen PM Brian Laub

Interview with Wohlsen PM Brian Laub

1. Who was the driving force behind using a Single Prime delivery method for the UHS project?

The school district

2. Why was a Single Prime delivery method preferred to a Multiple Prime delivery method?

Because the school had lots of issues and law suits on previous project with using multiple prime contracts.

3. How did Wohlsen/UCFSD get the exemption from the Separation Act to use a Single Prime delivery method in PA?

The school applied for a waiver to have the project be single prime.

4. Has the single prime been a good method during the project or have any issues come up?

It has been a good method for the school as they only have one person they need to contact.

5. What are the major benefits of using Single Prime on a job like this as opposed to Multiple Prime?

The owner does not need to hire a CM to manage the work. They have 1 person to contact it there are issues.

6. Who reports to whom during the project, and why? (ex. Wohlsen reports to Unionville School District, etc)

All of the subcontractors report to Wohlsen and Wohlsen reports to the school district and architect.

7. Are there any downfalls to using a Single Prime delivery method?

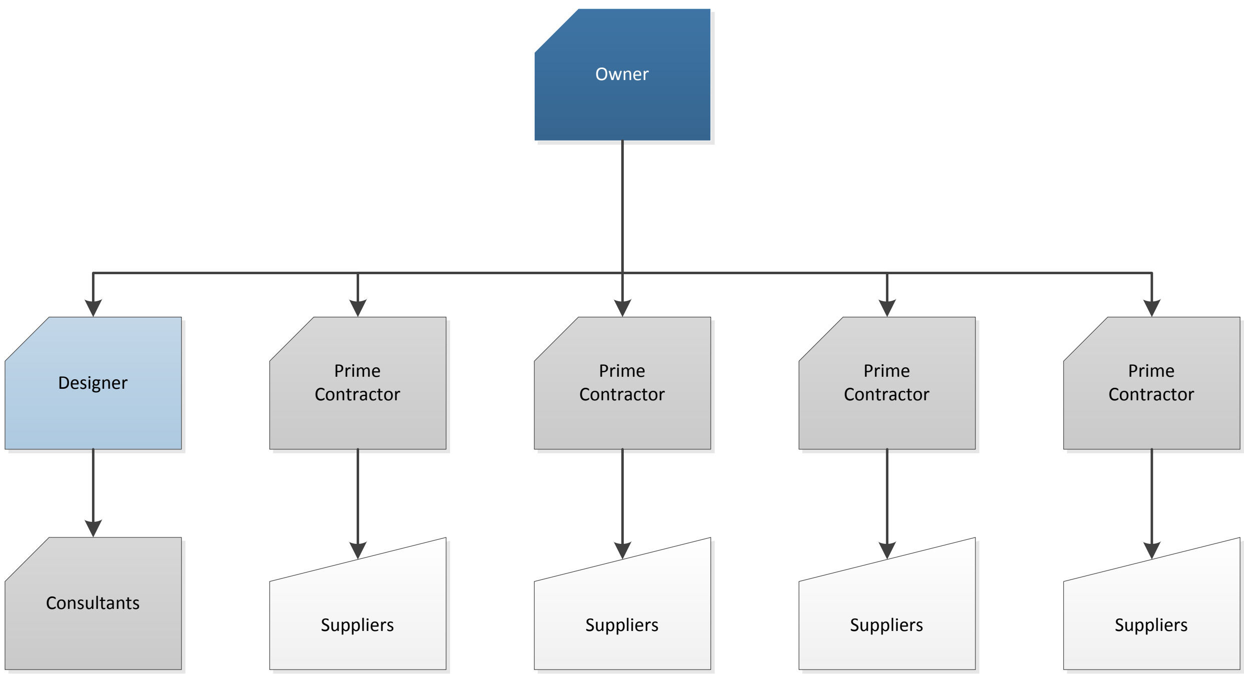
Not that I am aware of

8. Do you have experience on other school projects, what delivery method was used on those projects, and what were the differences?

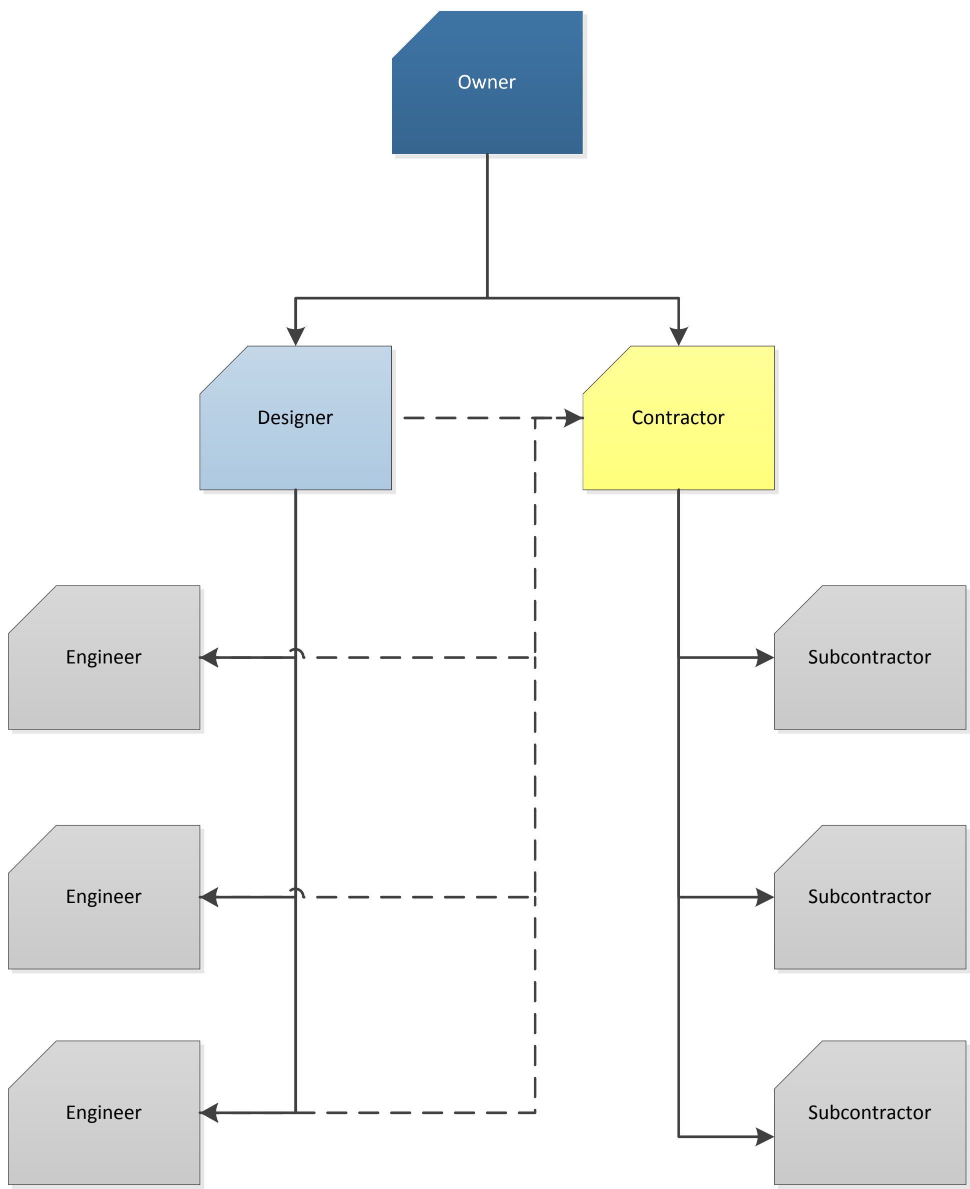
I have been involved in both single and multiple prime contacts on school. The difference is on the multiple primes the control of a prime is harder because they are not reporting directly to you and you are not paying their bills. Sometime they have their own agenda in mind.

APPENDIX G – Delivery Method Diagrams

Multiple Prime Delivery Method

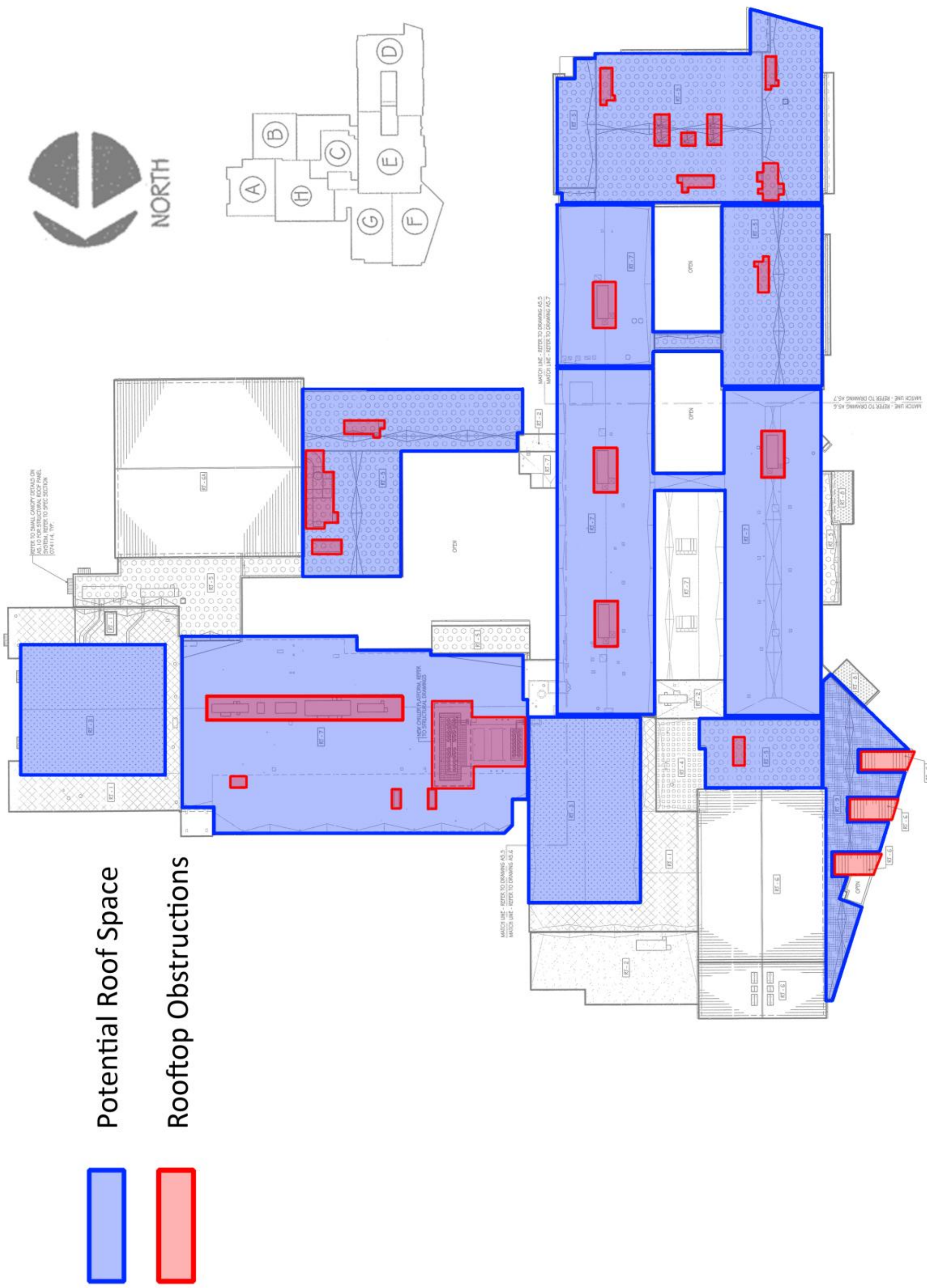


Single Prime Delivery Method



APPENDIX H – Potential Roof Regions for PV Array

Potential Roof Areas for PV Array



APPENDIX I – PV Array Shadow Analysis Images

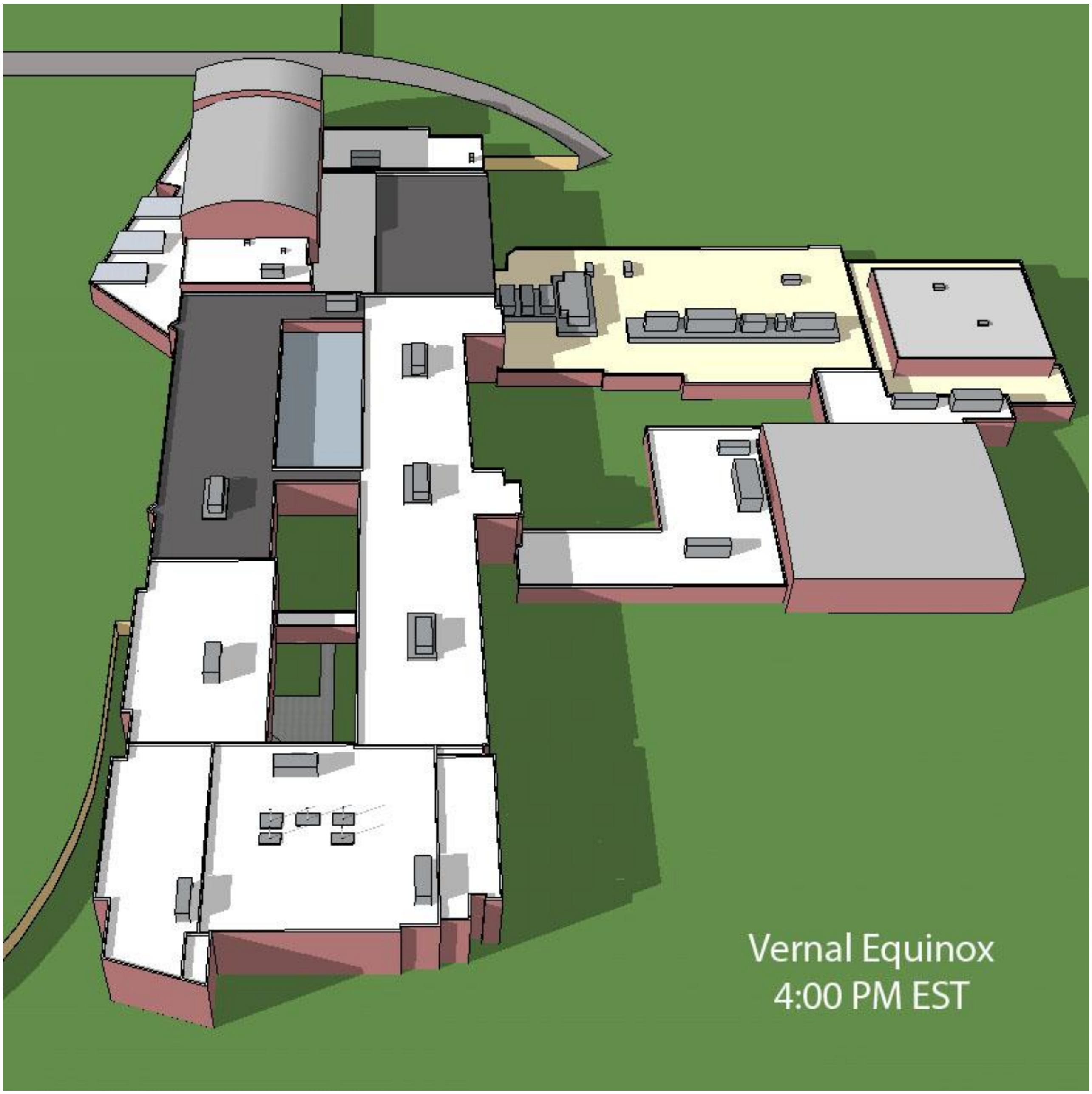
Shadow Analysis Images

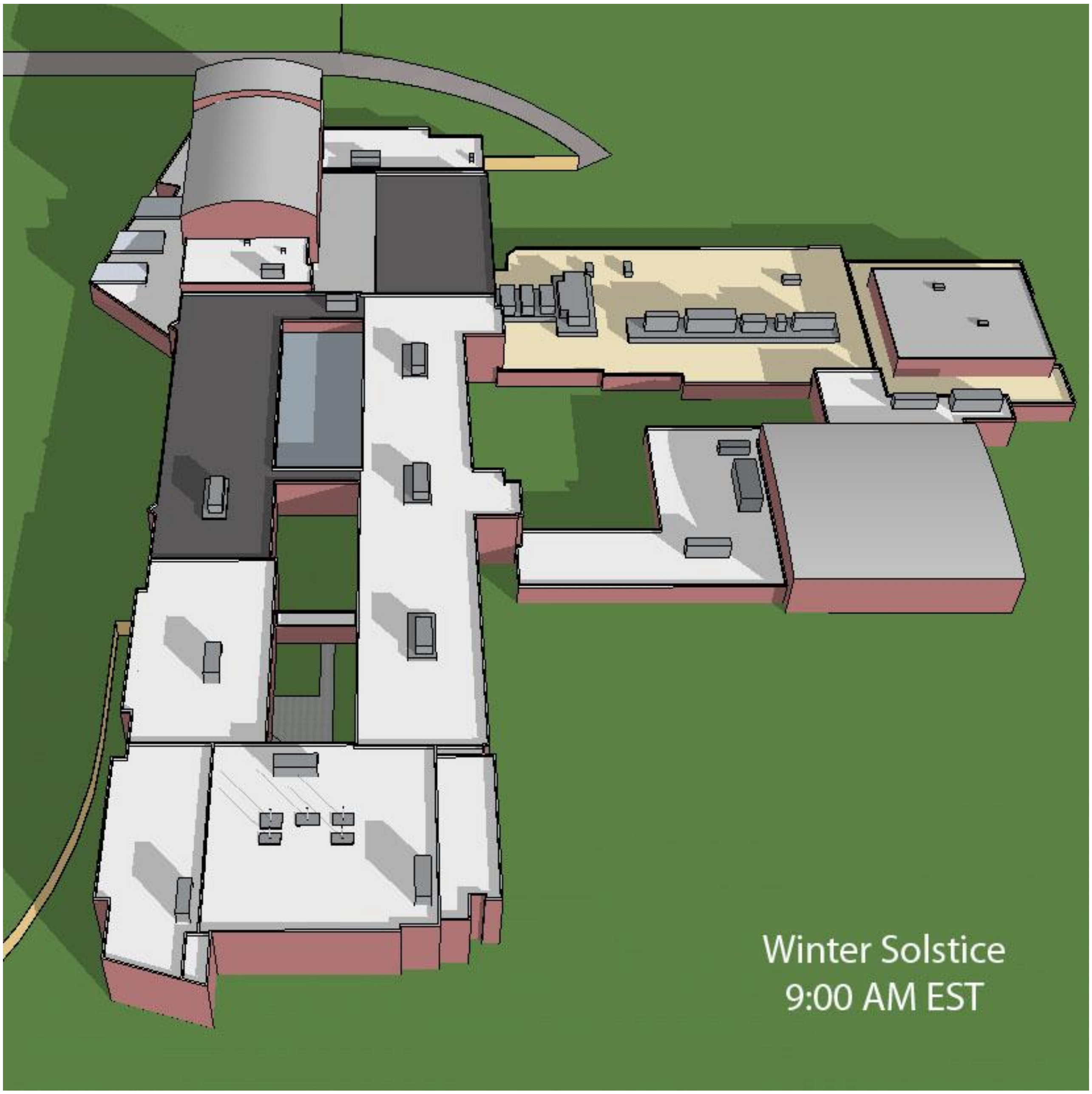

Autumnal Equinox
4:00 PM EST

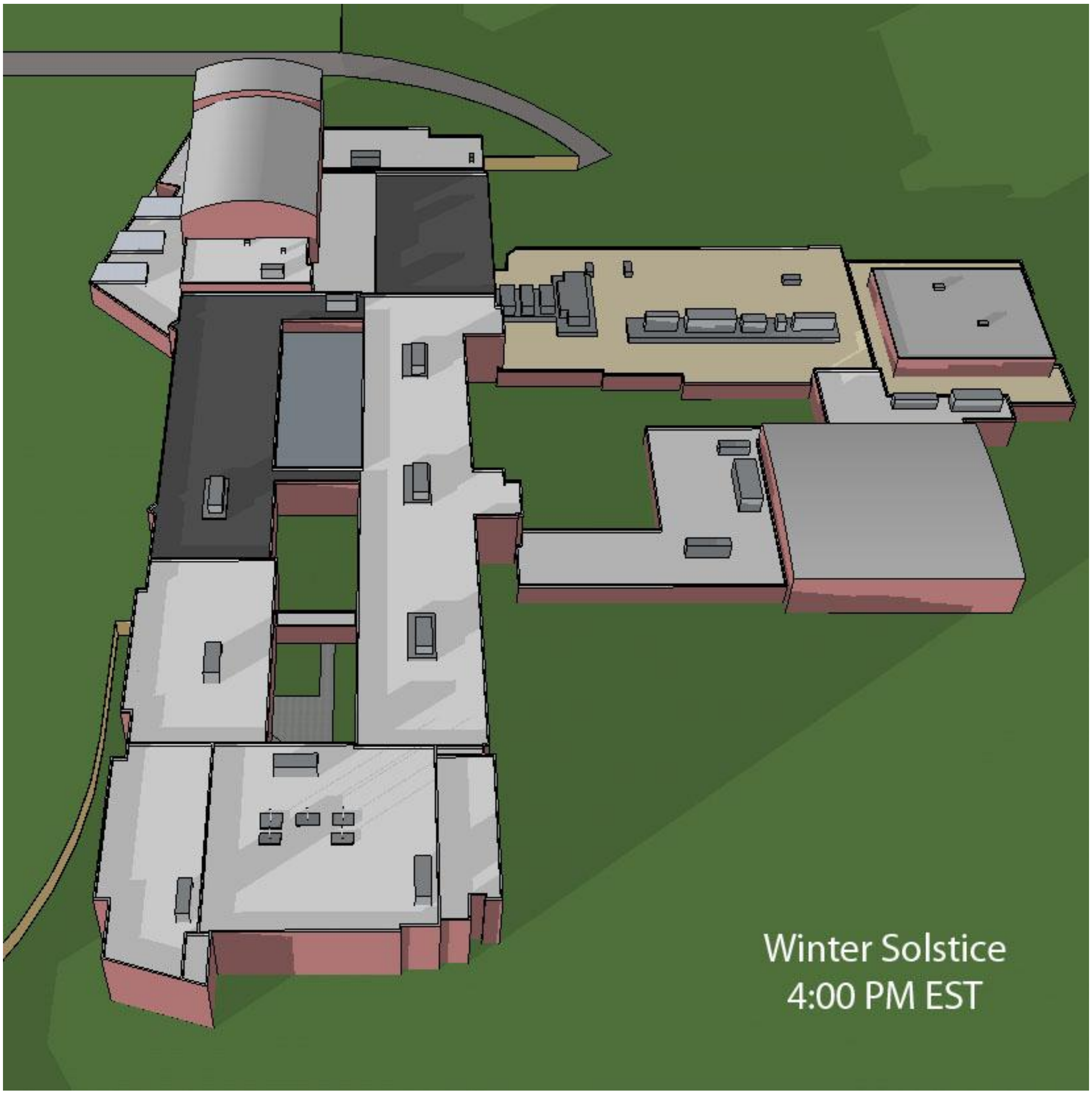

Summer Solstice
9:00 AM EST


Summer Solstice
4:00 PM EST


Vernal Equinox
9:00 AM EST


Vernal Equinox
4:00 PM EST


Winter Solstice
9:00 AM EST


Winter Solstice
4:00 PM EST

APPENDIX J – Selected Roof Regions for PV Array Installation

Potential Roof Areas for PV Array

Givens:					
N-S Spacing: 12' from front to front					
# of Rows = (Length)/(12' spacing) + 1 (front edge)					
Panel width (E-W) = 3.42ft (Note will be installed edge to edge)					

Building Area	Length (N-S) ft	Width (E-W) ft	Number of Rows in Area	Number of Panels in row	Number of Panels in Area
A1	96	86	9.00	25.15	225
B1	34	75	3.83	21.93	63
D1	40	90	4.33	26.32	104
D2	40	50	4.33	14.62	56
D3	36	52	4.00	15.20	60
E1	140	40	12.67	11.70	132
E2	36	50	4.00	14.62	56
E3	50	42	5.17	12.28	60
E4	24	40	3.00	11.70	33
F1	26	36	3.17	10.53	30
G1	90	52	8.50	15.20	120
H1	36	88	4.00	25.73	100
Total					1039

APPENDIX K – Solar Panel & Inverter Specifications

SUNPOWER

E19 / 320 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

BENEFITS

Highest Efficiency
SunPower™ Solar Panels are the most efficient photovoltaic panels on the market today.

More Power
Our panels produce more power in the same amount of space—up to 50% more than conventional designs and 100% more than thin film solar panels.

Reduced Installation Cost
More power per panel means fewer panels per install. This saves both time and money.

Reliable and Robust Design
Proven materials, tempered front glass, and a sturdy anodized frame allow panel to operate reliably in multiple mounting configurations.

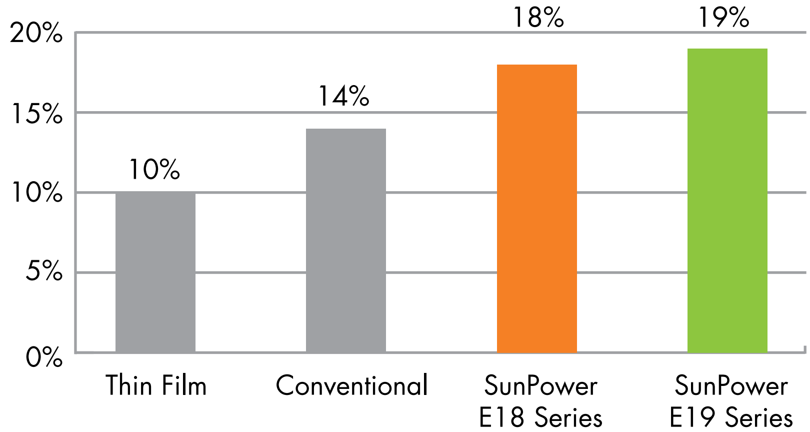
SPR-320E-WHT-D

E19 SERIES

The planet´s most powerful solar panel.

The SunPower™ 320 Solar Panel provides today's highest efficiency and performance. Utilizing 96 back-contact solar cells, the SunPower 320 delivers a total panel conversion efficiency of 19.6%. The 320 panel's reduced voltage-temperature coefficient, anti-reflective glass and exceptional low-light performance attributes provide outstanding energy delivery per peak power watt.

SunPower's High Efficiency Advantage



c UL us

E19 / 320 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

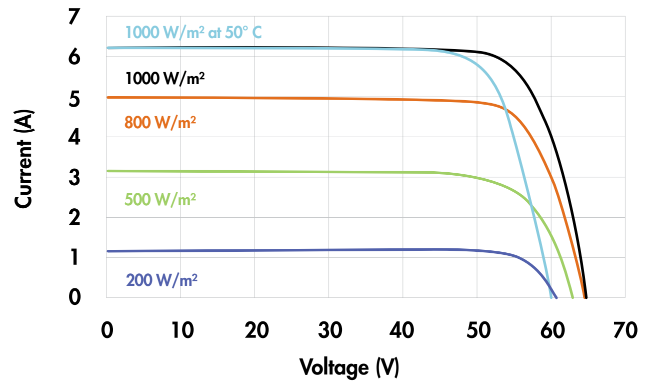
SUNPOWER™

Electrical Data

Measured at Standard Test Conditions (STC): irradiance of 1000W/m², AM 1.5, and cell temperature 25° C

Peak Power (+5/-3%)	P_{max}	320 W
Efficiency	η	19.6 %
Rated Voltage	V_{mpp}	54.7 V
Rated Current	I_{mpp}	5.86 A
Open Circuit Voltage	V_{oc}	64.8 V
Short Circuit Current	I_{sc}	6.24 A
Maximum System Voltage	UL	600 V
Temperature Coefficients	Power (P)	-0.38% / K
	Voltage (V_{oc})	-176.6mV / K
	Current (I_{sc})	3.5mA / K
NOCT		45° C +/-2° C
Series Fuse Rating		15 A

I-V Curve



Current/voltage characteristics with dependence on irradiance and module temperature.

Mechanical Data

Solar Cells	96 SunPower all-back contact monocrystalline
Front Glass	High transmission tempered glass with anti-reflective (AR) coating
Junction Box	IP-65 rated with 3 bypass diodes Dimensions: 32 x 155 x 128 (mm)
Output Cables	1000mm length cables / MultiContact (MC4) connectors
Frame	Anodized aluminum alloy type 6063 (silver); stacking pins
Weight	41.0 lbs (18.6 kg)

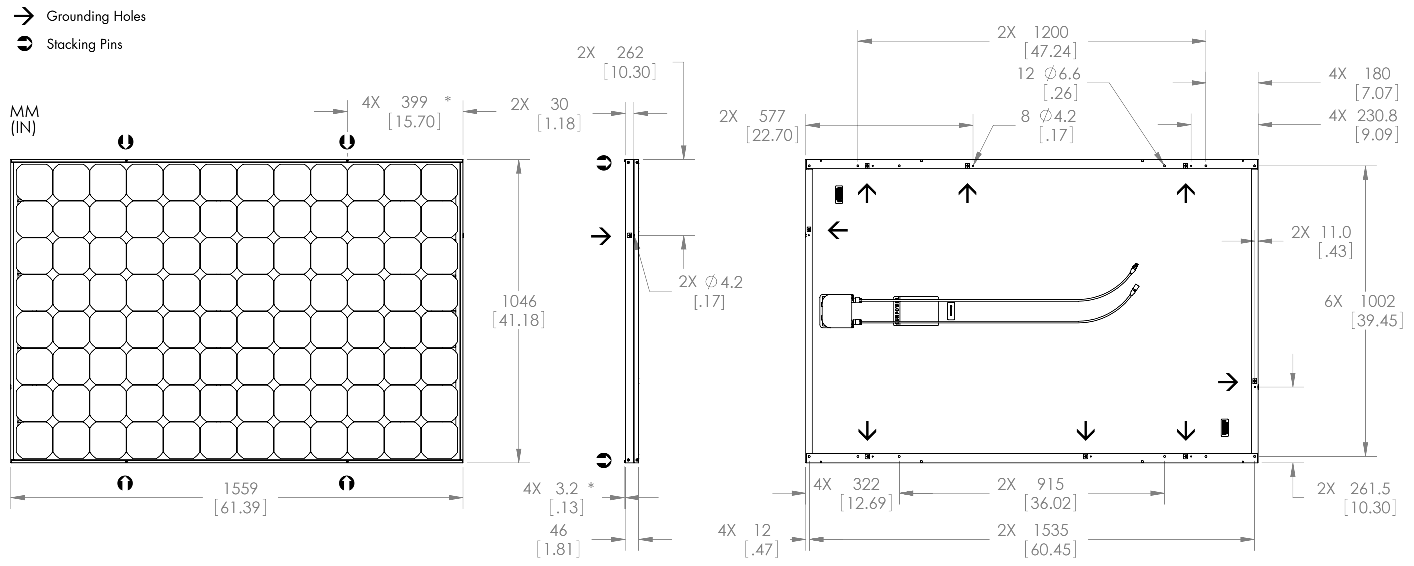
Tested Operating Conditions

Temperature	-40° F to +185° F (-40° C to + 85° C)
Max load	113psf 550 kg/m² (5400 Pa), front (e.g. snow) w / specified mounting configurations 50 psf 245 kg/m² (2400 Pa) front and back – e.g. wind
Impact Resistance	Hail 1 in (25 mm) at 51mph (23 m/s)

Warranties and Certifications

Warranties	25 year limited power warranty
	10 year limited product warranty
Certifications	Tested to UL 1703. Class C Fire Rating

Dimensions



CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Visit sunpowercorp.com for details

SUNPOWER and the SUNPOWER logo are trademarks or registered trademarks of SunPower Corporation.
© September 2010 SunPower Corporation. All rights reserved. Specifications included in this datasheet are subject to change without notice.

PowerGate Plus 375 kW UL

PVS-375-UL

Satcon PowerGate Plus PV inverters are the world's most widely deployed solutions, powering many of the largest commercial and utility-scale solar installations.

Advanced Performance

With their advanced system intelligence, next-generation EDGE® MPPT technology, and industrial-grade engineering, PowerGate® Plus inverters maximize system uptime and power production, even in cloudy conditions.

Utility-Ready Features

- Open communication protocol, compatible with virtually any third-party monitoring system and easily integrated into SCADA systems allowing fast communications
- Remote control of real and reactive power
- Low-voltage ride through
- Power factor control
- Simplified grid interconnection

EDGE MPPT

- Provides rapid and accurate control that boosts PV plant kilowatt yield
- Provides a wide range of operation across all photovoltaic cell technologies

Printed Circuit Board Durability

- Conformal coated to withstand extreme humidity and air-pollution levels

Profitable PV Power

The Satcon® PowerGate® Plus 375 kW PV inverters have a significant impact on the profitability dynamic of large-scale solar PV systems. With its system intelligence, next-generation EDGE® MPPT technology and industrial-grade engineering, the PowerGate Plus 375 kW inverters maximize system uptime and power production, even in the harshest environments.

Advanced, Rugged, and Reliable

Engineered from the ground up to meet the demands of large-scale installations, Satcon PV inverters feature an outdoor-rated enclosure, advanced monitoring and control capabilities and EDGE, Satcon's next-generation MPPT solution.

Proven Performance

The proven leader in solar PV inverter solutions for commercial installations, Satcon sets the standards for efficient large-scale power conversion.

Increased PV Plant Yield

At the heart of PowerGate Plus is EDGE, Satcon's next-generation power optimization solution. With rapid and accurate MPPT control, EDGE increases PV plant kWh yield by extending the production window of arrays, enabling them to operate at optimal voltage and current levels for longer periods of time—even in varied sun conditions. To maximize efficiency, EDGE improves the performance of all PV technologies, including fixed and tracking solar arrays, enabling you to get the most from your investment.

Satcon®

Utility-Ready Solar Inverters

PowerGate Plus 375 kW UL

Streamlined Design

With all components encased in a single, space-saving enclosure, PowerGate Plus PV inverters are easy to install, operate and maintain.

Rugged Construction

- Engineered for outdoor environments
- Wide thermal operating range: from -4° F to +122° F (-20° C to +50° C) without derating
- Solar shield attached to exterior of enclosure dissipate solar radiation, reduce heat buildup
- Dual cooling fans
- Single cabinet with small footprint

Easy Maintenance

- Modular components make service efficient
- Convenient access to all components
- Customizable large in-floor cable gland plates make installation of DC and AC cables easy
- Integrated DC two-pole disconnect switch isolates the inverter, with the exception of the GFDI (Ground Fault Detection and Interruption) circuit, from the photovoltaic power system to allow inspection and maintenance

Proven Reliability

Rugged and reliable, PowerGate Plus PV inverters are engineered from the ground up to meet the demands of large-scale installations.

Safety

- UBC seismic Zone 4 compliant
- Built-in DC and AC disconnect switches
- Protective covers over exposed power connections

Output Transformer

- Provides galvanic isolation
- Matches the output voltage of the PV inverter to the grid

PowerGate Plus 375 kW Specifications		UL/CSA
Input Parameters		
Input Voltage Range		320-600 VDC
Maximum Array Input Voltage		600 VDC
Maximum Operating Input Current[1]		1277 ADC
PV Array Configuration	Negative Ground	•
	Positive Ground	•
DC Input Combiner Options		
Combiner Bus Bar Inputs	•	24
Number of Inputs and Fuses	○ ○ ○	15 x 160A 20 x 110A 24 x 100A
Transformer		
Integrated Transformer[2]		Yes[3]
Efficiency		
Maximum[4]		96.3%
CEC		95.5%
Output Parameters		
Nominal Power		375 kW
Nominal Output Voltage		480 VAC
Output Voltage Range, [-12%/10%]		422-528 VAC
Maximum Output Current/Phase		451 A
Standby Consumptions (tare losses including control power and aux.)		124 W
Nominal Output Frequency, 3-Phase		60 Hz
Maximum Harmonic Distortion		<3% THD
Power Factor, Full Load		>99%
Dynamic Power Factor Control		+/- 0.8
Power Curtailment		0-100%, 1% steps
Environment		
Operating Temperature Range (Nominal Power)		-4° F to +122° F (-20° C to +50° C) (Opt. -40° C to +50° C)
Storage Temperature Range		-22° F to +158° F (-30° C to +70° C)
Cooling		Forced Air
Noise Level (Distance of 3 m)		<65 dB(A)
Relative Humidity (Non-Condensing)		up to 90%

Satcon®
Utility-Ready Solar Inverters

PowerGate Plus 375 kW Specifications	UL/CSA
Enclosure	
Dimensions (H x W x D)	89 x 166 x 40 in. (226 x 422 x 102 cm)
Weight[5]	5,811 lbs. (2641 kg)
Finish	RAL 7032
Protection Rating	NEMA 3R/IP44
Warranty and Services	
Five Year Warranty	•
Extended Warranty (1 and 5 year increments)	○
Preventative Maintenance Agreement	○
Uptime Guarantee[6]	○
Design Services	○
APEX Project Management	○
Communication Interface	
Modbus RS485	•
Modbus TCP/IP	○
Monitoring	
PV View Plus	○
PV Zone	○
Third-Party Compatibility	•
Regulations and Standards Conformity	
UL1741, CSA 107.1, IEEE 1547, IEEE C62.41.2, IEEE C62.45, IEEE C37.90.1, IEEE C37.90.2	•
UBC Zone 4 Seismic Rating	•

• Standard / Standard Option
○ Optional

[1] Calculated at nominal power and minimum DC voltage.
[2] The 20% boost tap on the isolation transformer increases the AC voltage output range for applications where the solar array DC operating voltage is at or near the lower end of the DC input range. This boost allows for continued inverter operation at lower DC voltage input levels.
[3] Inverter and transformer are connected via a 12" throat. See product manual for details.
[4] Calculated with auxiliary power.
[5] Dependent on options selected.
[6] Requires Preventative Maintenance Agreement.

NOTE: All specifications are subject to change.

Output Options

PowerGate Plus 375 kW	
UL/CSA	480 VAC Output

Power Efficiency

Power Level	Efficiency*
10%	92.6%
20%	95.4%
30%	96.0%
50%	96.3%
75%	96.2%
100%	95.8%

* 480V model

Energy Equity Protection (EEP)

Satcon provides a wide range of optional value-added services to protect your investment across the entire lifecycle of your project.

Design Services

Satcon's Design Services organization can guide you through all phases of project development using our broad experience and engineering skills.

APEX Project Management

Satcon APEX™ Project Management ensure that your project comes in on time and on budget.

- Project planning
- Logistics
- Project supervision
- Mitigating risk, maximizing ROI

Warranty and Services

- Help desk
- Training programs
- Support services
- Extended warranty
- Preventative maintenance plans
- 99% Uptime Guarantee

PowerGate Plus Options

- Satcon Smart Subcombiners: Intelligent string monitoring
- Fused input combiners
- Satcon communication card: CCM Gateway
- Weather station
- PV View Plus monitoring system
- PV Zone

www.Satcon.com

Please visit Satcon's Resource Library for additional tools and product information, including:

- Satcon's product configurator
- Satcon's string sizing calculator
- Training and support resources:
  - On-demand video training
  - Articles, white papers and case studies

Satcon®
Utility-Ready Solar Inverters

Satcon Corporate
25 Drydock Avenue, 7th Floor
Boston, MA 02210
USA
P: +1.617.910.5500
F: +1.617.910.5501
E: sales@satcon.com

Satcon West
46441 Landing Parkway
Fremont, CA 94538
USA
P: +1.510.897.4900
F: +1.510.897.4901
E: sales@satcon.com

Satcon Canada
835 Harrington Court
Burlington, ON L7N 3P3
Canada
P: +1.905.639.4692
F: +1.905.639.0961
E: sales@satcon.com

Satcon Germany
An der Welle 4
60322 Frankfurt Main
Germany
P: +49 (0)69 7593 - 8620
F: +49 (0)69 7593 - 8200
E: sales.eu@satcon.com

Satcon International s.r.o.
Jankovcova 1037/49
170 00 Praha 7
Czech Republic
P: +420.255.729.610
F: +420.255.729.611
E: sales.eu@satcon.com

Satcon Greece
1A Iraklitou St.
Patima Halandriou – 152 38
Greece
P: +30.210.6654424
F: +30.210.6654425
E: sales.gr@satcon.com

Satcon Shenzhen China
Unit C101-C102, Tower C,
Unisplendour Info. Harbor,
Langshan Road, Nanshan Dist.
Shenzhen 518057, China
P: +86.755.6168.2588
F: +86.755.6168.2599
E: sales@satcon.com

Satcon Shanghai China
Unit 2902-3, Tower A,
City Center of Shanghai,
100 Zun Yi Road,
Shanghai 200051, China
P: +86.21.6236.8236
F: +86.21.6236.8240
E: sales@satcon.com

www.Satcon.com

Satcon®

Utility-Ready Solar Inverters

© 2012 Satcon Technology Corporation. All rights reserved. Satcon is a registered trademark of Satcon Technology Corporation.
All other trademarks are the property of their respective owners. PGP375ULNAEWR010912MS

APPENDIX L – PV Watts Data Output

PVWatts

AC Energy & Cost Savings

Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 80 characters.)

Station Identification	
City:	Philadelphia
State:	Pennsylvania
Latitude:	39.88° N
Longitude:	75.25° W
Elevation:	9 m
PV System Specifications	
DC Rating:	332.8 kW
DC to AC Derate Factor:	0.770
AC Rating:	256.3 kW
Array Type:	Fixed Tilt
Array Tilt:	40.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	9.6 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.31	26975	2589.60
2	4.16	30678	2945.09
3	4.74	36969	3549.02
4	5.06	37039	3555.74
5	5.19	37880	3636.48
6	5.42	37116	3563.14
7	5.51	38421	3688.42
8	5.67	39856	3826.18
9	5.07	35336	3392.26
10	4.59	34548	3316.61
11	3.37	25392	2437.63
12	2.67	21096	2025.22
Year	4.56	401307	38525.47

Output Hourly Performance Data

Output Results as Text

About the Hourly Performance Data

Saving Text from a Browser

Run PVWATTS v.1 for another US location or an International location
Run PVWATTS v.2 (US only)

APPENDIX M – UHS Electricity Cost Savings

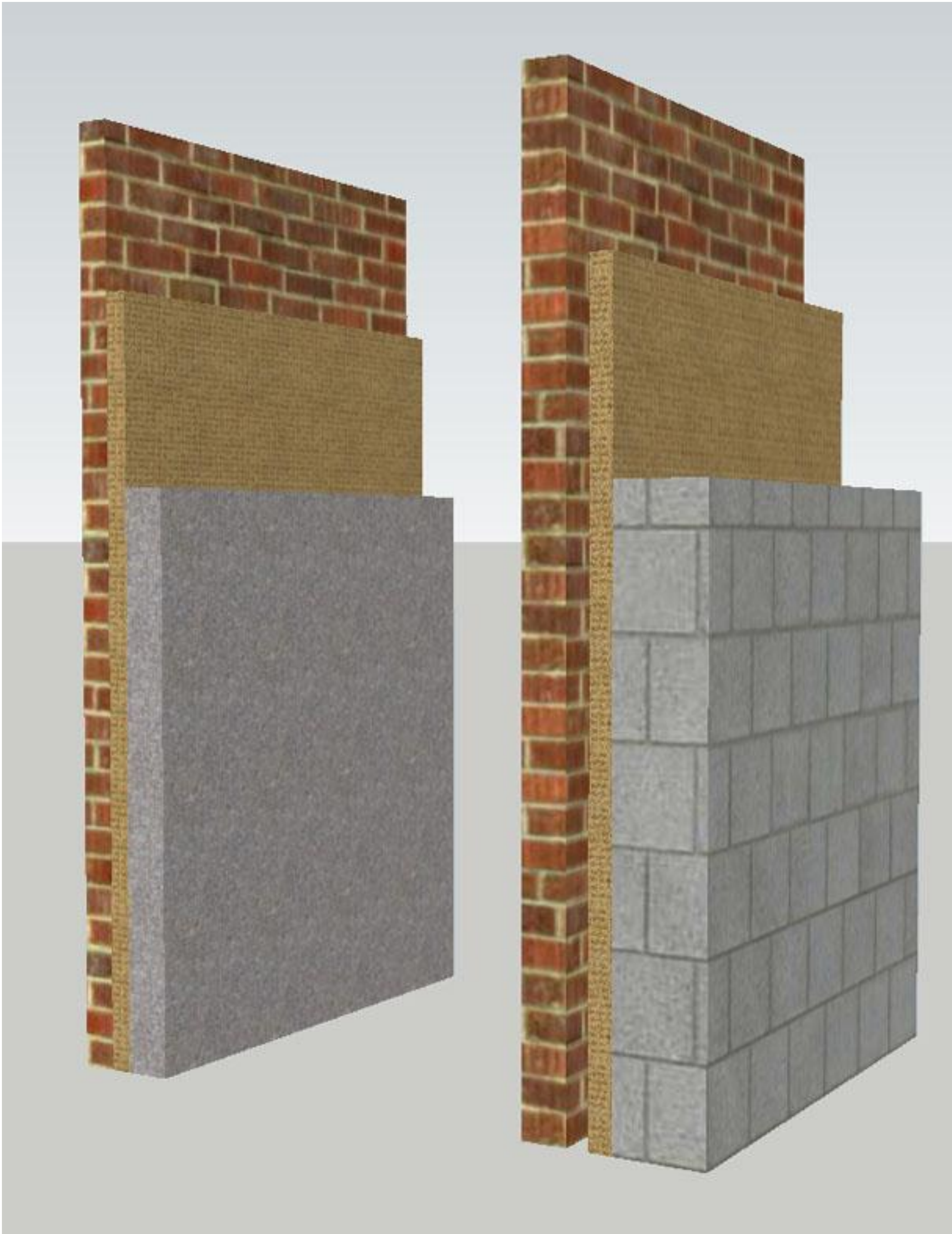
Year	Discounted Energy Price		Savings (Standard less PV electricty)	
1	$	24,271.05	$	14,254.42
2	$	24,513.76	$	14,396.97
3	$	24,758.90	$	14,540.94
4	$	25,006.48	$	14,686.35
5	$	25,256.55	$	14,833.21
6	$	25,509.11	$	14,981.54
7	$	25,764.21	$	15,131.36
8	$	26,021.85	$	15,282.67
9	$	26,282.07	$	15,435.50
10	$	26,544.89	$	15,589.85
11	$	26,810.34	$	15,745.75
12	$	27,078.44	$	15,903.21
13	$	27,349.22	$	16,062.24
14	$	27,622.72	$	16,222.86
15	$	27,898.94	$	16,385.09
16	$	28,177.93	$	16,548.94
17	$	28,459.71	$	16,714.43
18	$	28,744.31	$	16,881.58
19	$	29,031.75	$	17,050.39
20	$	29,322.07	$	17,220.90
21	$	29,615.29	$	17,393.11
22	$	29,911.44	$	17,567.04
23	$	30,210.56	$	17,742.71
24	$	30,512.66	$	17,920.14
25	$	30,817.79	$	18,099.34
Life of contract: 25 years				
Total Savings:			**$**	**402,590.56**

APPENDIX N – UHS Payback Period

UHS Payback Period		
1	0.0960	$ 38,525.47
2	0.0970	$ 38,910.73
3	0.0979	$ 39,299.83
4	0.0989	$ 39,692.83
5	0.0999	$ 40,089.76
6	0.1009	$ 40,490.66
7	0.1019	$ 40,895.56
8	0.1029	$ 41,304.52
9	0.1040	$ 41,717.57
10	0.1050	$ 42,134.74
11	0.1060	$ 42,556.09
12	0.1071	$ 42,981.65
13	0.1082	$ 43,411.47
14	0.1093	$ 43,845.58
15	0.1103	$ 44,284.04
16	0.1115	$ 44,726.88
17	0.1126	$ 45,174.15
18	0.1137	$ 45,625.89
19	0.1148	$ 46,082.15
20	0.1160	$ 46,542.97
21	0.1171	$ 47,008.40
22	0.1183	$ 47,478.48
23	0.1195	$ 47,953.27
24	0.1207	$ 48,432.80
25	0.1219	$ 48,917.13
26	0.1231	$ 49,406.30
27	0.1243	$ 49,900.36
28	0.1256	$ 50,399.36
29	0.1268	$ 50,903.36
30	0.1281	$ 51,412.39
31	0.1294	$ 51,926.52
32	0.1307	$ 52,445.78
33	0.1320	$ 52,970.24
34	0.1333	$ 53,499.94
35	0.1346	$ 54,034.94
36	0.1360	$ 54,575.29
37	0.1374	$ 55,121.04
38	0.1387	$ 55,672.25
39	0.1401	$ 56,228.98
40	0.1415	$ 56,791.27
	Total Value	**$ 1,883,370.61**

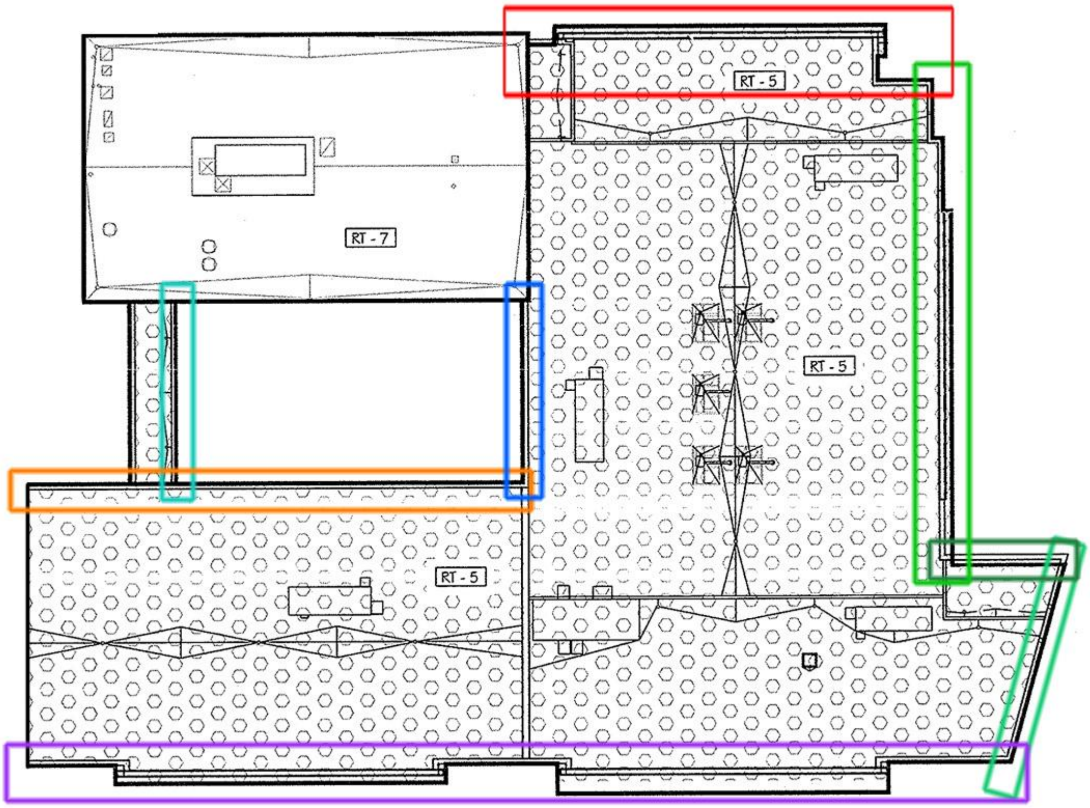
Total System Cost:	$ 1,863,680.00
40 year payback period for UHS	

APPENDIX O – Façade Assembly Comparison



APPENDIX P – Precast Panel Calculations and Information

Panel Type Information		
#	Panel Type	Size
1	A	12' X 13.5'
2	B	8' x 13.5'
3	C	12' X 28.5'
4	D	8' x 28.5'
5	E	6' x 13.5'
6	F	12' x 13.5'
7	G	12' x 13.5'
8	H	6' x 28.5'
9	I	12' x 28.5'
10	J	12' x 13.5'
11	K	12' x 28.5'
12	L	12' x 13.5'
13	M	12' x 13.5'
14	N	12' x 28.5'
15	O	12' x 28.5'
16	P	12 x 28.5'
17	Q	12' x 13.5'
18	R	12' x 28.5'
19	S	12' x 28.5'
20	T	12' x 13.5'
21	U	12' X 28.5'
22	V	12' X 28.5'
23	W	12' X 28.5'
24	X	12' X 28.5'
25	Y	12' X 28.5'
26	Z	12' X 28.5'
27	AA	10' X 28.5'
28	BB	10' X 13.5'
29	CC	12' X 13.5'
30	DD	12' X 13.5'
31	EE	12' X 13.5'
32	FF	12' X 13.5'
33	GG	12' X 28.5'
34	HH	12' X 13.5'
35	II	10' X 13.5'
36	JJ	12' x 13.5'
37	KK	12' x 13.5'



New Classroom Wing East Elevation

New Classroom Wing South Side (Elevation 3)

New Classroom Wing South Side (Elevation 2)

New Classroom Wing South Side (Elevation 4)

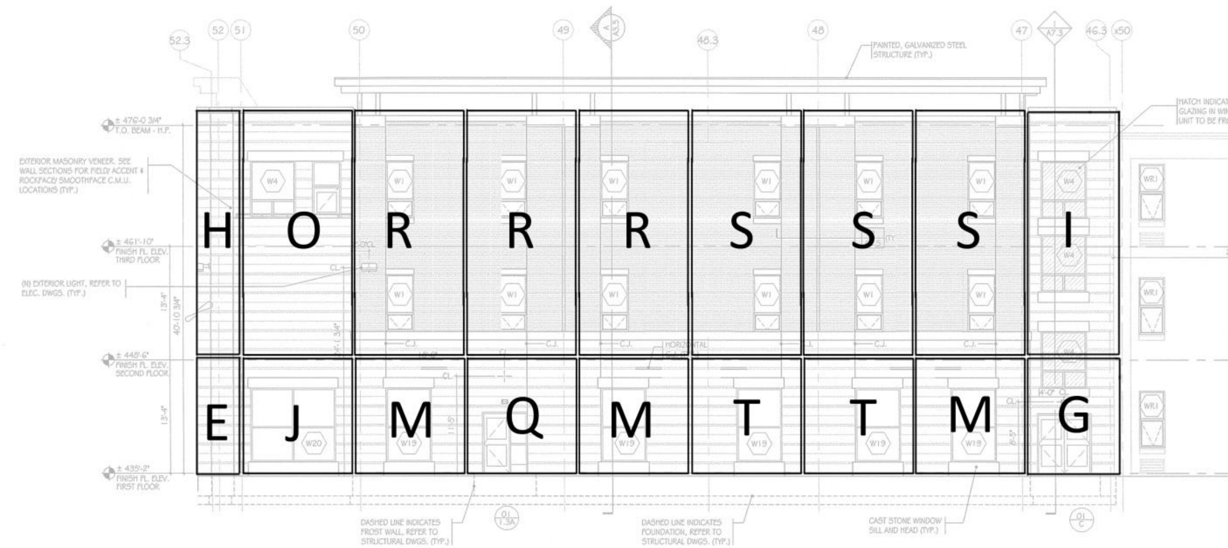
New Classroom Wing West Side

New Classroom Courtyard West Side (East Elevation)

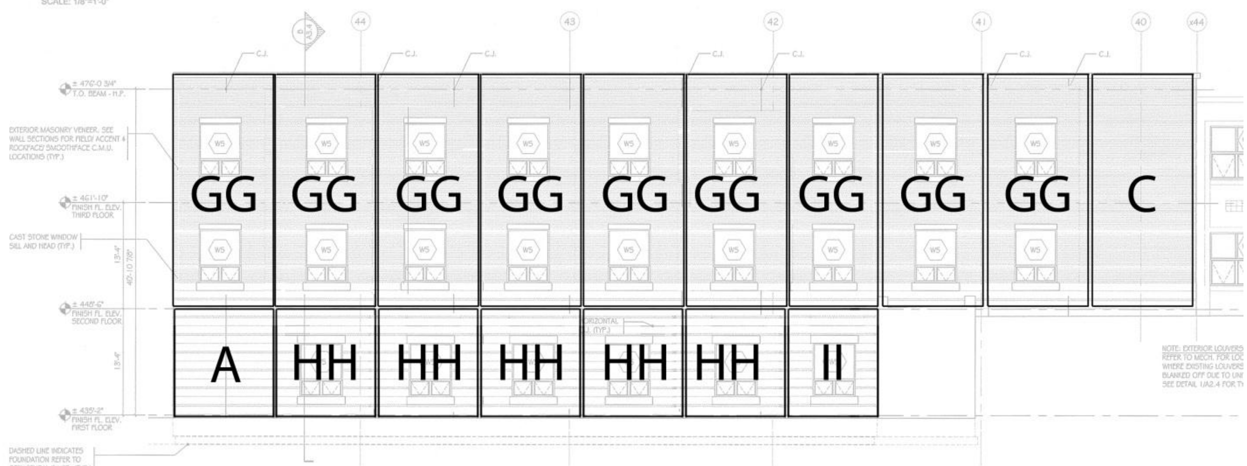
New Classroom Courtyard North Side

Classroom Courtyard South Side

East Elevation



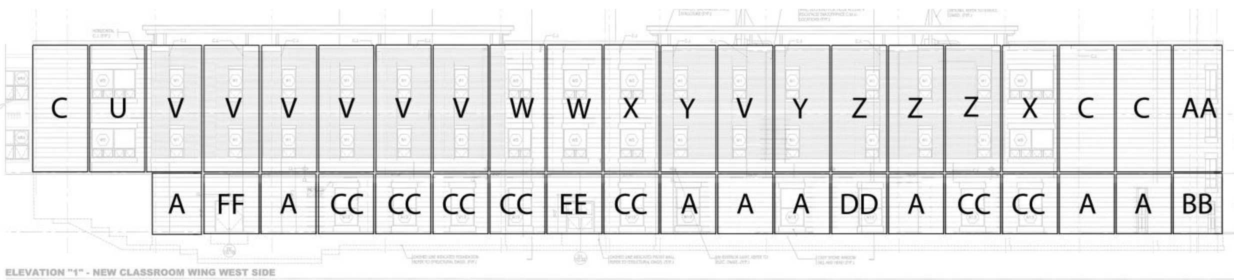
ELEVATION "1" - NEW CLASSROOM WING EAST ELEVATION



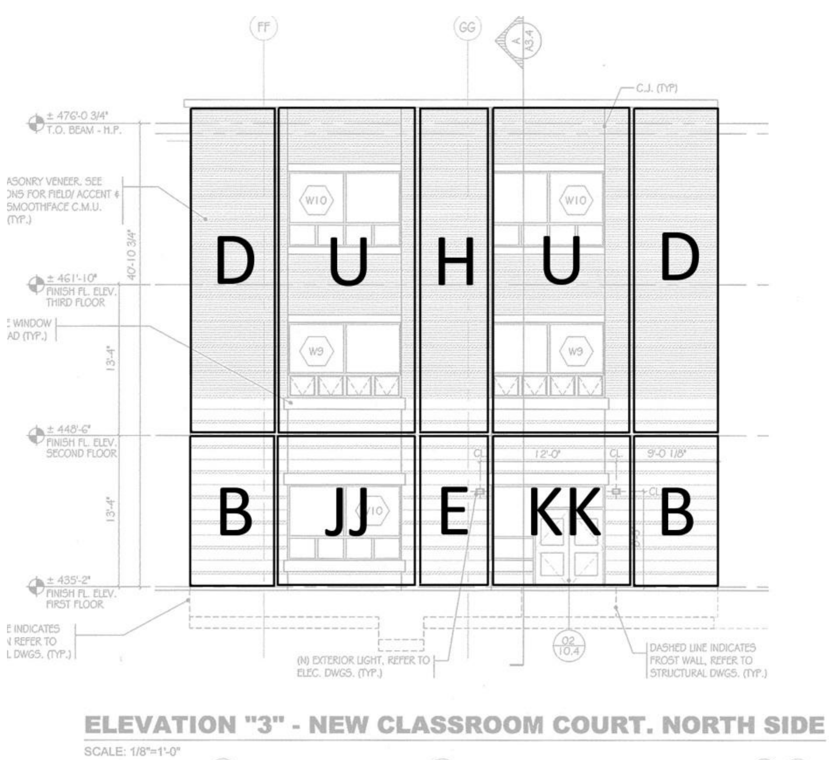
ELEVATION "4" - NEW CLASSROOM COURTYARD WEST SIDE

SCALE: 1/8"=1'-0"

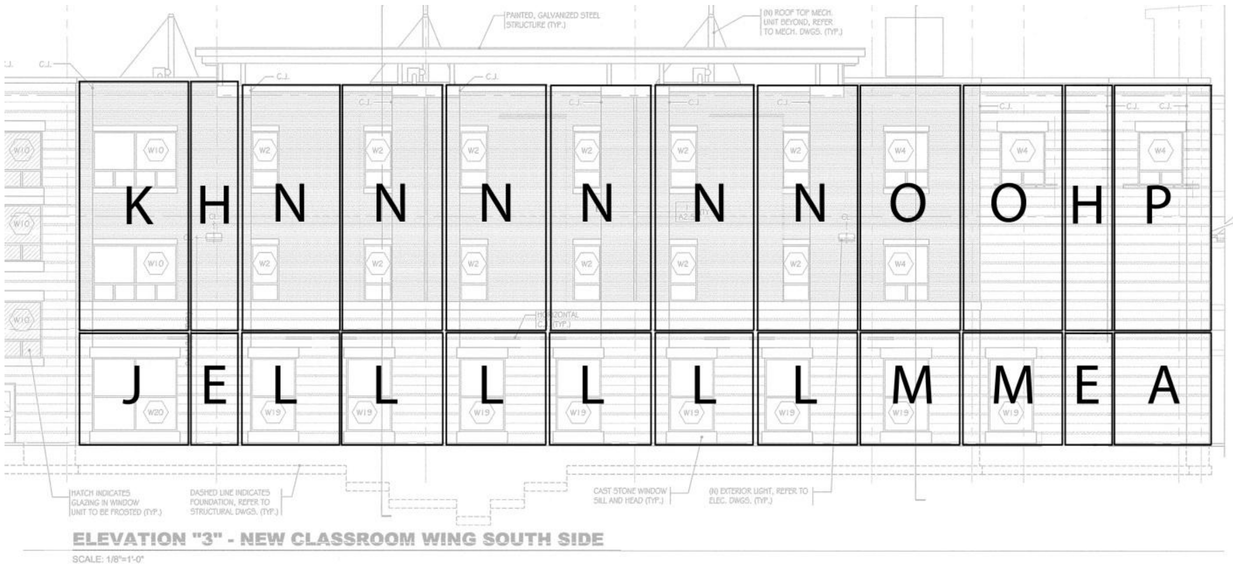
West Elevation

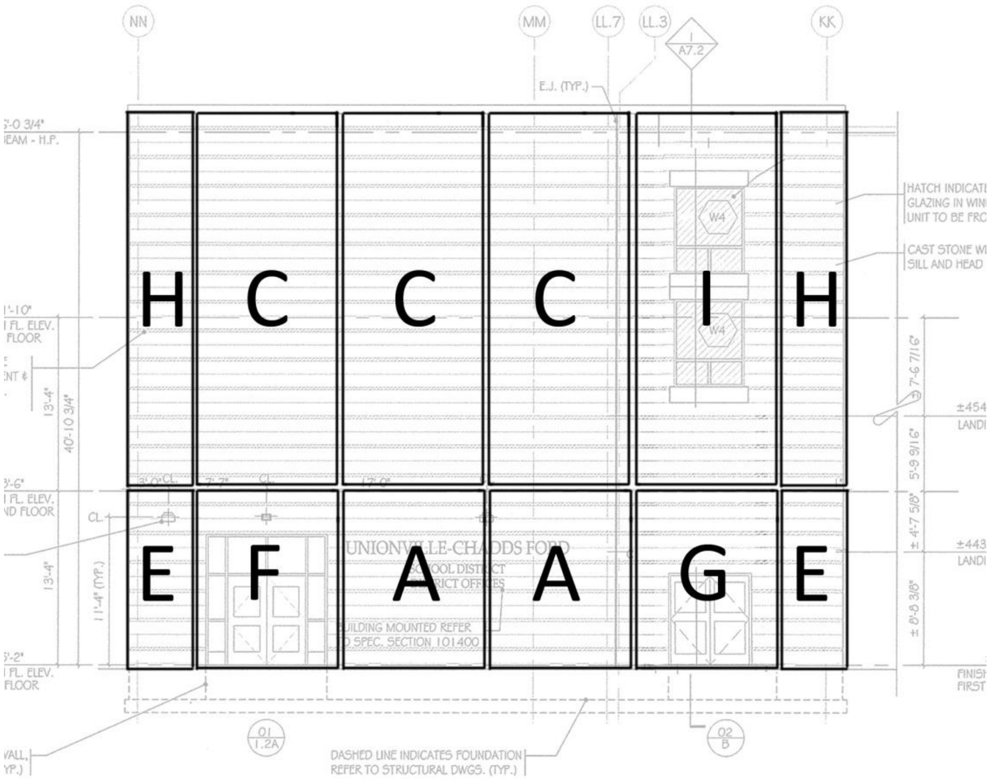


North Elevation



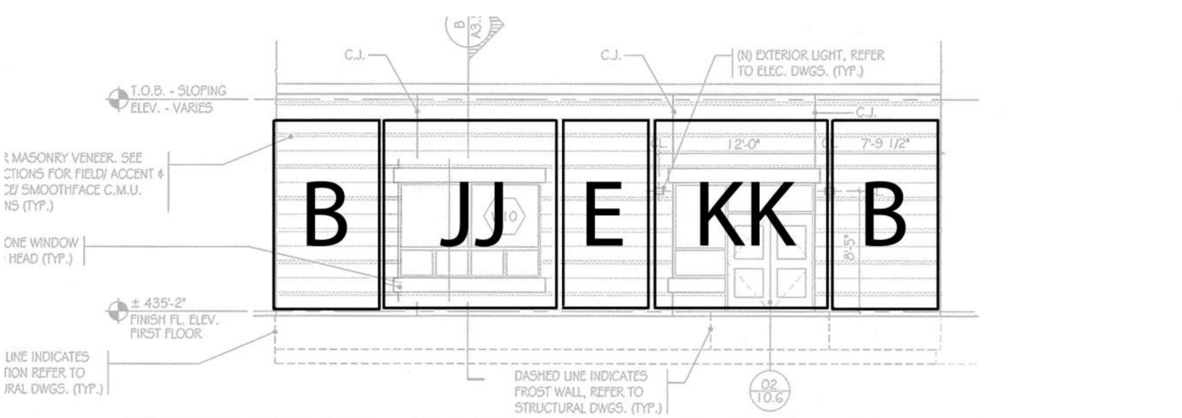
South Elevation





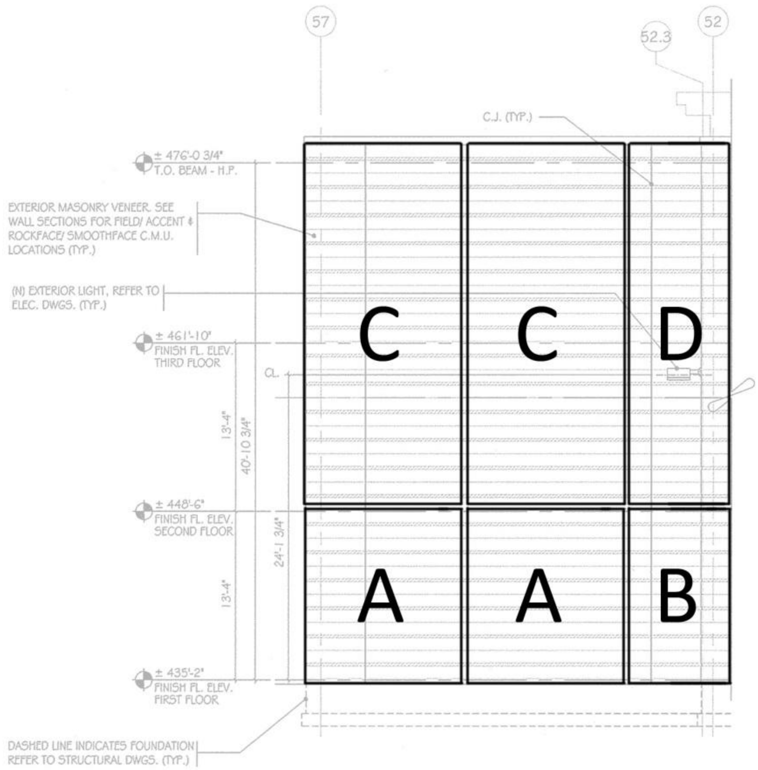
ELEVATION "4" - NEW CLASSROOM WING SOUTH SIDE

SCALE: 1/8"=1'-0"



ELEVATION "6" - CLASSROOM COURTYARD SOUTH SIDE

SCALE: 1/8"=1'-0"

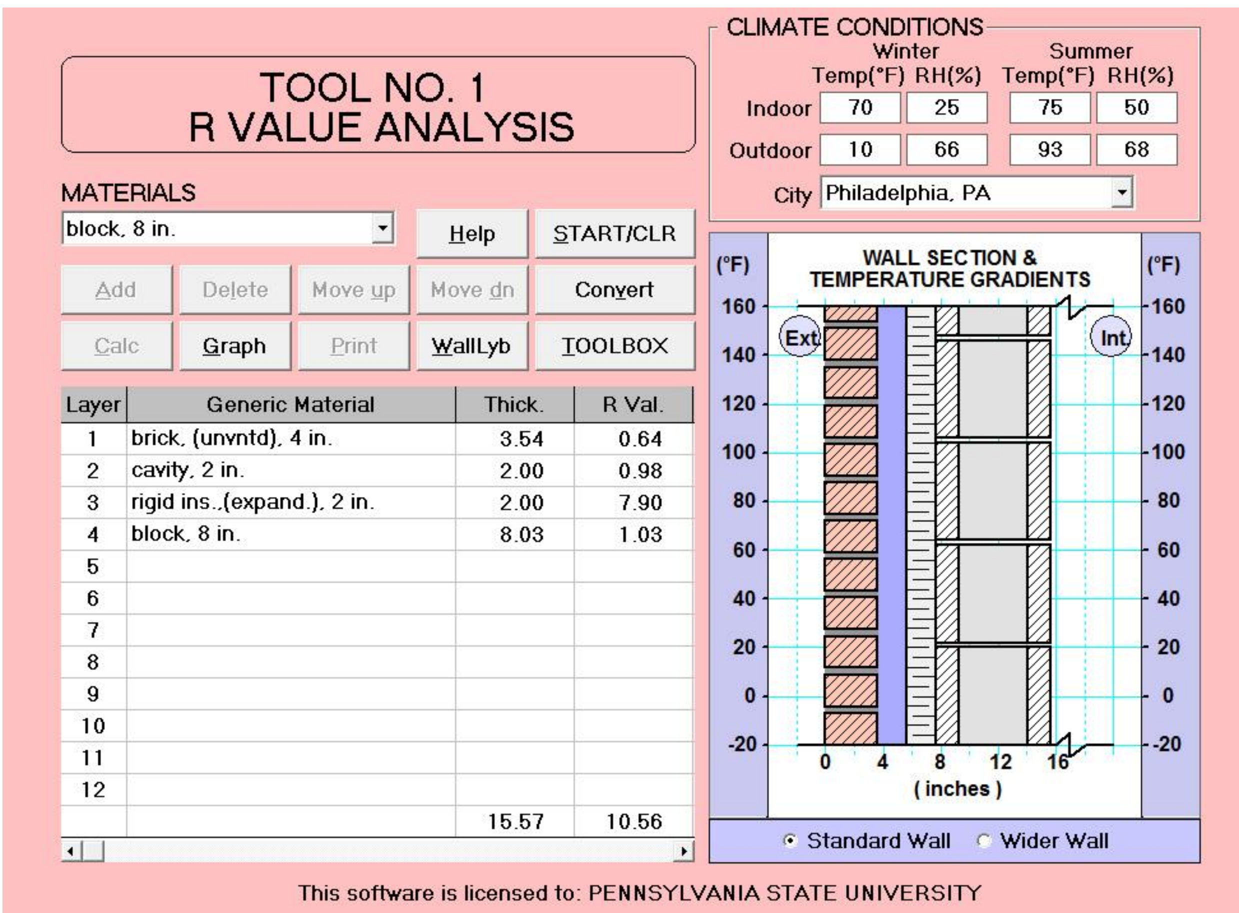


ELEVATION "2" - NEW CLASSROOM WING SOUTH SIDE

SCALE: 1/8"=1'-0"

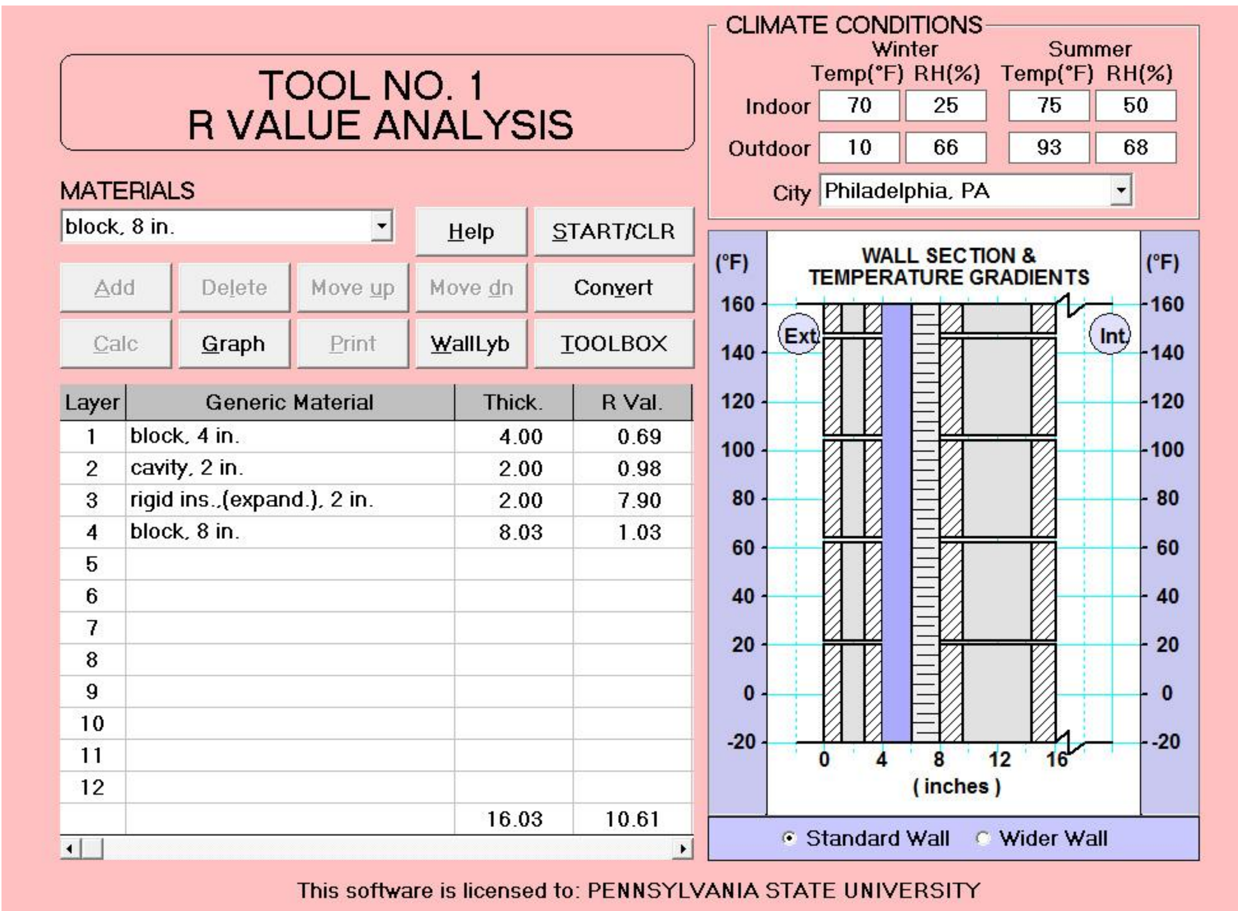
APPENDIX Q – HAM Toolbox Original Façade Analysis

Brick Veneer



Layer	Generic Material	Thick.	R Val.
1	brick, (unvntd), 4 in.	3.54	0.64
2	cavity, 2 in.	2.00	0.98
3	rigid ins.,(expand.), 2 in.	2.00	7.90
4	block, 8 in.	8.03	1.03
5			
6			
7			
8			
9			
10			
11			
12			
		15.57	10.56

Rock Face CMU Veneer

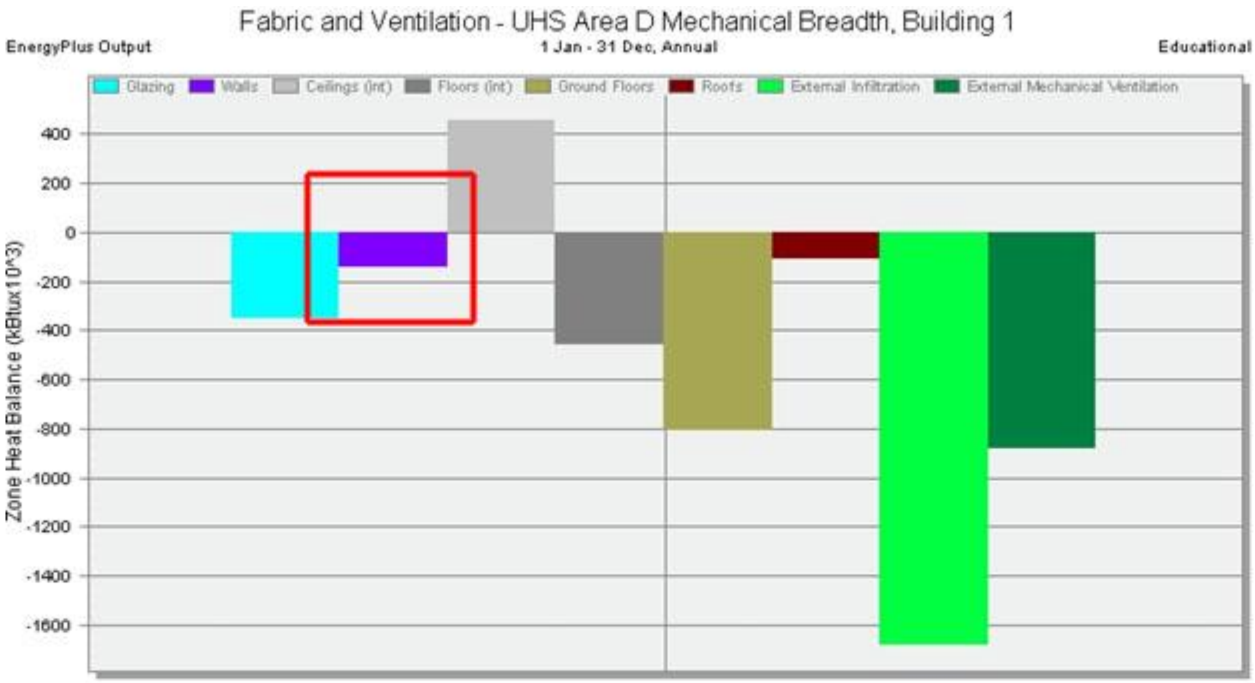


Layer	Generic Material	Thick.	R Val.
1	block, 4 in.	4.00	0.69
2	cavity, 2 in.	2.00	0.98
3	rigid ins.,(expand.), 2 in.	2.00	7.90
4	block, 8 in.	8.03	1.03
5			
6			
7			
8			
9			
10			
11			
12			
		16.03	10.61

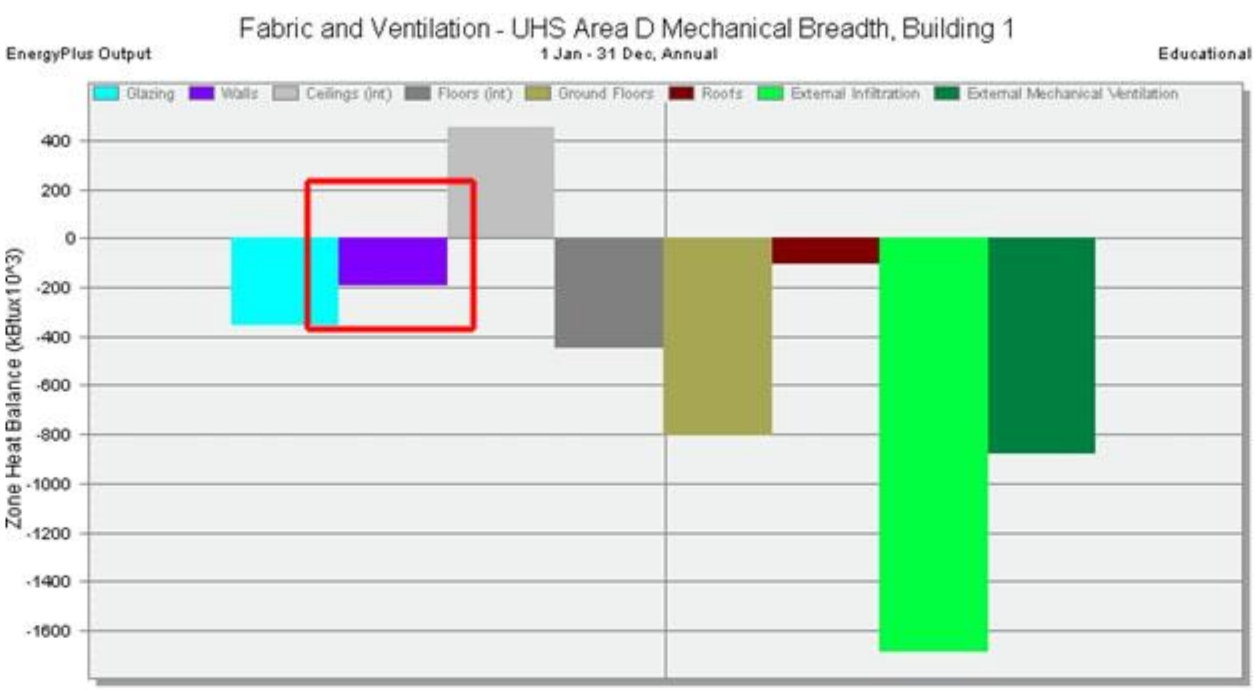
APPENDIX R – DesignBuilder Analysis Outputs

Annual Heat Loss

Original Façade

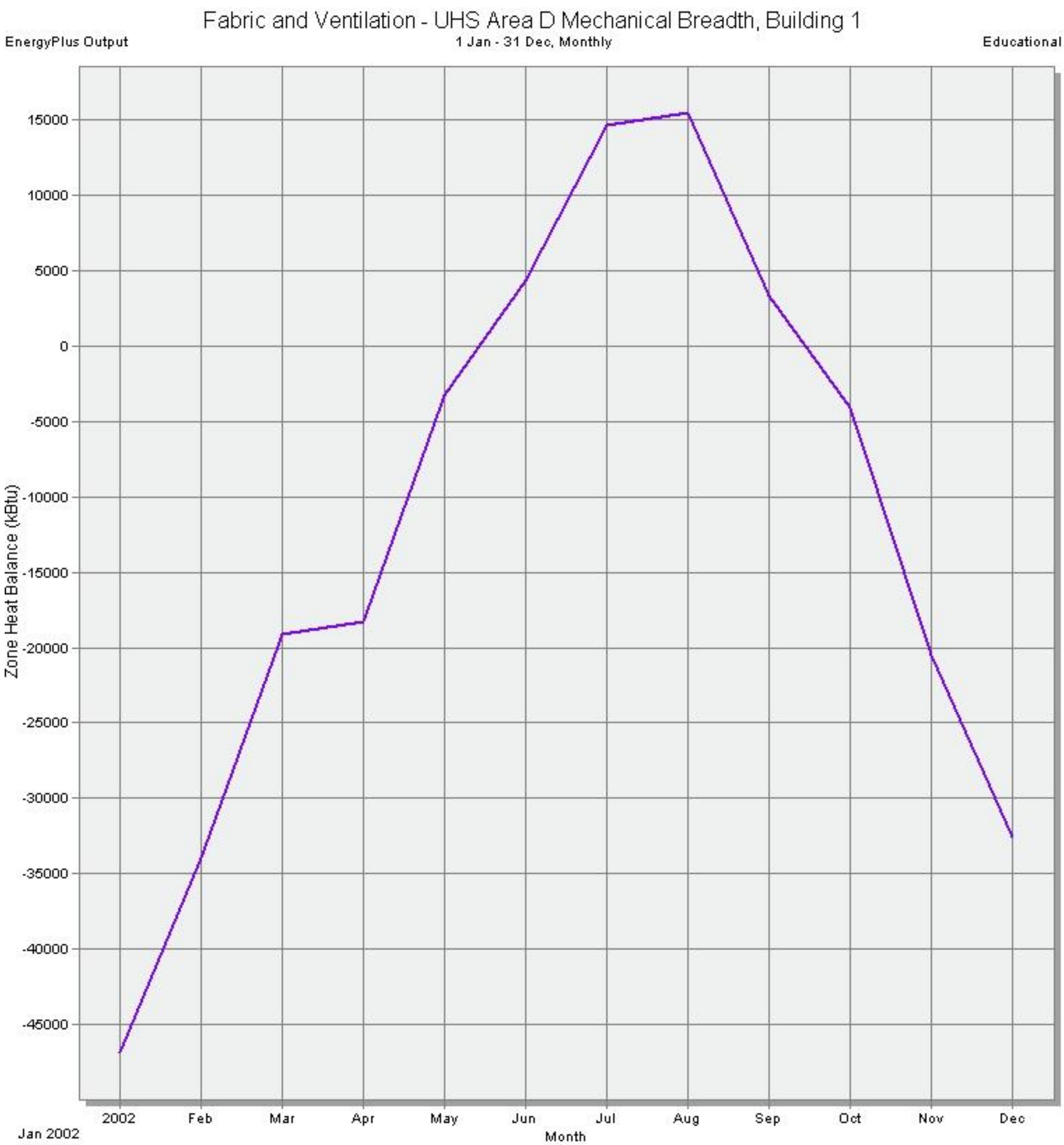


Proposed Precast Panel Façade

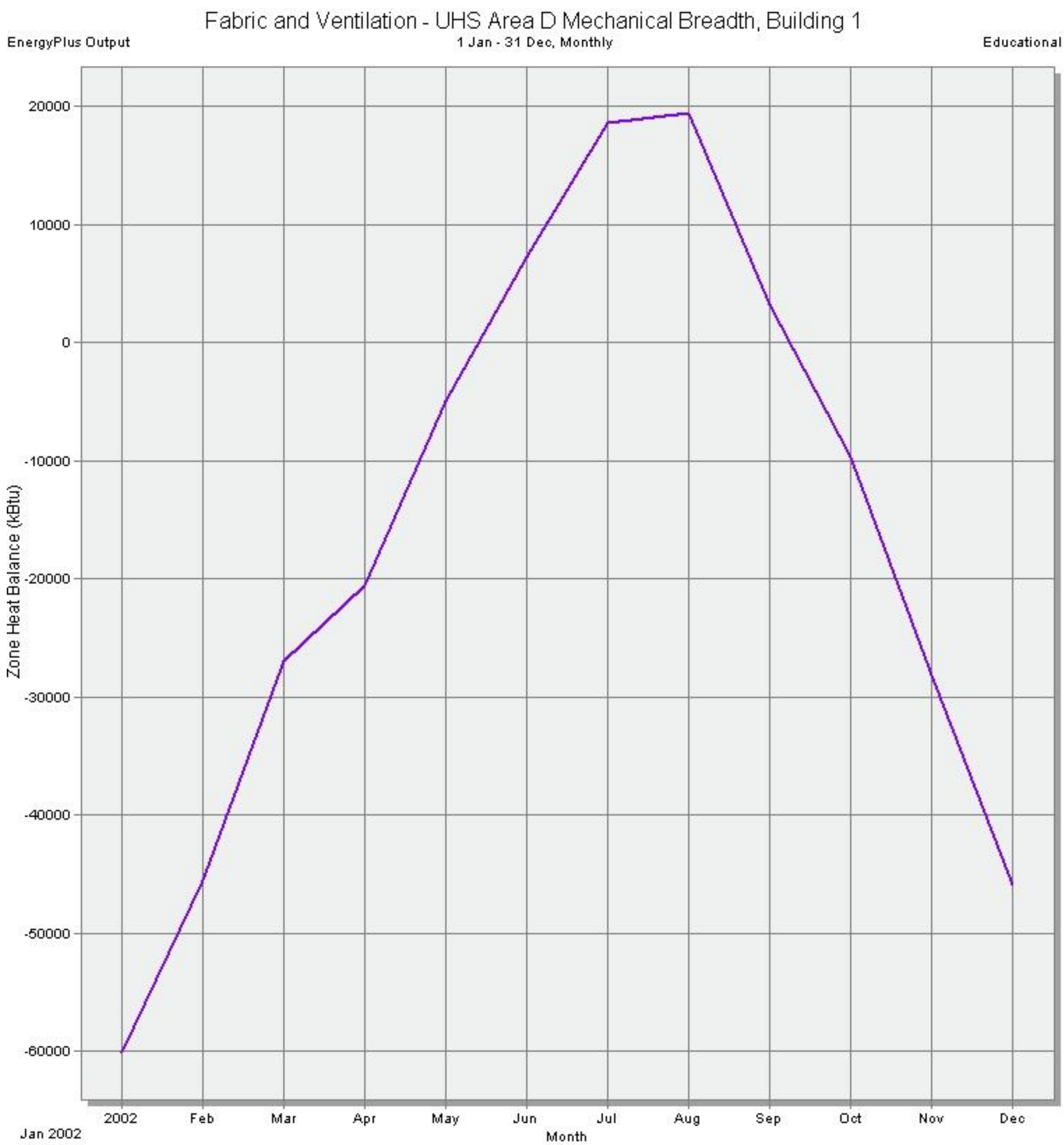


Monthly Heat Loss

Original Façade



Proposed Precast Panel Façade



APPENDIX S - Structural Breadth Calculations

1 Michael Beam | Structural Breadth | Original Facade

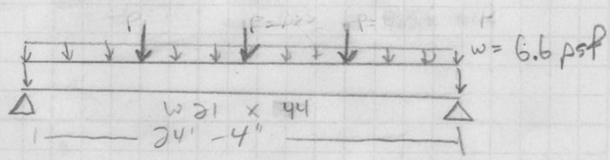
Existing Loads DL: 15 psf Super imposed
45 psf Slab self weight
5 psf Self weight allowance
55 psf CMU weight

LL: 40 psf Class room
20 psf partitions

Note: Assume no LL reductions

Beam btwn col. BB and Col CC @ col line 5)

Tributary width = 8'-4" + 8" = 9'-0"



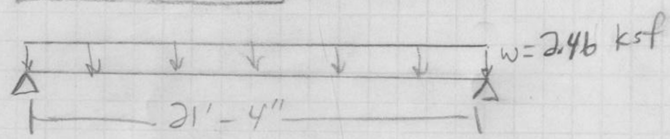
$W_{DL+LL} = 1.2[(15+45+5)(9')] + 1.6(40+20)(9') = \boxed{1.57 \text{ klf}}$

$W_{CMU\ wall} = (55 \text{ psf})(13.5')(1) = \boxed{.89 \text{ klf}}$ (wall ht)

- Simplified to all distributed loads

$W_{TOT} = 1.57 + .89$

$\boxed{w = 2.46 \text{ klf}}$



moments

$M_u = \frac{wL^2}{8} \rightarrow M_u = \frac{(2.46)(24.33')^2}{8} \rightarrow \boxed{M_u = 182.02 \text{ k-ft}}$

- Assume unbraced length = 6.1'

ϕM_n @ 6.1' ubl = 331 kip-ft
↳ from Steel Manual Table 3.10

$M_u < \phi M_n$
$182.02 < 331$
ok ✓

2 | Michael Beam | Structural Breadth Original Facade

Deflections

Total Load $\Delta = \frac{5wl^4}{384EI} = \frac{5(1.63)(24.33)^4(1728)}{384(29000)(843\ in^4)}$ $I = 843\ in^4$

$\Delta = .53$ in @ beam's center

$\Delta \leq L/240 \rightarrow .53 \leq (12.33' \cdot 12")/240 \rightarrow .53 \leq 1.2$ ok ✓

Live Load: $w = (20 + 40)\ psf \cdot 9' = .54\ kip/ft$

$$\Delta_{LL} = \frac{5(.54)(24.33)^4(1728)}{384(29000)(843)} \rightarrow \Delta_{LL} = .17"$$

$\Delta_{LL} \leq L/360 \rightarrow .17" \leq \frac{(24.33)(12")}{360} \rightarrow .17" \leq .81"$ ok ✓

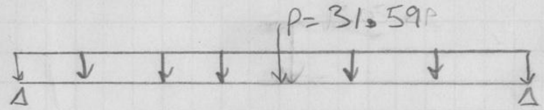
3 | Michael Beam | Structural Breadth | Precast Facade

Precast Facade Loads

DL: 15 psf — super imposed
45 psf — slab self weight
5 psf — self weight allowance
88 psf — panel self weight

LL: 40 psf — classroom
20 psf — partitions

NOTE: Assume no LL reductions



New total load

$w = 1.2[(15 + 45 + 5)9'] + 1.6[(20+40)9']$

$\boxed{w = 1.57 \text{ klf}}$

$P = (88\text{psf} \cdot \frac{28.5' + 24.33'}{2}) = \boxed{30.51 \text{ kip}}$

moments

distributed $M_u = \frac{1.57\text{klf}(24.33^2)}{8} \rightarrow M_u = 116.17$ k-ft

point load $= \frac{30.51(24.33)}{4} = 185.58$ k-ft

Total $M_u = \boxed{301.75 \text{ k-ft}}$

$M_u < \phi M_n$
$301.75 < 331$ ok ✓

Deflections

Total load $= \frac{5wl^4}{384EI} + \frac{Pl^3}{48EI}$

$\frac{5(1.57)(24.33)^4(1728)}{384(29000)(843)} + \frac{(30.51)(24.33)^3(1728)}{48(29000)(843)} \rightarrow \Delta_{TOTAL} = .506" + .647 \rightarrow$

$\Delta_{TOT} = 1.15"$

$\Delta \leq 1.2" \rightarrow 1.15" \leq 1.2"$ ok ✓

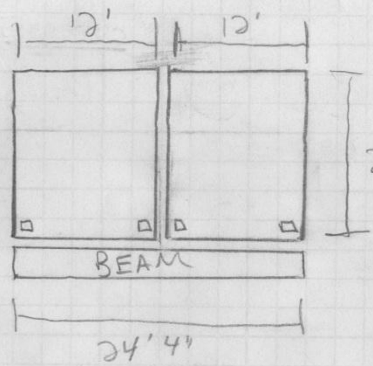
Δ_{LL} = same as original → ok ✓

$M_{u\,orig}$ vs. $M_{u\,new} \rightarrow 182.02$ vs. $301.75 \rightarrow \approx \boxed{60\% \ M_u \text{ increase}}$

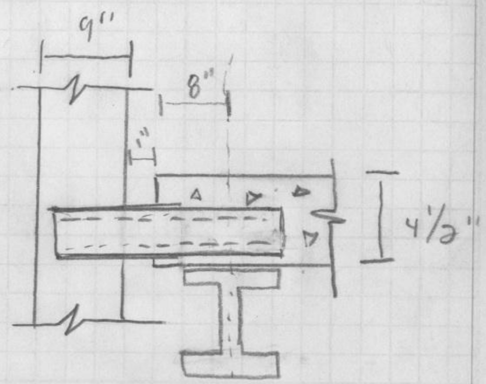
→ Result → 21X44 Beam is still sufficient

4 Michael Beam | Structural Breadth Tube Support

Tube Support Design



Elevation



Section

$M_u = P_u e = 15\,k\,(13.5'/12'/ft) \rightarrow M_u = 16.875$ k-ft

$\phi M_n = F_y Z$ $\quad F_y = 46$ ksi (for rectangular tube)

$Z_{min} = \dfrac{(12)(M_u)}{46} \rightarrow \dfrac{(12)(16.875)}{46} \rightarrow Z_{min} = 4.40\ in^3$

From steel manual shape tables page 1-92:

Use: HSS 3½" x 3½" x 3/8"

↳ $Z = 4.69\ in^3 > 4.40\ in^3$ ok ✓