Renovation of an Office Building in Washington D.C.

Senior Thesis Final Report

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Submitted: April 7, 2011

Office Building in D.C. | Washington, DC

Lynn Appel | Construction Management

Project Team

Owner: General Services Administration

GC: Turner Construction

CM: Heery International

Architect: Boggs and Partners

Structural Engineer: AECOM

MEP Engineer: GHT

Civil Engineer: A. Morton Thomas and Associates, Inc.

Landscape Architect: EDAW

CPEP Website: http://www.engr.psu.edu/ae/thesis/portfolios/2011/lpa5005/

Building Statistics

Location: 200 C Street SW

Building Occupant: cannot disclose

Type of Building: Class A Office Space

Size: 550, 000 ft^2

# of Stories: 2 below grade, 6 above grade + penthouse

Dates of Construction: March 2010 to Summer 2012

Cost Information: withheld at request of owner

Project Delivery Method: Design-Bid-Build

Architecture

- Office space
- 8-story central atrium is being cut into the building with interior storefronts, a skylight, and a cantilevered stair
- Replacement of the existing limestone façade with vast expanses of glazing
- Glass entrance pavilion at the building's North side
- Transformation of the existing surface parking lot into a public landscaped plaza

Structural

- Existing structure remains throughout the building with the addition of a couple features.
- Existing 8" concrete slabs with concrete on metal deck around perimeter.
- New steel moment frame beams and columns around perimeter to support curtain wall.

MEP

- Complete removal and replacement of MEP with exception of chiller plant.
- (4) chillers in the basement that serve the Ford Building across the street and the office building.
- (12) transformers total: (8) in the basement and (4) in the penthouse.

Sustainability Features

- Green roof
- Maximum use of natural light in the interior
- Storm water retention for landscape irrigation
- Energy saving LEDs
- Smart building controls technology
- Charging stations in the lower parking level for Electric Vehicles

1.0 EXECUTIVE SUMMARY

Senior Thesis Final Report is intended to discuss the findings and conclusions of the three analyses performed on the Office Building Renovation. This project includes 550,000 SF of renovation work to an existing office building. Each topic is centered on the central theme of energy and improving efficiency in the construction industry.

ANALYSIS #1: Critical Industry Issue – Integrated Project Delivery

Integrated Project Delivery (IPD) is an up and coming delivery method that could really impact the design and construction of the Office Building. This analysis will be conducted by speaking with industry professionals that have experience with IPD and by researching case studies of projects that have been completed by using IPD. Additionally, the faults and shortcomings of the design-bid-build delivery method will be examined in the coming semester.

ANALYSIS#2: Feasibility and Design Study for Photovoltaic Panels on the Green Roof

The Office Building project is slated to achieve LEED Gold Certification upon completion. However, as a public funded project, the Office Building should be doing everything possible to achieve LEED Platinum Certification. It should lead by example and take the extra steps to achieve this. The goal of this analysis is to perform a preliminary design of a building integrated PV energy system on top of a green roof and determine the financial feasibility to incorporate the system into the SmartGrid to reduce energy costs for the owner. This analysis will include the second part of the Critical Industry Issue research by analyzing how the PV panels can be incorporated in the SmartGrid. A structural breadth study will also be performed for analyzing load requirements and additional structural support for the PV panels. Also, an electrical breadth study will be performed to determine a system tie-in location along with electrical equipment and connection requirements for the renewable energy system.

ANALYSIS #3: Digital Modeling and Coordination of the Chilled Water Plant

The interior of the Office Building was completely demolished with the exception of an existing chilled water plant located on the Subbasement level, which provides chilled water for an adjacent building and must remain in operation 24/7. The chillers in the subbasement are eventually going to be replaced, but they are being replaced in the exact location of where they sit now. The project manager identified this as the largest constructability challenge. Building Information Modeling (BIM) was used on this project, but it could have been used more effectively to deal with this problem.

2.0 ACKNOWELDGEMENTS

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Dr. David Riley – CM Advisor

Industry Acknowledgements:

Turner Construction Company

HEERY

GSA

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Tom Sawyer at Turner Construction

Tony Lopacki at GSA

My Family and Friends

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3.0 PROJECT OVERVIEW

3.1 Introduction

The Office Building in Washington, D.C. is a complete renovation of an existing office building being constructed in the heart of Washington, D.C. within walking distance to the United States Capitol. Its 550,000 SF will consist of office space for two separate government tenants. The interior was demolished in 2005 to create shell space with the exception of an existing chilled water plant on the sub-basement level, which provides chilled water for a nearby office building and must remain in operation at all times.

This renovation consists of the construction of a new glass entry pavilion, new curtain wall, and bay windows on the north and south elevations. These new curtain walls require the removal of existing limestone façade and shear wall, which will be replaced with new steel columns and moment welded steel beams. The slab edges are also being extended in many locations. The existing roof will be removed and replaced with a Green Roof.

Building Name	Cannot disclose name of building
Location	200 C Street SW, Washington, D.C. 20024
Building Occupant Name	Cannot disclose occupant, but owned by GSA
Type of Building	Office Space - Group B Business Occupancy
Size	550,000 SF
Number of Stories	Below Grade - 2, Above Grade - 6 + Penthouse
Dates of Construction	March 2010 - Summer 2012
Cost Information	Withheld at the request of the owner
Project Delivery Method	Design-Bid-Build

Table 1: General Building Information

3.2 Project Location

The Office Building in D.C. is located at 200 C Street SW in the heart of Washington, D.C. With uninterrupted views of the Capitol, the Office Building is in a prime location for an office building. The Office Building is surrounded by other office buildings on its South, West and North sides and a major highway on its East side. Similar to the Office Building, all of the surrounding buildings are government buildings due to its close proximity to the Capitol. Across the street from the Office Building is the Metro-Federal Center SW Station. This station makes for a very pedestrian heavy area at the intersection of D Street and 3rd Street. The major highway located on the East side of the building, I-395, makes the Office Building very accessible when traveling from outside of the city. A map of the surrounding area can be seen below in ***Figure 1***. See **APPENDIX A** for the existing conditions site plan.

Figure 1: Project Delivery Method

3.3 Client Information

The Office Building is owned by the United States General Services Administration, or GSA. GSA is an independent agency of the United States government, established in 1949 to help manage and support the basic functioning of federal agencies. GSA is renovating the Office Building due to a change in function from lab space to a Class A office space.

The office building, built in the 1960s, was originally the central headquarters and lab space for the Federal Drug Administration. GSA felt that the Office Building would better serve as an office space rather than a lab space. The Office Building is located one block from the Capitol and is considered premium rental/office space. The unobstructed views of the Capitol make the Office Building everyone's ideal office location.

GSA is most concerned with the needs of the tenants. The tenants expect the Office Building to come in on time and on budget. The longer the project takes, the longer the tenants have to wait to occupy their space. GSA is also placing an emphasis green building and recycling. They are striving for LEED Gold and want to do everything they can achieve this. If the project team is able to successfully meet these objectives by providing a high quality end product within budget and on time, GSA will be satisfied.

3.4 Project Delivery Method

The Office Building is being delivered as a design-bid-build project with a Construction Manager. GSA first hired an Architect to design the renovation and prepare a complete set of contract documents. Once the project plans and specifications were complete, GSA purchased them from the Architect.

At the same time GSA hired the Architect, they hired a Construction Manager to help improve cost, schedule and quality control; improve constructability of the design; and improve field management. Once the design was complete, GSA brought on a General Contractor. The General Contractor is responsible to hire the subcontractors for every trade. The lowest bidder for each trade was awarded the contract.

Due to the confidentiality of this project, the owner has requested that generic names be used for all of the contractors and that the types of contract types are withheld. A visual of the project delivery method can be seen below in ***Figure 2***.

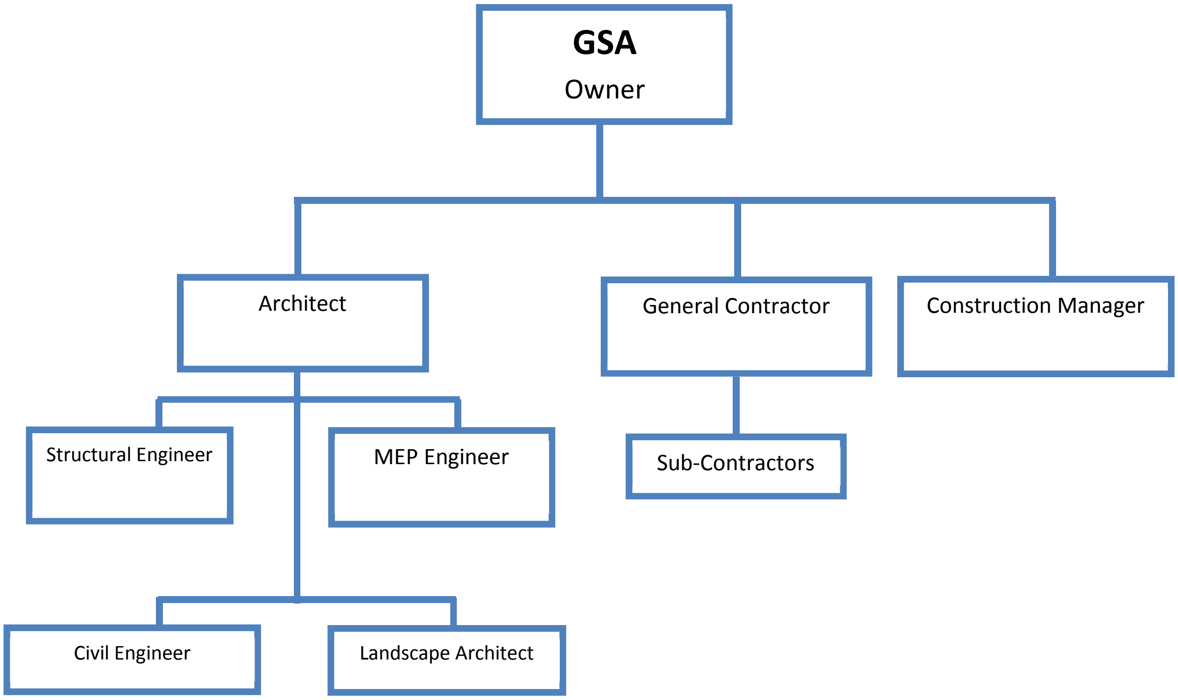


Figure 2: Project Delivery Method

3.5 Project Team Staffing Plan

3.5.1 Staffing Plan – Construction Manager

The construction management staffing plan of the Office Building, as outlined in the organizational chart above, involves a number of different players that all play a key role. First, you have the Project Executive that oversees the entire project and reports directly to GSA. Underneath the Project Executive is the Senior Project Manager, who is on the job site every day and oversees the Superintendent and the part-time project support staff. The responsibilities of the major trades of the project are divided amongst the five sub-positions of the Project Manager. The Superintendent is also assigned Inspectors who help oversee the work directly in the field. There is also a Cost Engineer and Administrative Assistant on site to perform and maintain all bookkeeping and ensure that everything is running smoothly in the office. A depiction of the Construction Manager staffing plan can be seen below in ***Figure 3***.

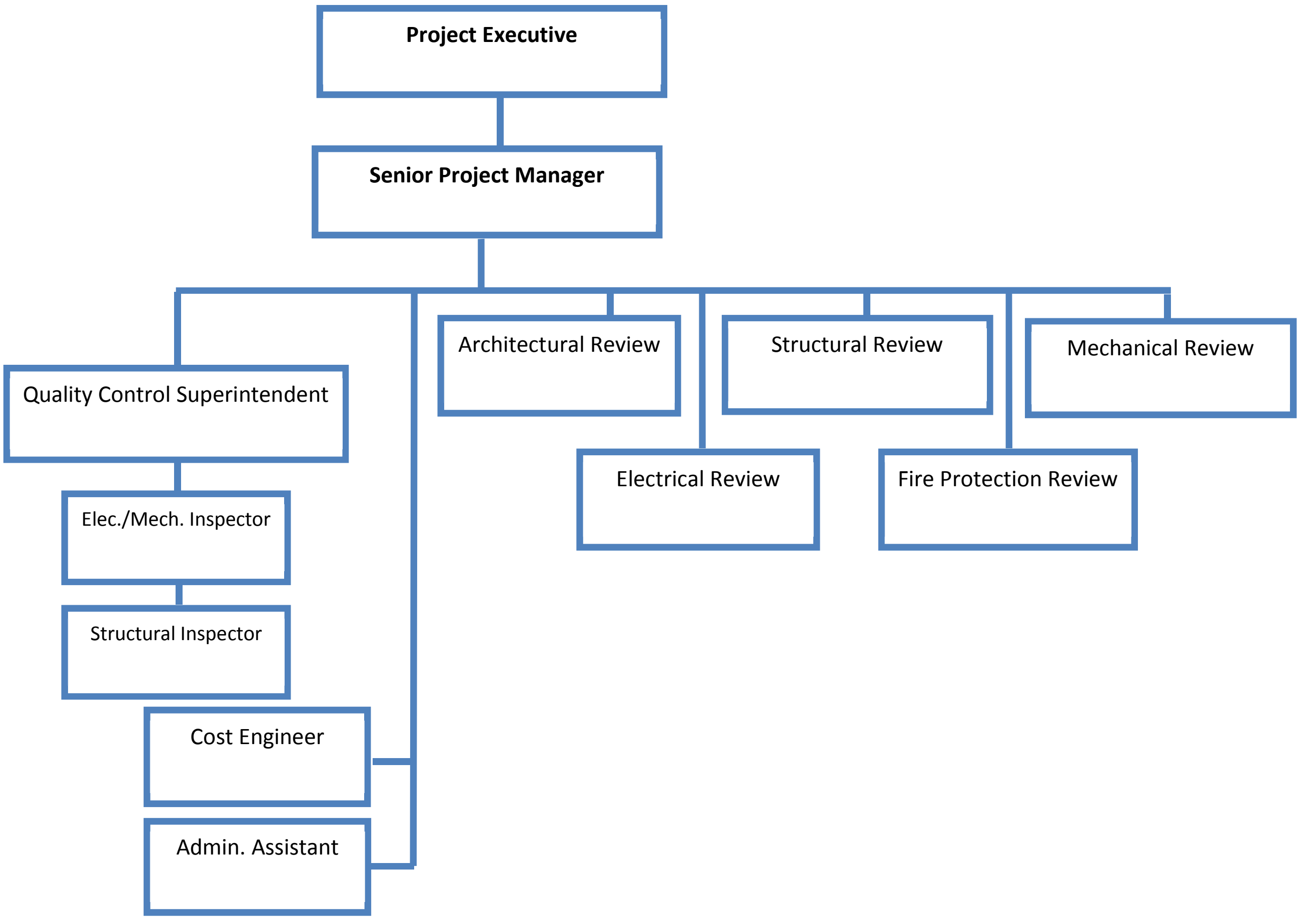


Figure 3: Staffing Plan – Construction Manager

3.5.2 Staffing Plan – General Contractor

The General Contractor staffing plan shown above lays out the relationships of people that are on site every day. First, you have the Project Manager on site that oversees everyone and makes sure that the project stays under budget and on schedule. Underneath the Project Manager is the General Superintendent. The General Superintendent oversees work being done in the field. The Superintendent and Safety Manager are there to help the General Superintendent in the field to ensure that work is completed in a timely and safe manner. Also underneath the Project Manager are the Engineer, Project Engineer and Support Administration. They are there to assist the Project Manager in day-to-day activities on the job site. A depiction of the General Contractor staffing plan can be seen below in ***Figure 4***.

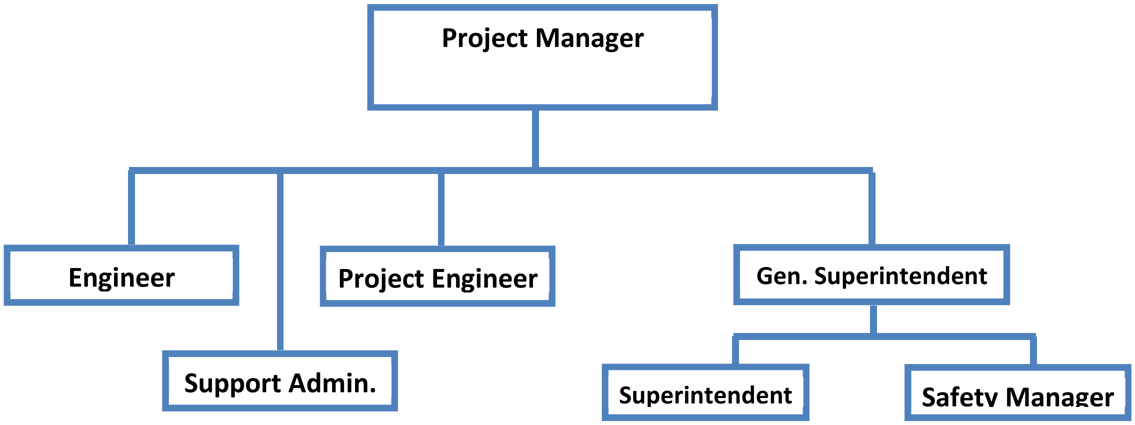


Figure 4: Staffing Plan – General Contractor

4.0 DESIGN AND CONSTRUCTION OVERVIEW

4.1 Building Systems

4.1.1 Demolition

Demolition of the Office Building involved the removal of asbestos, lead based paint and dust, Polychlorinated biphenyls (PCB), mercury in the pipes and biological and radiological elements. PCB was found throughout the building in concrete slabs and ballasts in the lighting. The subcontractor is removing as much as possible, but in some cases it is more cost effective to trap and monitor the PCB rather than removing it. When that is the case, three coats of epoxy paint are applied to the concrete and the PCB is trapped. Another case where a hazardous material needs to be trapped is in the cooling tower. The steel that is holding the cooling tower up has lead on it and it is cheaper to trap and contain it than it is to remove it.

4.1.2 Structural Steel

New steel columns are being installed around the exterior of the building to support the curtain wall. New steel moment frame columns (W14x82) are being installed as well as new steel beams (W14x82) to support existing concrete edge beams.

4.1.3 Cast-in-Place Concrete

The cast in place concrete included new concrete blast reinforcement and new concrete in fill slabs on existing slabs in the sub-basement and basement wherever the floor needed to be evened out. CIP Concrete also included new concrete in fill slab on metal deck on elevated floors and a concrete single span deck on top of new steel beams to help support the curtain wall.

4.1.4 Mechanical System

The mechanical rooms are located in the sub-basement and penthouse levels. The Office Building is undergoing a complete removal and replacement of all MEP equipment with the exception of the chiller plant, which is located in the sub-basement. Two out of the four chillers in the plant were recently exchanged for new ones so they will remain while the two older chillers will be replaced. The chiller plant also serves the Ford Building which is located across the street from the Office Building. Air handling units and cooling towers are located in the penthouse of the Office Building.

4.1.5 Electrical System

The Electrical room is located in the sub-basement of the building. All electrical equipment is being completely replaced. From the switchgear, the power is then distributed to the brand new transformers. There are eight transformers located in the sub-basement and four transformers located in the penthouse. There is an emergency generator in the penthouse to provide back-up power to the critical building systems during a power outage.

4.1.6 Façade

The exterior of the Office Building in D.C. consists of a combination of curtain wall and limestone assembly. All of the limestone being used is existing limestone from the existing building. A typical south and north façade (the long sides of the building) is made up of projecting window bays (laminated insulating glazing units) between strips of existing limestone and granite. A typical east and west façade includes two bays of laminated insulating glazing units and a single bay of existing windows. Similar to the north and south facades, the limestone exists from the original building.

4.1.7 LEED Requirements

GSA is adding a number of features to the Office Building to achieve a LEED Gold rating. Innovative environmental aspects of the project include a green roof, maximum use of natural light in the interior, storm water retention for landscape irrigation, energy saving Light Emitting Diodes (LEDs), smart building controls technology, and charging stations in the lower parking level for Electric Vehicles.

4.2 Project Cost

*See **APPENDIX B** for the Square Foot Cost Estimates

*See **APPENDIX C** for a Detailed Structural Estimate

The actual construction costs are based on a Schedule of Values report provided by the Construction Manager. The amounts are slightly altered and rounded for comparison purposes. All costs shown do not represent actual bid costs for the project.

General Costs		
	Cost	Per SF
Construction Cost	$ 58,750,000	$ 106.82
Total Cost	$ 72,812,000	$ 132.39

Table 2: General Costs

Building Systems Costs			
System	Cost	Per SF	% of CC
Cast-in-Place Concrete	$ 2,000,000	$3.64	3%
Metal Fabrications	$ 4,300,000	$7.82	6%
Glass and Glazing	$ 7,900,000	$14.36	11%
Mechanical and Plumbing	$ 14,150,000	$25.73	20%
Electrical	$ 9,950,000	$18.09	14%

Table 3: Major Building Systems Cost Estimate

The project cost of the Office Building was first evaluated by using the actual construction cost. Based on numbers provided by the owner, the construction cost was around $58,750,000 or $106.82/SF. Next the total cost was taken into consideration and it came out to be around $72,812,000 or $132.39/SF. Below the construction cost and total cost is a table that shows the major building systems costs and cost per square foot for each of the systems. After evaluation, it is determined that the mechanical and plumbing system is the most expensive, coming to a total of $14,150,000.

4.3 Local Conditions

The preferred method of construction in Washington, DC is the use of concrete. The reason for this method is because there is a height restriction in Washington, D.C. “In 1889, Congress passed the Heights of Building Act…but was amended in 1910 to the width of the adjacent street plus 20 feet.” As a result, when Federal Office Building No. 8 was originally built in 1961, concrete beams and concrete columns were used to maximize the floor-to-floor height, staying within the height restriction.

At the Office Building, there is very limited room for construction parking. On-site parking is only available for the Construction Manager and the General Contractor. Even though there is very limited parking for workers on site, the Office Building project site is conveniently located across the street from the Metro-Federal SW Station. This method of transportation gives the workers an easy and inexpensive way to commute to the job site.

Since the Office Building is striving for LEED Gold Certification, the site has a number of recycling dumpsters to help achieve points for certification. The initial cost of the dumpsters is around $500 and there is a tipping fee of about $130 for each dumpster. Recycling dumpsters play a heavy role with the building earning LEED certification. As a result, Turner Construction has a project engineer who is responsible for tracking the percentage of waste being recycled. Currently, the site has is recycling 99% of all waste.

4.4 Detailed Project Schedule

See Appendix D for the Detailed Project Schedule

The detailed project schedule is based on a Baseline schedule provided by the General Contractor. Notice to Proceed was received on March 2, 2010 and site mobilization began immediately following NTP. Due to the fact that this project is a renovation of an existing building, Demolition was a large portion of the schedule. Interior demolition began in the sub-basement, but then moved up to the penthouse and worked its way down through the building. Demolition of the typical floors included the removal of all doors/frames and MEP and then the removal of the concrete walls. The Exterior Demolition was broken into each elevation and then broken down even further into two quadrants. Overall, demolition will take about a year to complete.

Following Demolition, the schedule was broken into Exterior Construction, Interior Construction, and the construction of the Entry Pavilion/Atrium. Exterior Construction consisted of mainly installing new steel columns and beams followed by the Curtain Wall system. Interior Construction was broken down by floor and then further broken down into East Core Areas and West Core Areas. Construction began in the Penthouse and Roof and worked its way down to the first floor. Other sections of Interior Construction were the elevators and stairwells. The elevators were installed towards the beginning of the project, after demolition was complete, so they could be used during construction. The new stairwells were not constructed until the second half of 2011 because there were existing stairwells in the building that could be used during construction. The Entry Pavilion/Atrium part of the section was broken down into three sections; South Entrance Lobby, Entry Pavilion/Atrium, and Central Atrium.

4.5 Site Layout Planning

See Appendix E for the Site Layout Plan

Due to the fact that the Office Building is located in downtown D.C., the site is very restricted and therefore does not change throughout the construction of the building. The Construction Manager and General Contractor trailers are located along C Street, S.W. where a parking lot used to be. Besides the fact that this was the only location on site that the trailers could be placed, it was convenient that the area was already paved and flat. The CM and GC trailers remain in the same location throughout Demolition and Construction of the base building. The trailers sit on the future location of an extensive landscaped plaza. Once the landscaping is ready to begin, the CM and GC trailers will be moved and the staffs will be moved into the building. The subcontractors do not have any trailers and are located in the basement of the building and the underground parking garage.

There are two entrances to the main construction site and then one entrance to the loading dock and underground parking garage. There is one entrance on 2nd Street where the GC and subcontractors enter the site and another entrance on 3rd Street where the CM enters. There is a service road that connects these two entrances. This service road is used for the CM and GC staff and for deliveries. The entrance to the loading dock and underground parking garage is located on 2nd Street.

The electrical subcontractor is providing temporary power. They have provided temporary panels in various locations throughout the building. As far as temporary equipment goes, there will not be a tower crane used onsite. The subcontractors will bring out cranes when needed and they can be located around the perimeter of the building. However, due to weight, no crane can be located on the north side on top of the parking garage. All dumpsters are located in the loading dock in the underground parking garage and will be in that same location for the duration of the project.

4.6 General Conditions Estimate

See Appendix F for complete General Conditions Estimate

The estimate summarized in Table 2 below shows a representation of the costs for the general condition line items on the Office Building project. These numbers are an approximation and do not reflect the actual amounts contracted by the General Contractor.

Line Item	Unit Rate	Unit	Quantity	Cost
Project Staff	$ 15,565	Week	131	$ 2,039,015
Construction Facilities & Equipment	$ 1,665	Week	131	$ 218,160
Temporary Utilities	$ 2,600	Week	131	$ 340,640
Miscellaneous Costs	$ 1,389	Week	131	$ 181,965
				$ 2,779,780

Table 4 – General Conditions Estimate Summary

The estimate was broken down into four categories: Project Staff, Construction Facilities and Equipment, Temporary Utilities and Miscellaneous Costs. Project staff includes the entire management and support staff for the project for the duration of the project. The Construction Facilities and Equipment category incorporates items such as Office Trailers, Office Equipment and supplies, personal protective equipment, dumpsters, etc. As far as temporary utilities goes, the Electrical Contractor is providing temporary electric power while the General Contractor is providing the rest. These include installation and service costs for field telephone lines, temporary water/sanitary supply, and temporary toilet facilities. Finally, the Miscellaneous Costs accounts for items permits, progress photographs and document reproduction, clean-up expenses, etc.

As shown below in Figure 1, the Project Staff costs account for over 70% of the general conditions estimate, which is fairly typical for construction projects. The overall general conditions estimate of $2.7 million is just over 4% of the total project cost of $72 million.

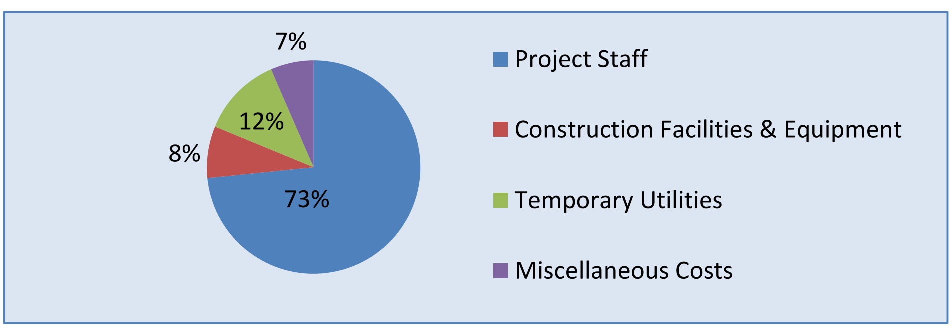


Figure 5 – General Conditions Percent Break-down

5.0 Critical Industry Issue – *Shift from Design-Bid-Build to Integrated Project Delivery*

5.1 Problem Identification

The current project delivery method for the Office Building is a traditional Design-Bid-Build. A design-bid-build delivery method is one of the most common and familiar delivery methods. However, it can create some problems along the way due to lack of coordination. The design is completed in stages and then pieced together at the end before it is sent out for bid to the contractors. This prevents each design firm from working together and creating one, cohesive design for the building. Additionally, with the design-bid-build delivery method, constructability issues with the design are not discovered until the bid process or during construction. Additional costs can result from these late findings if the design process is not closely monitored.

5.2 Research Goal

The goal of this analysis is to investigate the benefits and possible outcomes of using an Integrated Project Delivery Method compared to a traditional Design-Bid-Build. The design efficiencies and constructability methods that can be gained with this delivery method will also be examined closely.

5.3 Methodology

- Contact the General Contractor to receive information about issues that have dealt with concerning the Design-Bid-Build delivery method
- Find/research case studies of projects that have been designed and built using Integrated Project Delivery
- Compare data for projects completed under an IPD method and Design-Bid-Build
- Develop a summary of findings and provide possible guidelines for success when delivering a project with IPD

5.4 Background Information

It is no secret that the construction industry is one of the most inefficient industries in America. There is a lot being written about the construction industry's problems with productivity, cost over-runs and inefficiencies. One of the biggest factors that lead to this inefficiency is the way projects are delivered. In 2007, the AIA put out a press release that pointed to studies focusing on construction performance.

Recently, a number of studies have been conducted which show increasing inefficiencies and waste in the construction industry. An Economist *article from 2000 identifies 30 percent waste in the U.S. construction industry; a National Institute Standards and Technology (NIST) study from 2004 targets lack of interoperability as costing the industry $15.8 billion annually; and a U.S. Bureau of Labor Statistics study shows construction alone, out of all non-farm industry as decreasing in productivity since 1964, while all other industry has increased productivity by over 200 percent. These inefficiencies, coupled with new technologies such as building information modeling (BIM) and owner demand for better quality and cost controls, have created a need for a collaborative approach to construction and design.*

The traditional design-bid-build delivery method is not very collaborative and leads to designers, contractors and subcontractors all working against each other to maximize their profit.

5.5 Design-Bid-Build Analysis

As stated earlier in the Problem Identification section, the design-bid-build delivery method is very inefficient and can create some problems along the way due to lack of coordination. Design-bid-build does not take advantage of the collaboration between the owner, architect and construction manager. The owner has separate contracts with the architect and contractor. All of the separate parties are, at times, unwilling to help each other because they are worried about liability and risk and have only their interest in mind. Construction management personnel are not brought onto the project until the bid process and therefore have no significant input into the design. A design-bid-build delivery method typically involves competitive bidding by general contractors, resulting in a lump sum contract that is based on complete drawings prepared by a separate AE firm. Due to the confidentiality of this specific project, the specific types of contracts are unknown. If construction management personnel were brought on to the project at an earlier stage, they would be able to give valuable cost information. Because of this, value engineering is not conducted until after bidding. Having value engineering conducted after bidding causes the schedule to be extended for redesign and rebidding.

The first phase of the process, the design phase, is where the inefficiencies of the design-bid-build delivery method begin. First, the owner hires an architect to design the building. The architect then contracts out to other engineering firms to help them complete the design. The architect's design is then passed around to the structural engineer, then the MEP engineers and any other design teams that may need to design systems in the building. By the end of the process, the architect has a number of different sets of drawings that have not been completely coordinated with each other. If all of the designers were able to work off one set of drawings and bounce ideas off of each other throughout the process, the length of the design process could be significantly reduced. Not being able to coordinate as effectively as possible throughout this process may force some designers to compromise their design as the result of a previous design of another system. For example, at the Office Building, the mechanical, electrical, plumbing and many other trades had to all fit their designs into a very tight area between each floor. Without coordinating with each other, some of the smaller trades may have to compromise or adjust their design, which can lead to some expensive changes. If all of these trades were able to coordinate and communicate with each other, they could come up with a design that best suits everyone. Another issue that could arise from the design phase is the architect's inability to have access to real contractors pricing. When they give their estimate to the owner, they are not giving the owner the most accurate price. Therefore, the design suffers from lack of input from the contractors and subcontractors.

Following the design phase comes the bidding phase. The bid phase will reveal the current/accurate market conditions affecting the costs of the project. Projects typically come in over budget, which can cause stress between the owner and architect. Like previously mentioned, the architect does not have access to real contractors pricing so their estimate is not the most accurate. This creates a need for immediate value engineering, which ultimately costs the owner more time and money. Decisions to reduce the cost of the project are often made at the expense of entire building systems and components. If all of the different parties were brought in during the design phase, value engineering after the bid phase would essentially go away because it would have taken place throughout the whole design phase.

Once the project reaches the construction phase, even more issues can start to arise. At this point, the owner has awarded a contract to the general contractor with the lowest bid. The general contractor and architect have not worked together at all up to this point. Due to their lack of construction experience, architects may be unsure of the constructability of certain details. As a result, they tend to forget to include certain details in the construction documents. When this happens, the general contractor or construction manager will issue an RFI and upon the response, a change order may be issued to the owner for the increased cost of the work. For a large project like the Office Building, there can be hundreds of RFI's throughout the whole process. This can increase the cost of the project and lengthen the schedule. This also goes back to the design phase. Since the different designers are not coordinating with each other, they are only thinking of what works best for them and not the building as a whole. This will lead to many RFI's throughout the design phase. It can also cause a bad working relationship between the trades and add additional expense for the rework.

One of the biggest issues of the design-bid-build delivery method are the change orders and RFI's. Unfortunately, many issues that need clarification are not discovered until the construction phase. As a result, work on site cannot move forward until an answer is received for the RFI. This can cause work to be completed out of sequence and consequently schedule delays. As previously mentioned, designers may not be familiar with the constructability of certain details so they leave them out of the design and then wait for the RFI. However, designers may not be the only ones to blame for RFI's. Some contractors and subcontractors can leave certain scope items out of their bids to lower their initial estimate and ultimately win the bid. These contractors and subcontractors rely on change orders to make money on their projects. However, these change orders can be detrimental to a project's final budget and schedule. ***Figure 6*** illustrates how more expensive change orders can be as the schedule of the project progresses. This is why it is important to correct as many issues as possible before construction begins.

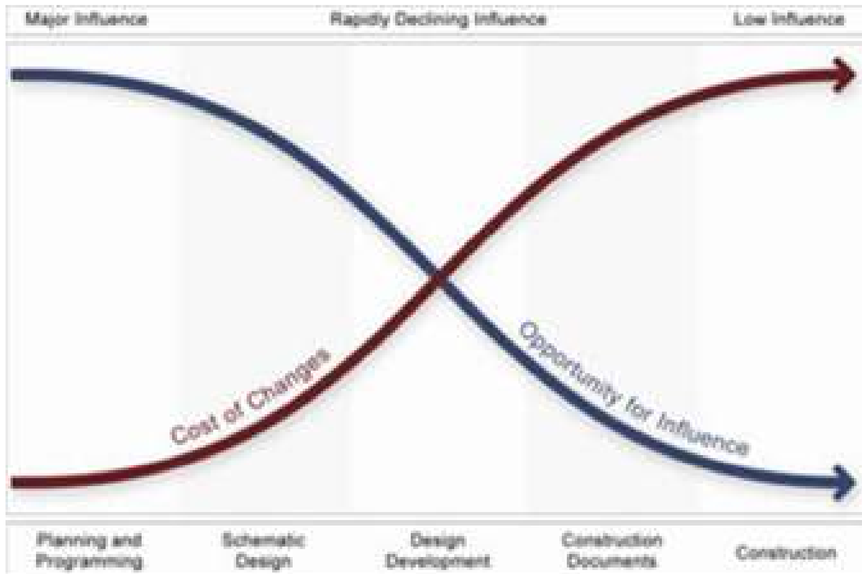


Figure 6: Cost of Changes vs. Opportunity for Influence (Cherry & Petronis, 2009)

5.6 Integrated Project Delivery Analysis

5.6.1 Overview

Integrated project delivery may not be a new idea, but it is just starting to grab the attention of owners across the country. Owners see IPD as a way for them to receive a high quality building at a reasonable price. Integrated project delivery and design-bid-build differ in the way that the work is contracted. In a design-bid-build, each party has their own separate project and therefore takes on their own risk. In an IPD, the owner, designers and general contractor all sign one contract. This contract ensures that all parties share the risks and rewards of the project. Having one contract allows everyone to work together as a team and make decisions on what is best for the project rather than what is best for their company.

5.6.2 Cost

In comparison to the traditional design-bid-build delivery method, Integrated Project Delivery has more upfront costs in hopes that it eliminates RFI's and change orders down the road. All key players, the owner, architect, contractors and possibly sub-contractors, are brought on at the very beginning of the project. Bringing everyone on early allows everyone to have input into the design at an early change.

Figure 7 shows how decisions or changes throughout the design and construction of a building can impact the cost of the project. Changes made at the beginning of the process have a large impact on the design of the project, but do not cost as much than a change made later on in the process. This shows the importance of having all necessary parties brought on early in the process. ***Figure 8***, the Macleamy Curve, shows how the different delivery methods of IPD and DBB affect the cost of the project. With IPD, more decisions and changes are made in the beginning of the process so when it is time to start building the project, the design is practically complete with little need to make changes.

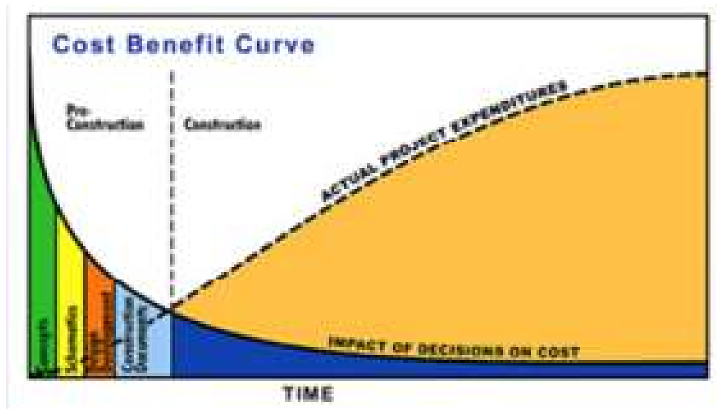


Figure 7 – Impact of Decisions vs. Time

The cost benefits of an IPD delivery method does not necessarily mean that the owner will end up paying less for their building. The cost savings incurred by using an IPD delivery method can be used to deliver a higher quality building to the owner. Bringing everyone on earlier in the project allows the team to come up with a more accurate cost model early on and therefore make more effective decisions.

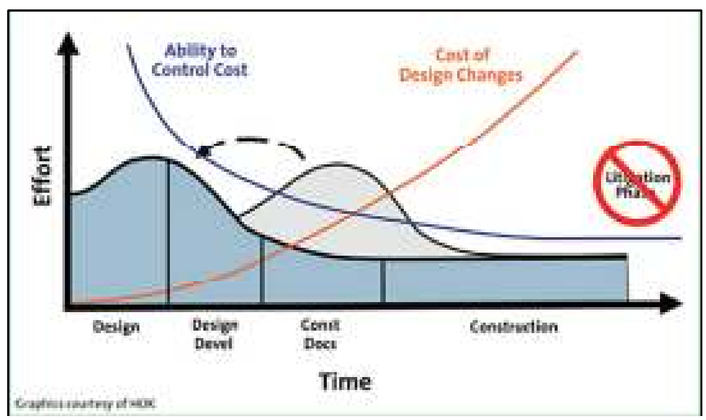


Figure 8 – MacLeamy Curve

5.6.3 Contracting

Although integrated project delivery systems are perceived as beneficial to the design and construction industry, overcoming the opposition between the architect and the contractor to form a truly collaborative team could prove difficult. One place to neutralize this natural opposition is through the contracts. IPD requires collaboration so the typical construction contracts do not fit very well. In the traditional design-bid-build contracts, everyone has their own interests in mind rather than the interest of the project. IPD contracts need to be open to collaboration and innovation. There are a couple of different IPD contracts out there, including the AIA IPD contract and the Consensusdocs 300 IPD contract, but they all have the same purpose and intent. All of these contracts require the owner, the architect, and the construction manager to sign the same contract. Additionally, as other designers and subcontractors are brought on board, they are required to sign adjoining agreements officially making them part of the team.

With every member of the team working under the same contract, everyone's goals become aligned and they are all working for the same goal. Each member of the team isn't working to reach its own individual goal as a company, but instead to make the project better as a whole. According to the contract, if the project fails, everyone fails. Michael Tardiff of Grunley Construction stated that: "Shared risk/reward means that if a problem comes up on a project, the focus of the team is on finding a solution rather than assigning blame for a problem. So it instantly eliminates a lot of 'defensive documentation' and changes the focus of the parties from protecting themselves to solving problems and getting the project done." This "defensive documentation" wastes a lot of time and money that could be adding value to the project.

5.6.4 Communication

Communication is one of the largest contributing factors to the success of a project delivered by an integrated delivery method. According to the AIA California Council:

> *Focus on team performance is based on communication among all participants that is open, straight and honest. Responsibilities are clearly defined in a no-blame culture leading to identification and resolution of problems, not determination of liability.*

Collaboration is the foundation for IPD. As a result, it can only be successful if the participants share and apply common goals. One way to share and apply these common goals is to have co-location of the project team. Co-location provides opportunities for collaboration and innovation increase. Project commitments are more likely to be met when one becomes closer to one's teammates. Edith Green-Wendell Wyatt Federal Building (EGW) modernization, a project delivered in a collaborative manner, used co-location on their project. ***Figure 9*** below shows co-location in action at the EGW project. The project team for EWG named their co-location area the iRoom. This iRoom is a shared spaced that is used by all members of the project team. Having the project team located in one central location allows problems to be solved in a reasonable time. There is no need to send an RFI to the designer because the designer is already in the room. This can help reduce the duration for the design phase. One resource that helps with the decision making process is all of the equipment and software located in the co-location room. Having all of the proper software readily available allows all of the different trades to have access to their specific programs. This makes it easy to fix coordination mistakes between the trades.

Figure 9 – iRoom at Edith Green-Wendell Wyatt Federal Building modernization

5.6.5 Schedule

The schedule of a collaborative project differs significantly from the schedule of a traditional design-bid-build project. Conventional terms or phases like schematic design, design development and construction documents create workflow boundaries. IPD will have increased team involvement and collaboration in the early phases of the design. The process will flow from determining project goals to what will be built to how the design will be realized. A comparison of the processes of traditional and integrated delivery methods can be seen below in ***Figure 10***. With a collaborative project, it takes a shorter amount of time to establish the goals of the project because all of the important players are involved from the beginning. How the building is going to be built is also established earlier than the traditional method. The subcontractors provide valuable information because of their experience and expertise in their particular area. Input from the collaborative team, paired with the capabilities of BIM to model and simulate the project allow the project to be brought to a higher level of completion before the documentation phase is even started. This higher level of completion allows the

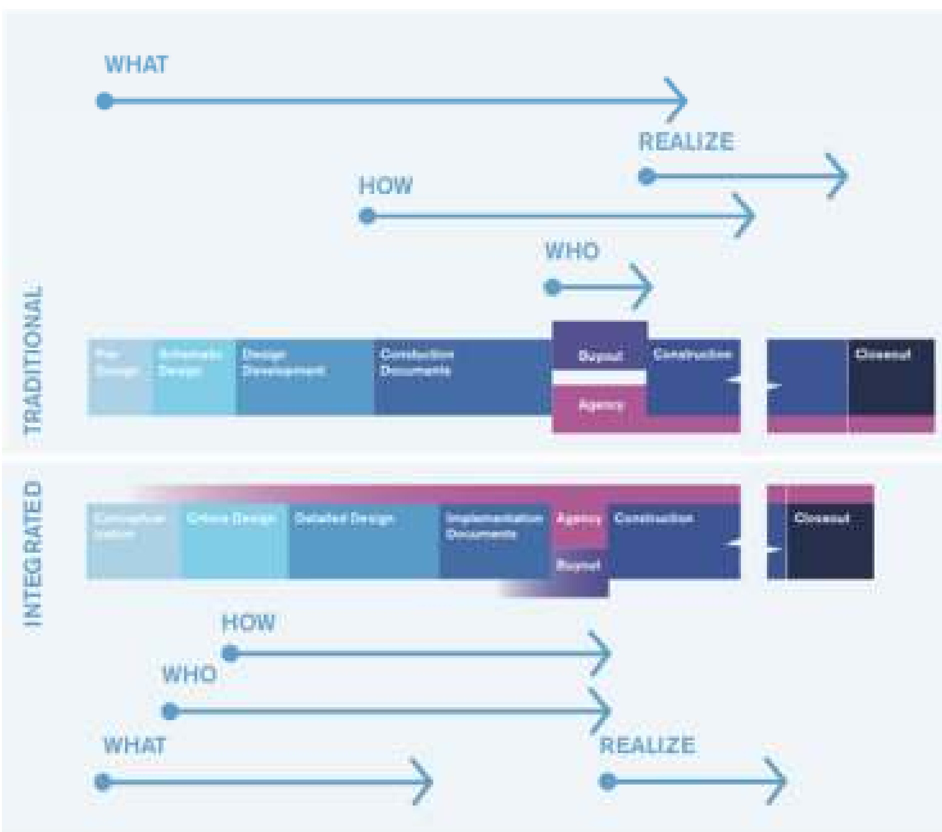


Figure 10 – Integrated vs. Traditional Delivery

Implementation Documents phase to be shorter than the traditional Construction Documents phase. Early participation of subcontractors and manufacturers allows shortening of the Agency Review and Buyout phases. The whole point of an integrated approach is that the project is defined and coordinated at a much higher level prior to construction start. This allows the building to be constructed more efficiently and the construction period to be shortened.

5.7 Integrated Project Delivery for the Office Building

A more collaborative project delivery method would be very beneficial for the Office Building. However, because the Office Building is a federal, or public, project and "true" IPD may not be possible. A "true" IPD is when the owner signs a multi-party contract with at minimum the architect and contractor. The Association of General Contractors considers this to be a Level 2 IPD or IPD-ish method. Project managers at GSA do not have the authority to enter into multi-party agreements, to agree to not litigate on projects, to accept insurance policies with provisions that do not meet their requirements and to bring subcontractors onto the design process. If the project manager is interested in enhancing collaboration and the benefits to be gained from collaboration, there are aspects of IPD that they can still use without entering into a multi-party agreement.

There are many ways to incorporate a higher level of collaboration into the project without having to use a multi-party contract. Some of the key elements of a Level 2 collaboration are co-location of team members, design team involvement in performance and risk sharing, construction team incentivized by productivity and subcontractor participation in performance incentives and risk sharing. These can all be achieved while still holding separate contracts with GSA. As far as selecting a team, where possible, GSA should state in their selection criteria that they are looking for architects and contractors that have experience and success with IPD projects or projects that have used some form of collaborative measures.

One of the most important aspects of the IPD method is owner involvement. In order for this delivery method to be successful for the Office Building, GSA would need to remain involved throughout the process working as a team member, not an enemy. They must act as a leader and guide the team in a collaborative direction. GSA would need to recognize that successful collaborative processes require more staff time than traditional design-bid-build processes. One example of this is the Edith Green-Wendell Wyatt Federal Building (EGW) modernization project. Similar to the Office Building, EGW was a public project so it could not be delivered as a "true" IPD. Therefore, they had to be innovative in their delivery method. To ensure that this project was a collaborative one, the owner of the project, which happened to be GSA, provided on-site management. This allowed GSA to be a part of the design process and decision-making process. They were there to act as a leader and ensure that everyone is working for the same goal. Finally, GSA is owner of the building but there will be two different tenants occupying the building once it is completed. GSA needs to make sure that these two clients are equally committed to collaborating with the project team. As the eventual users of the building, the tenants should play a pivotal role in the design process.

Support from GSA is essential for the Office Building to be delivered as an IPD-ish project. It is GSA's responsibility to create a sense of shared, common ownership. If they can get all of the members to work as a team and towards one common goal, the Office Building can be successfully delivered as an IPD-ish project.

5.8 Conclusion and Recommendations

Integrated Project Delivery is an innovative solution to solving the problems that are associated with a Design-Bid-Build delivery method. Although it may not be perfect yet, it is definitely headed in the right direction. Having everyone work as a team and always think of what is best for the project is a great benefit of IPD.

Because each project is different, a true IPD may not be possible. For the Office Building, which is a federal government project, it is just not possible to deliver a project as a true IPD. Like previously mentioned, delivering the project with the ideals of a true IPD, but without signing a multi-party contract may be the best option for the Office Building and other public projects. That is why it is recommended that the Office Building be delivered as an IPD-ish project. The project will be still hold the collaborative values of a "true" IPD, but without the multi-party contract. If the Office Building had been delivered in a more collaborative fashion, it is believed that the owner would end up with a higher quality building.

6.0 Feasibility and Design Study for Photovoltaic Panels on the Green Roof

6.1 Problem Identification

The Office Building project is slated to achieve LEED Gold Certification upon completion. However, as a public funded project, the Office Building should be doing everything possible to achieve LEED Platinum Certification. It should lead by example and take the extra steps to achieve this. Photovoltaic (PV) roof panels set on top of the already planned green roof is one step the owner can take. The fact that the owner will own and occupy this facility for over 50 years makes PV panels a great option in sustainable design and reusable energy.

6.2 Research Goal

The goal of this analysis is to determine the feasibility, advantages and disadvantages of implementing photovoltaic panels onto the green roof of the Office Building. A quantification of the amount of energy that a standard PV panel can produce will be obtained and then translated into power generation that the building could provide as a whole. The analysis will cover the initial costs of installation as well as determining the payback period of the system.

The intention is that the PV panels on top of the green roof will reduce the energy consumption by the tenants in the long-term operation of the building. It is understood that there will be a greater upfront cost with the addition of the panels. However, through analysis, I hope to find that the long-term benefits will outweigh the short-term investment and ultimately save the tenants and owner money.

6.3 Methodology

- Research PV panel technologies and sustainable design techniques
- Research sustainable roofing systems and the effectiveness of the combination of PV panels and green roof
- Determine quantity of panels to be placed on roof and amount of kWh able to be produced
- Analyze how the PV system will connect to the existing electrical power system (Electrical Breadth)
- Perform feasibility analysis on life-cycle cost and payback period

6.4 Background Information

Photovoltaic roof panel systems and green roofs have come a long way in recent years and are gaining in popularity. Many people assume that it is an either/or type situation and a choice has to be made between the two. The two systems can actually co-exist on a roof (see ***Figure 11*** below). Not too many people know that photovoltaic arrays have an efficiency drop as ambient temperatures on a rooftop climb steadily during a hot day. Green roofs can improve photovoltaic efficiency by reducing the ambient temperature. Shading provided by the solar panels benefit green roof vegetation, which often suffers during hot, dry months. With the installation of a green roof already in the plans, a photovoltaic array would only enhance the building and help reduce the cost of energy for the Office Building.

Figure 11 – PV Panels and a Green Roof

6.5 Sun Path and Shadow Analysis

Based on the layout of the roof, it was simple to determine where to place the photovoltaic panels. There was a large, square, open area on the west side of the roof that seemed to be the most logical spot to place the panels. The general area of where the panels will be located can be seen in yellow in the ***Figure 12.***

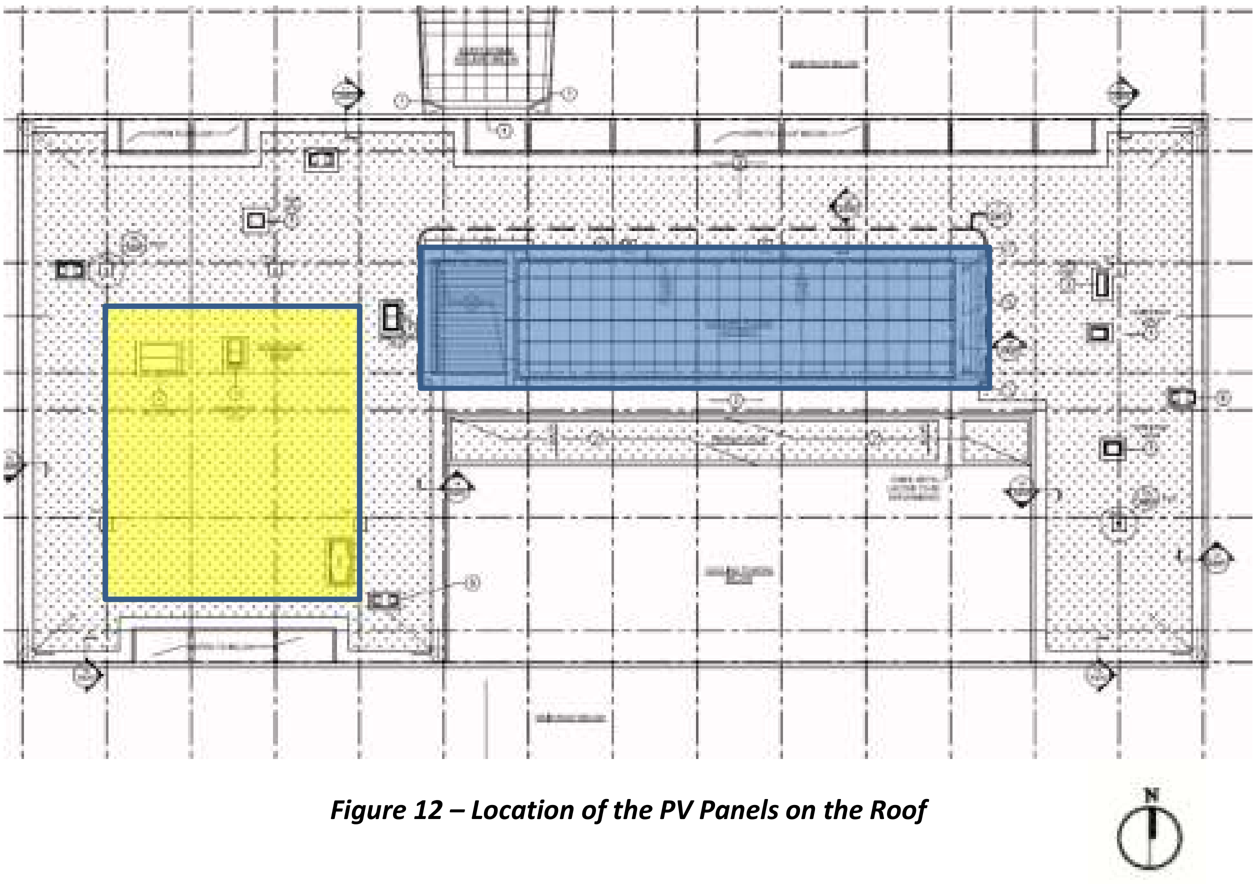


Figure 12 – Location of the PV Panels on the Roof

The central atrium skylight, highlighted in blue in the ***Figure 12***, extends above the roof by as much as 18 feet. To confirm that the selected location of the PV panels is the best location, a sun path and shadow analysis was conducted by using Google Sketch-up. ***Figures 13-15*** on the next page show the solar shading on the rooftop at 9 AM and 4 PM for the summer solstice, fall/spring equinox and winter solstice. The purple box is the outline of where the solar panels will be located on the roof. As shown, there is no shading on the solar panels at any given point during the year.

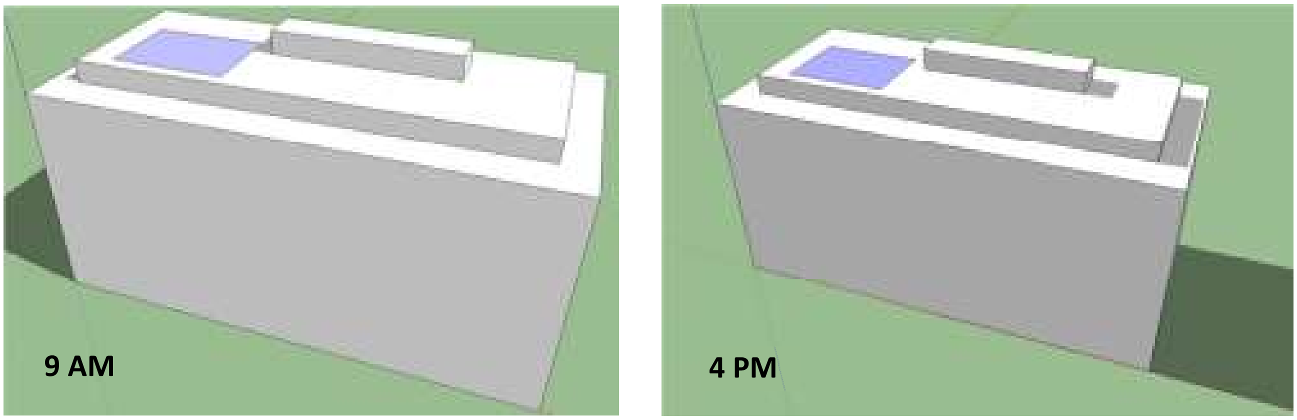


Figure 13 – Summer Solstice Shading (June 20)

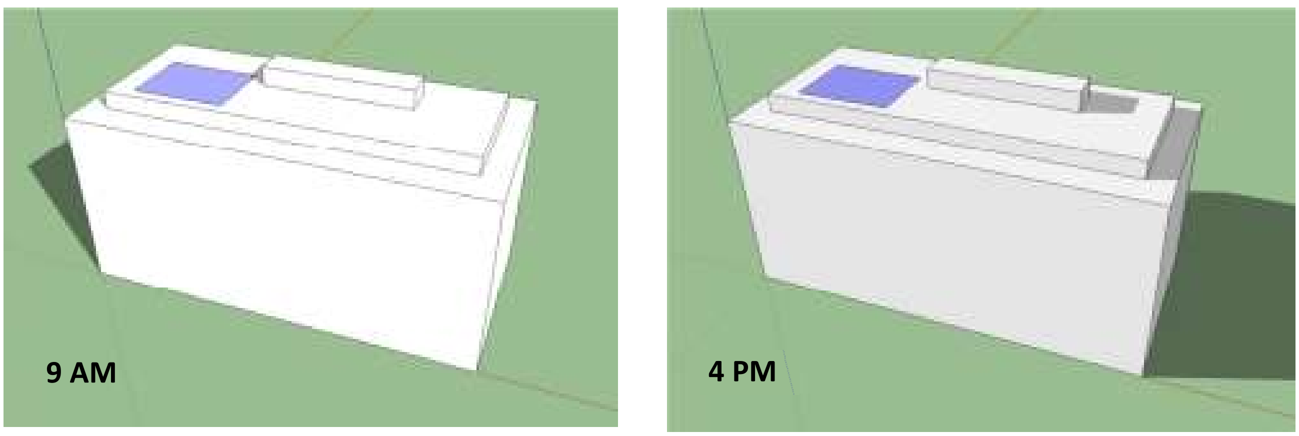


Figure 14 – Fall/Spring Equinox Shading (March 20/September 22)

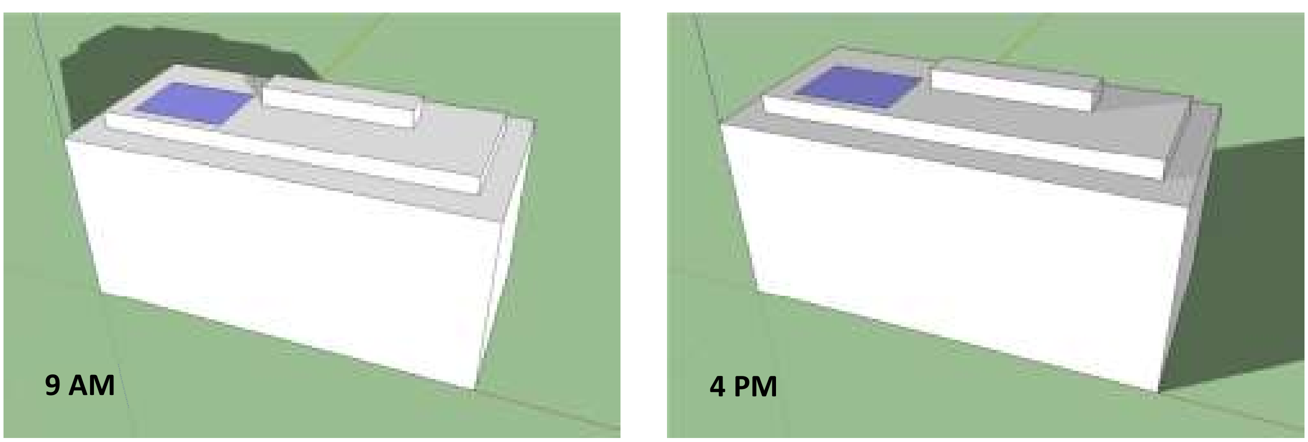


Figure 15 – Winter Solstice Shading (December 21)

6.6 Product Information

See **APPENDIX G** for the complete product data cut sheets for the selected solar panel and inverter.

Electrical Characteristics

	1000W/m² (STC[1])	800W/m² (NOCT[2])
Maximum Power (P_{max})	220W	158.4W
Voltage at MPP (V_{mpp})	29.0V	25.8V
Current at MPP (I_{mpp})	7.6A	6.1A
Short circuit current (I_{sc})	8.4A	6.8A
Open circuit voltage (V_{oc})	36.2V	32.9V

Efficiency at 1000W/m²	13.2%
Efficiency reduction at 200W/m²	< 5% reduction (efficiency 12.5%)
Limiting reverse current	8.4A
Temperature coefficient of I_{sc}	(0.065±0.015)%/K
Temperature coefficient of V_{oc}	-(0.36±0.05)%/K
Temperature coefficient of P	-(0.5±0.05)%/K
NOCT[3]	47± 2°C
Maximum series fuse rating	20A
Application class (According to IEC 61730:2007)	Class A installation
Maximum system voltage (N-Type junction box)	1000V (IEC 61730) 600V (UL)

[1]STC: Standard test conditions - irradiance of 1000W/m² at an AM1.5G solar spectrum and a temperature of 25°C
[2]800W/m², NOCT, AM 1.5G solar spectrum
[3]NOCT: Nominal Operation Cell Temperature 800W/m², Air 20°C, wind speed 1m/s

Figure 16 – Photovoltaic Panel Type: BP Solar sx3220 220 Watt PV Module

INVERTER SPECIFICATIONS: GT5.0	
Power Data	
Max AC Power Output	5000W : 4500W
AC OUTPUT (nominal)	240 V : 208V
AC FREQUENCY (nominal)	60 Hz
Max Continuous Output Current	21-22 A
Max Output over Current Protection	30
Max Utility Backfeed Current	12:00 AM
Power Factor	>0.99
Output Characteristics	Current Source
Size	
Weight	58 lbs.
Dimensions	29" x 16" x 6"

Figure 17 – Inverter Type: Xantrex GT 5.0 Series Grid Tie Solar Inverter

6.7 Design Methodology

ELECTRICAL BREADTH

The following section will provide a detailed look into the design of the PV system and its eventual integration into the building through a step-by-step process.

GIVEN: Basic Array Design and Layout

- One single array at the West end of the roof
- The array consists of 9 rows of 11 panels (99 total panels)
- Panels are rated at 220 W and measure 65" x 40" for a total area of approximately 18 SF
- After taking into account the angle of the sun at winter solstice, it is determined that each panel accounts for 37.1 SF (see ***Figure 18*** below for calculation)
- The array is fixed facing directly south with the optimal 39.2° tilt
- Xantrex GT 5.0 Grid Tie Inverters have been chosen to convert to AC power

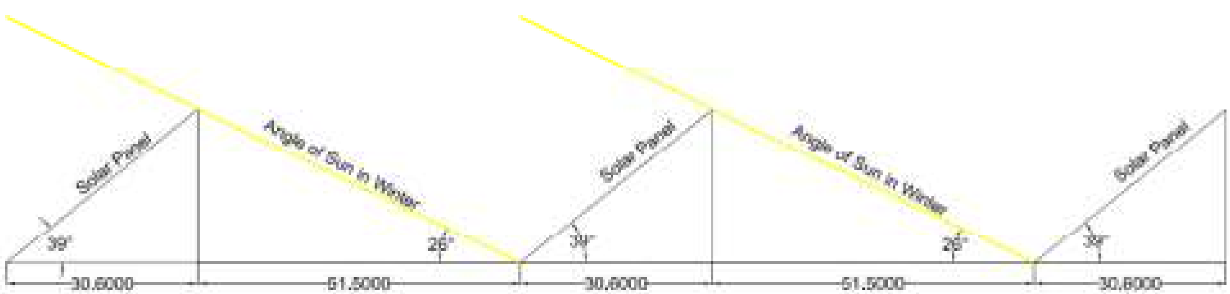


Figure 18 – Diagram of Panel Spacing

STEP 1: Determining the Number of Panels in a Series

Using the open circuit voltage of 36.2 V per panel and the U.S. NEC rating of 600V, it is determined that 16.57 panels are allowable per series which converts to a round number of 16 panels per series.

Number of Panels in Series = (600V)/(36.2V/Panel) = 16.57 = 16 Panels

STEP 2: Sizing the Inverters

In order to size the inverters, the number of panels in a series is multiplied by the max power of each panel.

Size of Inverter = (16 Panels)(220W/Panel) = 3520 W = 3.52 kW

Based on this data, the Xantrex GT 4.0 was chosen which is rated at 4000 W and has a 208 V AC output. The full specs for the GT 4.0 Inverter can be found in ***APPENDIX E.***

STEP 3: Determining the Number of Inverters Required

Calculating the number of inverters required is as simple as dividing the total number of panels in the array by the number of panels in a series. The result yields a total of 7 inverters.

Number of Inverters = (99 Panels)/(16 Panels/Series) = 6 Inverters

KNOWN: Electrical Impact and System Integration

- There is room on the roof to place the inverters
- The inverters will be placed on the same side of the building as the electrical room which is located in the sub-basement
- To simplify the integration into the building system, a new panel board will be added to the electrical room to house the inverter load

STEP 1: Determining the Load each Inverter has on the Panel Board

For a single phase, it is determined that the load of each inverter needs to be divided by two in order to get the loading of each on the panel board.

Load per Inverter on Panel Board = (4.0 kW)/(2)

STEP 2: Sizing the Circuit Breakers

To size the inverters, divide the watts of the inverter by 208 V; this will yield amperes.

Circuit Breakers Size = (4000 W)/(208 V) = 19.23 = 20A Circuit Breaker

STEP 3: Wire Sizes

Based off the circuit breaker size and the fact that each inverter comes with pre-determined locations for the wires, it is determined that **(2) #12 AWG and (1) #12** AWG wire sizes should be used. This conforms THHN/THWN at 600 V, the U.S. NEC Rating.

Load Description	Wire and Conduit	kW Load			CB/Phase	Circuit #	Φ
		A	B	C			
Inverter 1	(2) #12 AWG	2.0			25/2	1	A
	(1) #12 AWG		2.0		25/2	3	B
Inverter 3	(2) #12 AWG			2.0	25/2	5	C
	(1) #12 AWG	2.0			25/2	7	A
Inverter 5	(2) #12 AWG		2.0		25/2	9	B
	(1) #12 AWG			2.0	25/2	11	C

Table 5.1 – Inverter 1, 3, 5 Panel Layout

Φ	Circuit #	CB/Phase	kW Load			Wire and Conduit	Load Description
			A	B	C		
A	2	25/2	2.0			(2) #12 AWG	Inverter 2
B	4	25/2		2.0		(1) #12 AWG	
C	6	25/2			2.0	(2) #12 AWG	Inverter 4
A	8	25/2	2.0			(1) #12 AWG	
B	10	25/2		2.0		(2) #12 AWG	Inverter 6
C	12	25/2			2.0	(1) #12 AWG	

Table 5.2 – Inverter 2, 4, 6 Panel Layout

6.7.1 Electrical Components and System Tie-in

In order to determine the required electrical components for the PV system, the system tie-in design needs to be identified. Teris Pantazes of Seven Seas Energy, LLC, a company representing BP Solar, explained how the PV system was to be connected to the building's electrical system. The PV system must tie in to the existing electrical system via a supply-side interconnection. This requires the PV power feed to tie in with the utility power supply at a service tap meter box before the main distribution panel. The power sources are combined in the meter box and one feed is sent to the panel and distributed throughout the building to the designated loads. Figure X below depicts the supply-side interconnection for the PV array.

Figure 19 – Schematic of System Tie-in

A supply-side interconnection system requires the following electrical components to connect the PV array to the existing electrical system in the building:

- DC Wire Run – connects panels to inverters
- DC Disconnects
- Inverter – converts DC power to AC power
- AC Disconnects
- AC Wire Run – connects inverter to meter box
- Service-Tap Meter Box – combines PV power feed with utility power feed

Because the electrical room is located in the basement of the Office Building, there is potential for large voltage drops. As a result, it was determined that the inverters would be placed on the roof to minimize these voltage drops. DC wire is also more expensive than AC wire so locating the inverters on the roof would be less expensive than locating them in the electrical room in the basement. The Xantrex GT 4.0 inverters can be installed using lightweight and vertical mounting brackets. The overall dimensions for each inverter are 28.5” x 16” x 5.75” and they each weigh 58 pounds. This brings the total inverter system weight to approximately 400 pounds. The location of the inverters is one in which the inverters will be concealed and therefore minimizing the architectural impacts. The yellow shaded area on the roof plan below in ***Figure 20*** shows the proposed location of the inverters. See ***APPENDIX E*** for complete product data for the selected inverters.

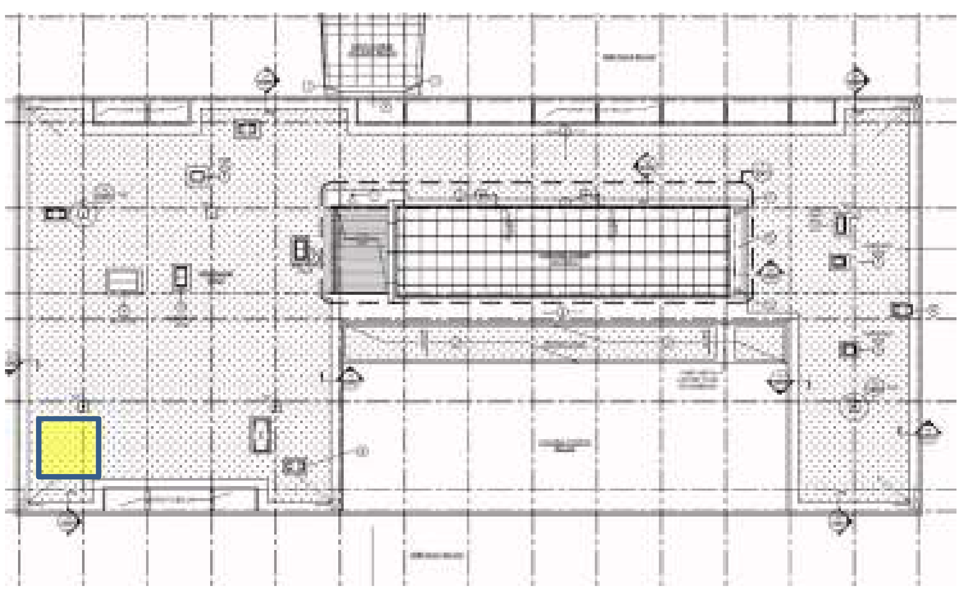


Figure 20 – Location of Inverters

Like previously mentioned, it was determined that the inverters be placed on the roof. It is recommended to place the inverters in the southwest corner of the roof because the electrical room is located in the southwest corner of the basement. The AC wire can run straight down from the inverters directly into the electrical room. This is where the utility power supply feed enters the building. As far as wire length goes, the DC wire run will be approximately 85' while the AC wire run will be about 107'. Placing the inverters in the basement would have resulted in a much longer DC wire run which would result in a larger, more expensive wire cost. As far as constructability is concerned, locating the inverters on the roof is the smart choice. The PV panels and cooling towers will already require a crane to lift them onto the roof. To save time and money, the same crane can be used for the inverters. With the total inverter system weight to be approximately 400 pounds, there are no structural concerns with placing them on the roof level.

6.8 Energy Impact

The size of a photovoltaic system is its nameplate DC power rating. This is determined by adding the PV module power listed on the nameplates of the PV modules in watts and then dividing by 1,000 to convert it to kilowatts (kW). OV module power ratings are for standard test conditions (STC) of 1,000 W/m^2 solar irradiance and 25°C PV module temperature. The default PV system size is 40 kW.

Station Identification	
City:	Sterling
State:	Virginia
Latitude:	38.95° N
Longitude:	77.45° W
Elevation:	82 m
PV System Parameters	
DC Rating:	40.0 kW
DC to AC Derate Factor:	0.77
AC Rating	30.8 kW
Array Type:	Fixed Tilt
Array Tilt:	39.0°
Array Azimuth:	180.0°
Energy Parameters	
Cost of Electricity:	13.34 ₵/kWh

Table 6 – Station Identification

To calculate the yearly value of energy produced based on the given parameters, the PVWatts calculator at www.pvwatts.org and the station identification information for Sterling, VA was used. As shown in ***Table 6,*** a yearly value of 49,282 kWh was calculated. Sterling, VA was selected since it was the closest location to Washington, D.C. The PV Watts calculator provides the yearly AC energy produced by the system.

PV Watts Energy Production Results			
Month	**Solar Radiation (kWh/m²/day)**	**AC Energy (kWh)**	**Energy Value ($)**
1	3.59	3544	283.52
2	4.28	3719	297.52
3	4.80	4492	359.36
4	5.34	4644	371.52
5	5.32	4534	362.72
6	5.66	4676	374.08
7	5.46	4556	364.48
8	5.38	4569	365.52
9	5.07	4258	340.64
10	4.72	4227	338.16
11	3.56	3206	256.48
12	3.03	2854	228.32
Year	4.68	49282	3942.56
PV Watts Factor = Annual AC Energy/System DC Rating = 1232			

Table 7 – PV Watts Energy Production Results

6.9 Constructability of Support System

The array on the roof will be a fixed tilt array set at 39.2° in order to maximize energy absorption. This also allows the solar panels to provide shade to the green roof vegetation. Typical green roofs can suffer during the hot, dry months of summer.

In this case, an ISYS Roof Mount System by Unirac was selected because it is a "low cost – high quality easily deployable mounting solution for commercial buildings that have flat or low sloping roofs." See ***Figure 21*** below for a picture of the ISYS Roof Mount system. One factor that had to be considered was that this support system would have to be installed on top of a green roof. After talking to Teris Pantazes of Seven Seas Energy, he assured that this system would be sufficient when interfaced with a green roof. The ISYS Roof Mount system also does not require any roof penetrations. Also, one may wonder how the ISYS Roof Mount system addresses problems that are commonly encountered on a commercial roof. These problems include, but are not limited to, drains, vent pipes, and electrical conduit. Typically, the ISYS Roof Mount system provides an average of 10" clearance under the lowest support beam. Additional height can be achieved by using different styles or sizes of the roof support pad products that can increase the sub-array height above the roof surface. This additional height may be needed to accommodate for the green roof to ensure that the green roof vegetation can survive.

Figure 21 – ISYS Roof Mount System

6.10 PV Impact on Building Cost

The following cost and power analysis provides initial cost estimates for the Office Building. It is assumed that the amount of PV panels being used on the roof will not take the Office Building off of the grid. The system is just not big enough to provide enough power for the entire building. The first thing to be analyzed is the potential solar radiation gain that an array system of this size and location can produce. Using the PV Watts software, as seen earlier in this analysis, the following results were obtained.

Power Data (kWh/m^2/day) - Sterling, VA (Washington, DC)												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Power	3.59	4.28	4.80	5.34	5.32	5.66	5.46	5.38	5.07	4.72	3.56	3.03

Table 8 – Power Data

For Washington, DC, or Sterling, VA to be exact, a 40 kW array system can produce a total of 49,282 kWh per year (AC), with the maximum gain occurring in June and the minimum occurring in December.

Many owners are turned off from PV systems because of the initial investment of the system. Although the initial investment may be significant, the cost of the system can be returned in what is known as the payback period. By definition, a payback period refers to the period of time required for the return on an investment to “repay” the sum of the original investment. The owner is more inclined to install a PV system if there is a reasonable payback period.

When analyzing the amount of power generated by the solar array, the following figures were used in accordance with the Power Data shown in ***Table 8*** above:

- Panel Power – 220W (max power)
- Panel Voltage – 36.2V (open circuit voltage)
- Washington, DC Energy Price - $0.1334/kWh
- Panel Installation - $5.75/watt

6.10.1 Initial Investment

When looking into the cost of photovoltaic systems and their installation, it was determined that the overall cost of the system would be about $5.75 per watt. This includes the installation and support structure for the 39.2° tilt used for maximum solar gain.

Washington, D.C. has one of the most aggressive incentive packages for photovoltaic solar installations and energy efficiency improvements than many of the country’s “real” states.

Many people look to Washington, D.C. as a leader in demonstrating America's priorities. The following are the credits found to be available to the Office Building and used to calculate the payback period and feasibility of the Office Building photovoltaic array:

- Business Energy Investment Tax Credit (BEIT) – 30% gross installation cost
- District of Columbia Renewable Energy Incentive Program (DC-REIP)
  - $3.00/W DC for the first 3 kW installed
  - $2.00/W DC for the following 7 KW installed
  - $1.00/W DC for the next 10 kW installed
  - Incentives are capped at a maximum of $33,000 per site per year

The following table depicts the initial investment cost of the system:

Initial Investment			
Item	Quantity	Cost/Unit	Total Cost
PV Panels	40,000 W	$5.75/W	$ 230,000.00
Inverters	6	$ 3,000.00	$ 18,000.00
Incentive Savings	BEIT: $90,000		($69,000)
	DC-REIP: $33,000		($33,000)
Total Cost			$ 146,000.00

Table 9 – Initial Investment of PV System

6.10.2 Savings and Life-Cycle

Using the data provided by the PV Watt Calculator and environmental factors, the following power savings were calculated.

PV Watts Energy Production Results		
Month	AC Energy (kWh)	Energy Value ($)
1	3544	283.52
2	3719	297.52
3	4492	359.36
4	4644	371.52
5	4534	362.72
6	4676	374.08
7	4556	364.48
8	4569	365.52
9	4258	340.64
10	4227	338.16
11	3206	256.48
12	2854	228.32
Year	49282	3942.56

Table 10 – Initial Investment of PV System

The addition of a 40 kW solar array would essentially save **$3,942.56** on electricity cost annually. This equates to a total of $80,000 over the span of 20 years.

Considering the initial investment of $146,000 and the fact that the array produces $4,000 of electricity per year in savings, the total payback period for the system would be approximately **36 years**. However, this did not take into account the inflation of energy price over time. Therefore, the payback period would most likely be less than 36 years. Assuming that the life cycle of the building is 50 years, the initial investment would end up being paid off, but at that time the building will need to be updated soon.

6.11 Recommendations and Conclusion

Through the analysis, the following results were determined:

- A 40 kW solar array would occupy approximately 3600 sf of the roof and provide 49,282 kWh of energy annually.
- The proposed array would require an initial investment of $146,000 after the incentive savings were taken into account.
- Through a savings and life-cycle cost analysis, it was determined that $3,942.56 worth of electricity would be produced annually.
- The payback period of the proposed 40 kW array system would be approximately 36 years.

These results have led me to recommend that the array system not be installed at this time. From the perspective of the owner, the benefits do not outweigh the initial investment.

7.0 Coordination of the Chilled Water Plant

7.1 Problem Identification

The interior of the Office Building was completely demolished with the exception of an existing chilled water plant located in the Subbasement level, which provides chilled water for an adjacent building and must remain in operation 24/7. The chillers in the subbasement are eventually going to be replaced, but they are being replaced in the exact location of where they sit now. The project manager identified this as the largest constructability challenge. Building Information Modeling (BIM) was used on this project, but it could have been used more effectively to deal with this problem.

7.2 Research Goal

The goal of this analysis is to determine how BIM could have been used more effectively to help with the coordination of the chilled water plant.

7.3 Background Information

Before demolition took place in the Office Building, there were four chillers located in the sub-basement. Two out of the four chillers were only replaced five years so they were to remain in the sub-basement and not be demolished. These two chillers were intended to keep running throughout the construction process so the adjacent building would continue to receive chilled water. Meanwhile, there are six cooling towers located on the roof. At first, it was determined that only two out of the six cooling towers were needed for the two chillers to continue to run properly. The drawings had called for four out of the six cooling towers to be demolished. When the project team went to look at the cooling towers before demolition, they discovered that all six cooling towers were running at full power to keep the two chillers running. Because the cooling towers were in such bad shape, it was necessary for all of them to be running. Another issue that arose with the chilled water plant was the sequence of construction listed out on the drawings. The drawings called for a shutdown of two weeks, but the government would not allow it. These issues eventually led the general contractor to issue a change order to the owner calling for temporary chillers. This change order allowed the contractor to demo all six cooling towers on the roof and all four chillers in the sub-basement at one time without having any shutdowns. This change ended up being a more efficient process for the contractor to go about the demolition and replacement of the chillers and cooling towers.

7.4 How BIM Could Have Helped

Although BIM was used throughout the project to help coordinate the MEP trades, it could have been used more efficiently to help with the coordination of the chilled water plant located in the sub-basement. BIM could have been used more efficiently in the beginning of the design and construction process to completely avoid this problem in the first place. The existing conditions could have been assessed more accurately and BIM could aid in that process. With the use of BIM, there would be more flexibility in finding a location for the new chillers so they did not interfere with the demolition of the existing chillers. Part of the BIM process is to survey of the existing conditions so BIM can be used to the best of its ability. A better survey of the chillers and cooling towers could have been performed. With a more in depth survey, the project team would have discovered that using only two of the existing cooling towers were not strong enough to run the two chillers in the sub-basement.

BIM would also be helpful with a constructability review of the process of demolishing and replacing the chillers and cooling towers. There were two options that needed to be thought through; keeping the two existing chillers running or bringing in temporary chillers in the first place and doing a complete demolition. With the first option, the project team has to take into account a two-week shutdown when putting the schedule together. They would also have to coordinate bringing a crane onto the site on two separate occasions to first remove four of the cooling towers and then the remaining two cooling towers. Having a crane on-site for an additional day will cost money and take up some valuable time. With the second option, the owner is paying for the temporary chillers to be on-site for however long the demolition would take. Temporary chillers cost $40,000 per month per chiller. However, there is no lost time with a shutdown. Also, the second option is more efficient and flexible for the contractor and it offers more reliability for the owner. The upfront cost of using BIM more efficiently is worth it to the owner because it will eventually pay for itself. There would be no need for a change order and the cost of the temporary chillers would not be a surprise cost for the project team.

BIM could also be used to help quickly develop a new design for the change order so that the changes are coordinated properly with the existing conditions. Once it had been determined that the proposed sequence of construction would not work and that a change order was necessary, BIM could help implement a new design quickly and accurately. The current BIM model can be adjusted to incorporate all of the new changes listed out on the change order. A screenshot of the current BIM model can be seen below in ***Figure 22.***

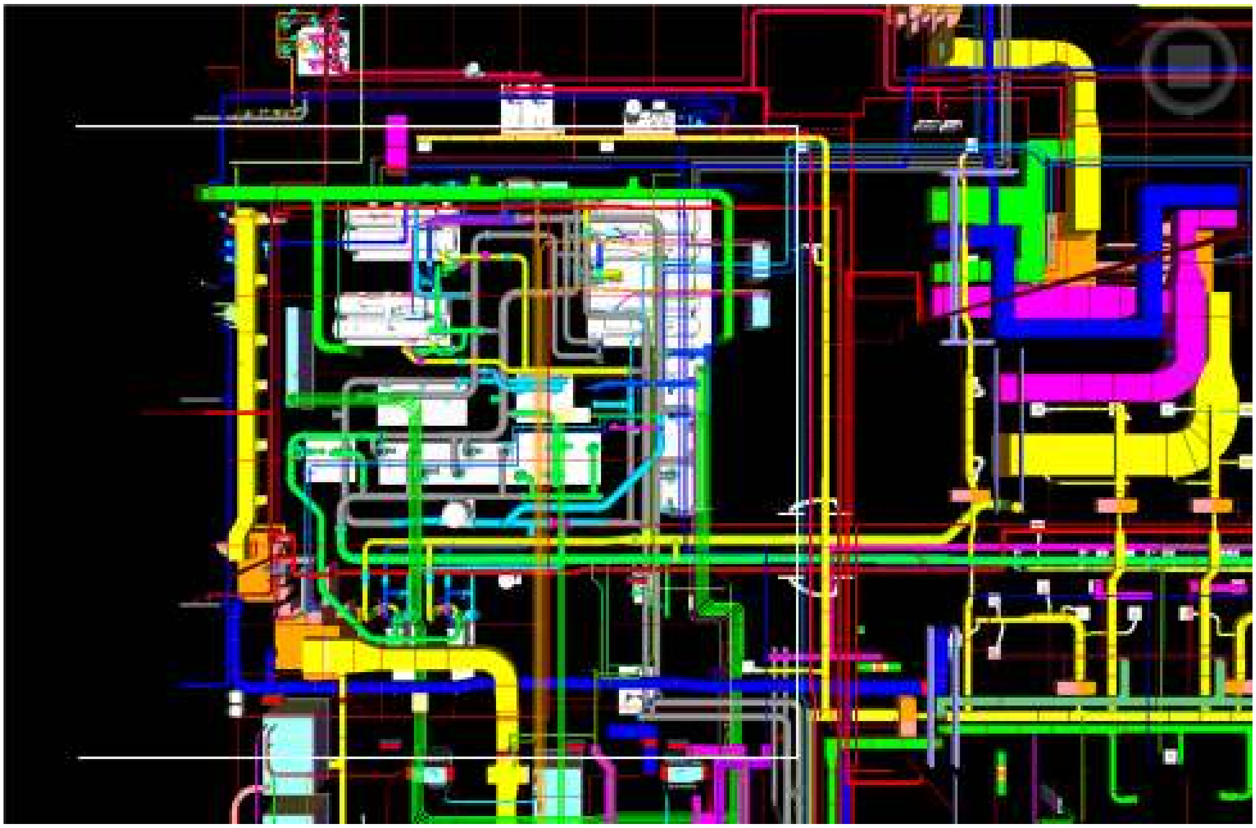


Figure 22 – Screenshot of Current BIM Model

This would allow the project team and everyone involved to see a model of what is actually going to happen. BIM is a great tool because it can speed up the coordination process and help save time and money with the schedule. Temporary chillers are expensive to rent and operate so it is key to minimize the amount of time that they are needed. Remember, temporary chillers cost $40,000 per month per chiller. BIM is a great tool and can be very beneficial in the event of a change order.

Once it was decided that temporary chillers were needed, BIM could have been used to help plan and coordinate the work and logistics of the temporary chillers installation, commissioning, and eventual replacement with the new equipment. BIM could incorporate the site plan and find the best location for the temporary chillers. The flexibility of BIM would allow the project team to test out many different locations. BIM would also be able to incorporate the utilities to locate all of the connections necessary to ensure that the chiller is properly delivering chilled water to the adjacent building. BIM would also be able track the performance of the temporary chillers and the loads throughout the day. Overall, BIM would be a great asset to help coordinate the installation of the temporary chillers and eventually the new equipment.

ACOUSTIC BREADTH

7.5 Acoustic Concerns of the Temporary Chillers

One of the concerns of using temporary chillers on site for an extended amount of time is the amount of sound that they can produce. Having the project located in the center of Washington, D.C. and walking distance to the U.S. Capitol, one has to take into consideration the affect that the temporary chillers would have on not only the construction workers, but the people working nearby. The Office Building is located next to other office buildings on three of its sides. The temporary chillers were placed on the north side of the building, right across the street from another office building. Currently, the temporary chillers have no sound treatment. The goal of this acoustic analysis is to reduce the airborne sound pressure around the temporary chillers. In order to achieve this goal, a sound barrier must be constructed around the temporary chillers and then the attenuation must be calculated. The attenuation is how much the sound of the chillers is being reduced as a result of the sound barrier. The equation used to calculate this is:

$$\mathbf{A = 10*\log(H^2/R) + 10*\log \mathit{f} - 17}, \text{ where}$$

H = height above the acoustical line of sight
R = distance between the source and the barrier wall
f = frequency

The airborne sound pressure information for the selected chillers can be seen in ***TABLE 12*** below. These values were attained from the manufacturer of the temporary chillers. These sound pressure levels were measured in an acoustical free-field, i.e. a non-reflective environment. It was noted in the submittal that field sound measurements can vary significantly as a function of the reflectivity and proximity of nearby surfaces and the presence of other sound sources.

Airborne Sound Pressure, dB (L1)									
	Octave Band Center Frequency, Hz								
Percent Load	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
100	71	72	74	74	74	74	75	83	76
75	73	72	77	78	75	74	78	83	72
50	75	74	78	78	78	77	80	82	72
25	76	76	79	79	79	78	81	82	74

Table 12 – Airborne Sound Pressure, no sound treatment

Once the above values were attained, the next step is to calculate the attenuation, or noise reduction, after the sound barriers were set into place. The height above the acoustical line of sight, H, is 10 feet and the distance between the source and the barrier wall, R, is 3 feet. The attenuation numbers can be seen below in ***TABLE 13.***

Sound Attenuation/Noise Reduction, dB (A)									
	Octave Band Center Frequency, Hz								
Percent Load	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
100	13.2	16.2	19.2	22.2	25.2	28.2	31.2	34.3	37.3
75	13.2	16.2	19.2	22.2	25.2	28.2	31.2	34.3	37.3
50	13.2	16.2	19.2	22.2	25.2	28.2	31.2	34.3	37.3
25	13.2	16.2	19.2	22.2	25.2	28.2	31.2	34.3	37.3

Table 13 – Sound Attenuation/Noise Reduction

The final step is to calculate how much sound can be heard outside of the sound barriers. This can be achieved by subtracting the airborne sound pressure of the temporary chillers before the sound barriers were put into place by the attenuation values. The final answers can be seen below in ***TABLE 14.***

Airborne Sound Pressure, dB (L2)									
	Octave Band Center Frequency, Hz								
Percent Load	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
100	57.8	55.8	54.8	51.8	48.8	45.8	43.8	48.7	38.7
75	59.8	55.8	57.8	55.8	49.8	45.8	46.8	48.7	34.7
50	61.8	57.8	58.8	55.8	52.8	48.8	48.8	47.7	34.7
25	62.8	59.8	59.8	56.8	53.8	49.8	49.8	47.7	36.7

Table 14 – Airborne Sound Pressure, with sound barrier

As one can tell from the results in ***TABLE 14***, adding a sound barrier around the temporary chillers can reduce the sound levels ranging from 13 to 37 dB, depending on which octave band is looked at. These sound levels would provide a more comfortable work environment for the construction workers and people working close to the site.

7.6 Conclusions and Recommendations

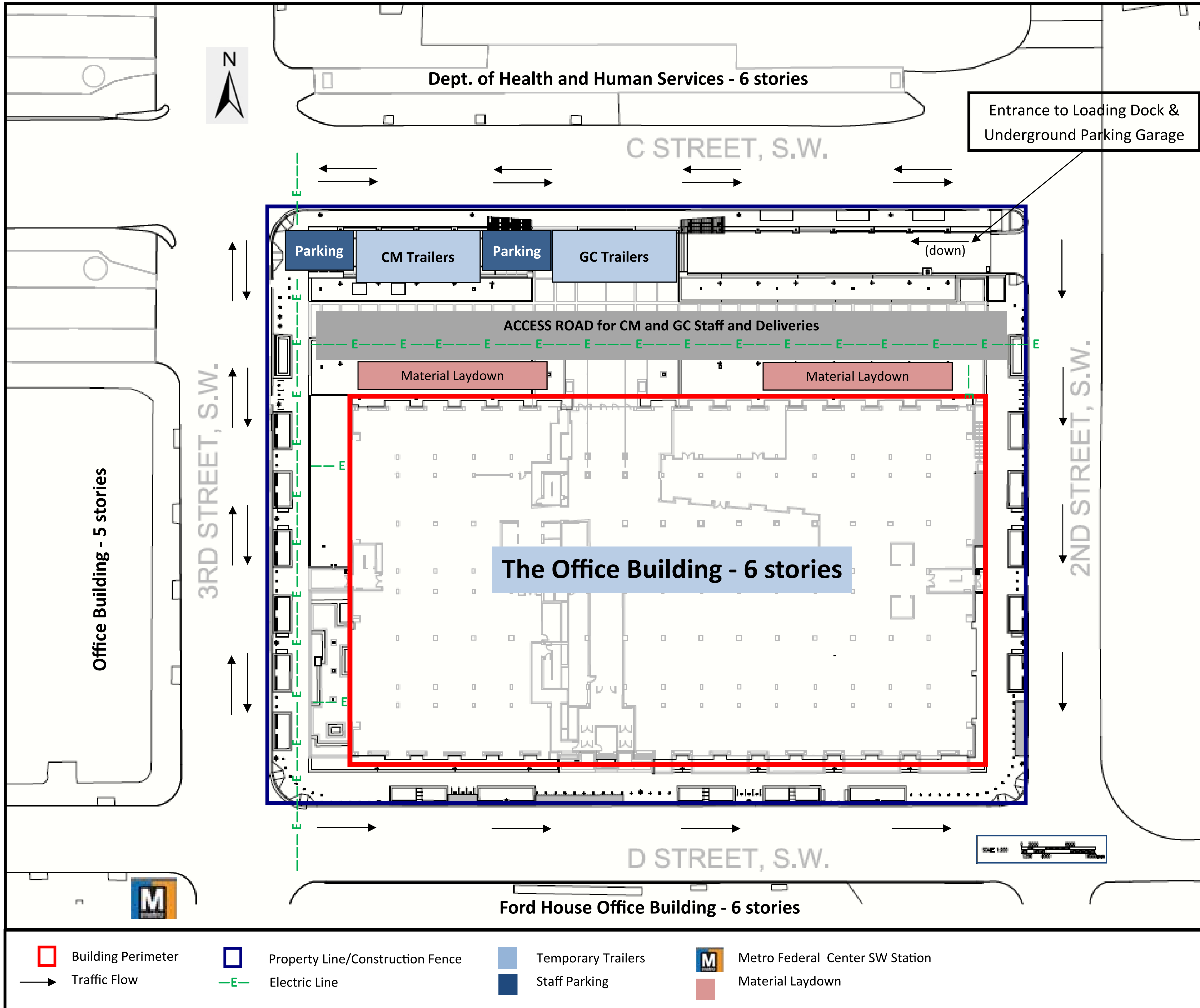
BIM can be a great tool for any project as long as it is executed properly and used in the right way. Although nothing went with BIM for the Office Building, there were some design flaws that led to a costly change order. The design engineers made the mistake of placing new piping in the chiller plant in the exact same location of where the old piping was located. The chiller

plant had to remain in operation 24/7 so this problem had to be fixed. As a result, temporary chillers had to be brought on to the project so that they could demo the existing chillers that were scheduled for demolition.

If there had been better communication between the design teams during the design stage of the project, this problem could have been avoided and temporary chillers could have been used from the beginning. The project manager indicated that using temporary chillers is better for them for coordination reasons. To reduce the expense of the temporary chillers, it is recommended that the demo and replacement of the chillers in the chiller plant be done in the very beginning of the project so that the temporary chillers are on site for as little time as possible. BIM could have helped the project team weight their options from the beginning so a change order could have been avoided.

Appendix A

Existing Conditions Site Plan



Lynn Appel

Technical Assignment #1

Site Layout Plan

The Office Building

Appendix B

Square Foot Cost Estimates

Office Building in D.C.

Building Size	550,000	Building Use:	Office
No. of Floors	6	Foundation:	CON
Building Height	90'	Ext. Walls:	CUR
1st Floor Height	12.5'	Int. Walls:	DRY
1st Floor Size	37,000	Roof Type:	MEM
		Floor Type:	CON
		Project Type:	NEW

Division		Percent	SF Cost	Amount
00	Procurement & Contracting Req.	2.08%	$3.02	$1,659,096
01	General Requirements	12.41%	$18.03	$9,917,603
02	Existing Conditions	3.12%	$4.53	$2,490,756
03	Concrete	18.83%	$27.36	$15,050,310
04	Masonry	1.73%	$2.51	$1,379,010
05	Metals	9.16%	$13.31	$7,321,398
06	Woods, Plastics & Composites	0.19%	$0.28	$154,908
07	Thermal & Moisture Protection	1.00%	$1.45	$798,335
08	Openings	20.77%	$30.18	$16,600,312
09	Finishes	1.38%	$2.00	$1,100,428
10	Specialties	3.21%	$4.67	$2,569,249
12	Furnishings	1.22%	$1.78	$978,353
14	Conveying Systems	4.23%	$6.15	$3,380,595
15	HVAC	13.15%	$19.11	$10,509,042
16	Electrical	7.54%	$10.96	$6,027,030
Total Project Costs			$145.34	$79,936,425

Square Foot Cost Estimate Report

Estimate Name:	**Office Building in DC**
Building Type:	**Office, 5-10 Story with Precast Concrete Panel / Steel Frame**
Location:	**WASHINGTON, DC**
Story Count:	**6**
Story Height (L.F.):	**12.5**
Floor Area (S.F.):	**550000**
Labor Type:	**Union**
Basement Included:	**No**
Data Release:	**Year 2010 Quarter 3**
Cost Per Square Foot:	**$138.47**
Building Cost:	**$76,158,000**

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 by RSMeans.

		% of Total	Cost Per S.F.	Cost
A Substructure		2.10%	$2.23	$1,228,000
A1010	Standard Foundations		$1.25	$690,000
A1030	Slab on Grade		$0.81	$445,000
A2010	Basement Excavation		$0.05	$25,500
A2020	Basement Walls		$0.12	$67,500
B Shell		22.70%	$23.71	$13,039,000
B1010	Floor Construction		$17.65	$9,707,500
B1020	Roof Construction		$0.91	$501,500
B2010	Exterior Walls		$3.49	$1,920,000
B2020	Exterior Windows		$0.70	$383,500
B2030	Exterior Doors		$0.23	$129,000
B3010	Roof Coverings		$0.72	$397,500
C Interiors		21.50%	$22.45	$12,345,000
C1010	Partitions		$1.53	$840,000
C1020	Interior Doors		$2.56	$1,407,000
C1030	Fittings		$0.70	$384,500
C2010	Stair Construction		$2.68	$1,475,500
C3010	Wall Finishes		$0.88	$482,000
C3020	Floor Finishes		$7.95	$4,375,000
C3030	Ceiling Finishes		$6.15	$3,381,000
D Services		53.70%	$56.12	$30,865,500
D1010	Elevators and Lifts		$15.91	$8,749,500
D2010	Plumbing Fixtures		$2.22	$1,222,500

D2020	Domestic Water Distribution		$0.49	$270,000
D2040	Rain Water Drainage		$0.25	$138,000
D3050	Terminal & Package Units		$15.67	$8,620,000
D4010	Sprinklers		$2.71	$1,490,000
D4020	Standpipes		$0.62	$343,000
D5010	Electrical Service/Distribution		$0.27	$146,500
D5020	Lighting and Branch Wiring		$11.54	$6,346,500
D5030	Communications and Security		$5.36	$2,950,000
D5090	Other Electrical Systems		$1.07	$589,500
E Equipment & Furnishings		0.00%	$0.00	$0
E1090	Other Equipment		$0.00	$0
F Special Construction		0.00%	$0.00	$0
G Building Sitework		0.00%	$0.00	$0
Total Building Cost			$138.47	$76,158,000

Appendix C

Detailed Structural Estimate

Cast-In-Place Concrete Estimate Take-Off Charts				
In-Fill Slabs on Existing Openings				
Floor	**Area (SF)**	**Thickness (FT)**	**Quantity**	**Concrete (CY)**
SB	54	0.667	4	5.34
SB	1776.33	0.667	4	175.53
SB	65	0.667	4	6.42
SB	30	0.667	4	2.96
SB	136	0.667	4	13.44
SB	120	0.667	4	11.86
BT	514.17	0.667	3.5	44.46
BT	145.42	0.667	3	10.78
BT	536.25	0.667	17	225.21
BT	518.33	0.667	9.5	121.64
BT	171.67	0.667	3.5	14.84
1	536.25	0.667	12	158.97
1	518.33	0.667	11	140.85
1	171.67	0.667	3	12.72
1	514.17	0.667	2	25.40
2	536.25	0.667	18	238.45
2	518.33	0.667	9	115.24
2	171.67	0.667	9	38.17
3	357.5	0.667	9	79.48
3	518.33	0.667	12.5	160.06
3	171.67	0.667	9	38.17
3	536.25	0.667	6	79.48
4	268.125	0.667	4	26.49
4	518.33	0.667	4	51.22
4	357.5	0.667	4	35.33
5	536.25	0.667	18	238.45
5	518.33	0.667	13	166.46
5	171.67	0.667	10	42.41
6	536.25	0.667	16	211.96
6	518.33	0.667	13	166.46
6	171.67	0.667	9	38.17
				2,696.43

Cast-in-Place New Concrete Slabs					
Floor	Area/ Department	Area (SF)	Thickness (FT)	Quantity	Concrete (CY)
1	NE	200	0.417	13	40.16
1	SE	200	0.417	13	40.16
1	SWQ	400	0.417	4	24.71
1	NWQ	400	0.417	4	24.71
1	NEQ	400	0.417	4	24.71
1	SEQ	400	0.417	4	24.71
1		40	0.417	91	56.22
1		40	0.417	82	50.66
1		32	0.417	168	83.03
2	NE	200	0.417	13	40.16
2	SE	200	0.417	13	40.16
2	SWQ	400	0.417	4	24.71
2	NWQ	40	0.417	4	2.47
2	NEQ	400	0.417	4	24.71
2	SEQ	400	0.417	4	24.71
2		40	0.417	91	56.22
2		40	0.417	82	50.66
2		32	0.417	168	83.03
3	NE	200	0.417	13	40.16
3	SE	200	0.417	13	40.16
3	SWQ	400	0.417	4	24.71
3	NWQ	400	0.417	4	24.71
3	NEQ	400	0.417	4	24.71
3	SEQ	400	0.417	4	24.71
3		40	0.417	91	56.22
3		40	0.417	82	50.66
3		32	0.417	168	83.03
4	NE	200	0.417	13	40.16
4	SE	200	0.417	13	40.16
4	SWQ	400	0.417	4	24.71
4	NWQ	400	0.417	4	24.71
4	NEQ	400	0.417	4	24.71
4	SEQ	400	0.417	4	24.71
4		40	0.417	100	61.78

4		40	0.417	100	61.78
4		32	0.417	168	83.03
5	NE	200	0.417	13	40.16
5	SE	200	0.417	13	40.16
5	SWQ	400	0.417	4	24.71
5	NWQ	400	0.417	4	24.71
5	NEQ	400	0.417	4	24.71
5	SEQ	400	0.417	4	24.71
5		40	0.417	91	56.22
5		40	0.417	82	50.66
5		32	0.417	168	83.03
6	NE	200	0.417	13	40.16
6	SE	200	0.417	13	40.16
6	SWQ	400	0.417	4	24.71
6	NWQ	400	0.417	4	24.71
6	NEQ	400	0.417	4	24.71
6	SEQ	400	0.417	4	24.71
6		40	0.417	91	56.22
6		40	0.417	82	50.66
6		32	0.417	168	83.03
PH/R		104.5	0.417	10	16.14
1	PVLN	1294.8	0.417	2	39.99
					2,264.94

Cast-in-Place Concrete Estimate Pricing

Description	Quantity	Unit	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O&P	Total Cost
In-Fill Slabs on Existing Openings (3000 psi)	2,696.4	CY	$ 106.00	$ 22.50	$ 10.90	$ 139.40	$ 182.00	$ 490,744.80
CIP New Concrete Slabs	2,246.4	CY	$ 106.00	$ 22.50	$ 10.90	$ 139.40	$ 182.00	$ 408,844.80
							TOTAL:	**$ 899,589.60**

Structural Steel Estimate Take-Off Charts

Columns

Type		Length (ft)	# of 12' Section	Quantity	Total Section
SE Elevation	W10x77	77	6	1	6
	W10x68	96	8	1	8
	W8x67	125	10	1	10
	W8x48	48	4	1	4
NE Elevation	W10x77	77	6	1	6
	W10x68	96	8	1	8
	W8x67	125	10	1	10
	W8x48	48	4	1	4
SW Elevation	W10x77	77	6	1	6
	W10x68	67	6	1	6
	W8x67	125	10	1	10
	W8x48	48	4	1	4
NW Elevation	W10x77	77	6	1	6
	W10x68	67	6	1	6
	W8x67	125	10	1	10
	W8x48	48	4	1	4

Beams

Type	Unit	Length	Quantity	Total
W21x50	LF	12	24	288
W21x50	LF	10	48	480
W21x50	LF	18.667	24	448
W21x50	LF	11	24	264
W21x57	LF	648	1	648
W12x87	LF	150	1	150
W18x40	LF	20	1	20

Central Atrium

Type	Length (ft)	# of 14' Sections	Quantity	Total Sections
HSS 10x8x5/8	311	22	1	22
HSS 10x8x5/8	200	14	7	100
HSS 10x8x5/8	51.833	4	6	22

Entry Atrium

Type	Length (ft)	# of 14' Sections	Quantity	Total Sections
2 - HSS 10x8x1/2	50.000	4	2	7
2 - HSS 8x8x3/8	11.396	1	2	2

2 - HSS 8x8x3/8	2.333	1	6	6
2 - HSS 8x8x3/8	40.000	3	2	6
3 - HSS 10x8x1/2	50.000	4	2	7
3 - HSS 8x8x5/8	40.000	3	2	6
3 - HSS 8x8x3/8	2.333	1	2	2
3 - HSS 8x8x1/2	12.500	1	2	2
4 - HSS 10x8x1/2	50.000	4	2	7
4 - HSS 8x8x3/8	11.396	1	2	2
4 - HSS 8x8x3/8	2.333	1	6	6
4 - HSS 8x8x3/8	40.000	3	2	6
5 - HSS 10x8x1/2	50.000	4	2	7
5 - HSS 8x8x5/8	40.000	3	1	3
5 - HSS 8x8x5/8	5.000	1	9	9
6 - HSS 10x8x1/2	50.000	4	2	7
6 - HSS 8x8x3/8	11.396	1	2	2
6 - HSS 8x8x3/8	2.333	1	6	6
6 - HSS 8x8x3/8	40.000	3	2	6
PH/R - HSS 8x8x5/8	4.000	1	3	3
PH/R - HSS 8x8x5/8	90.000	1	1	1
PH/R - HSS 8x8x5/8	10.000	1	6	4
PH/R - HSS 8x8x5/8	8.000	1	7	4
Roof - HSS 8x8x5/8	20.000	1	8	11
Roof - HSS 8x8x5/8	5.750	1	5	5
Steel Decking				
Type	**Unit**	**Area**	**Quantity**	**Total**
2" Galvanized, Composite Steel Decking	SF	50	156	7800
2" Galvanized, Composite Steel Decking	SF	385.7	24	9256.8

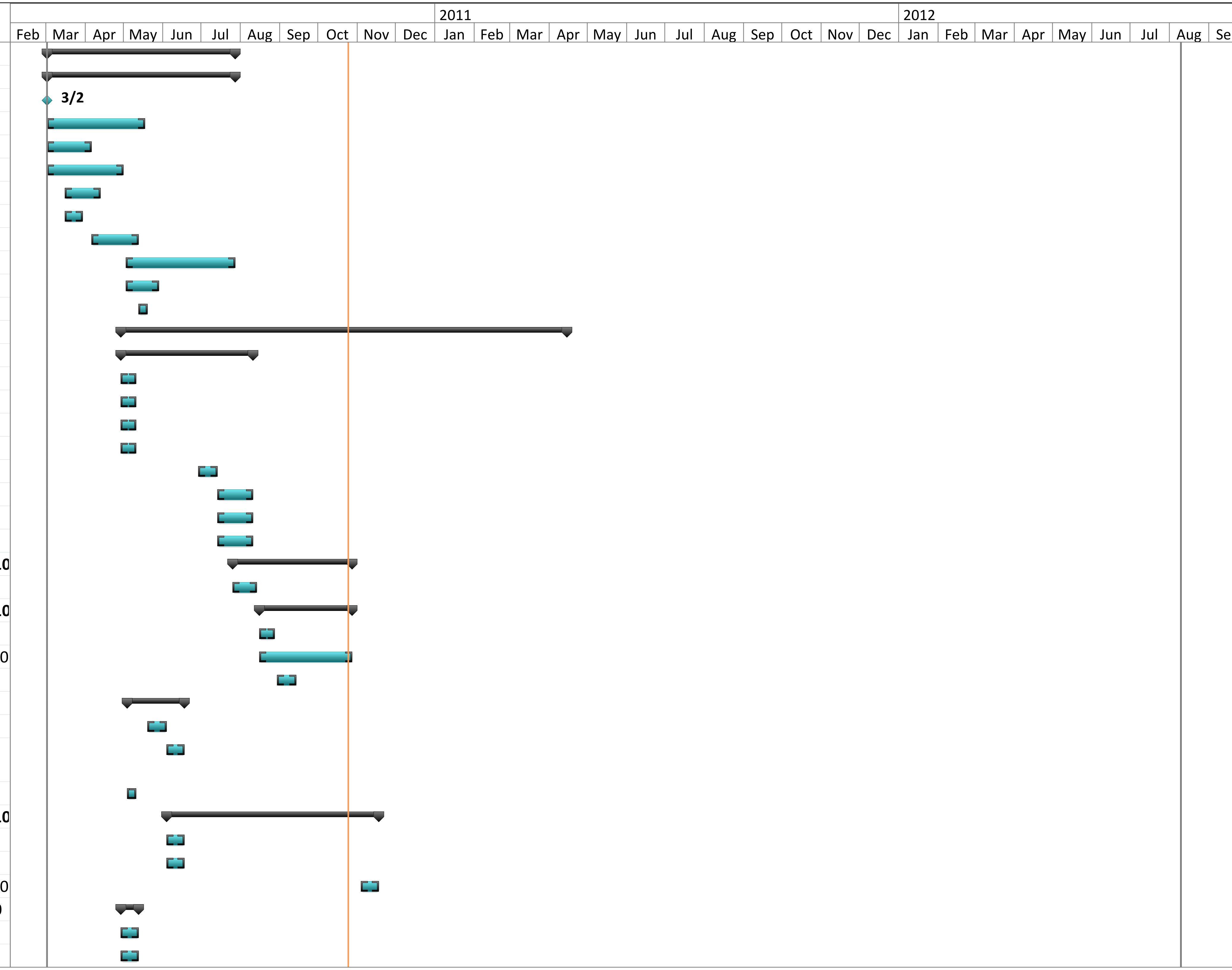
Detailed Structural Steel Estimate Pricing

Description	Quantity	Unit	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O&P	Total Cost
Columns								
W 10x77	308	LF	$ 128.79	$ 2.85	$ 1.74	$ 133.38	$ 147.85	$ 45,537.80
W10x68	326	LF	$ 78.13	$ 2.79	$ 1.70	$ 82.62	$ 92.29	$ 30,086.54
W8x67	500	LF	$ 76.71	$ 2.79	$ 1.70	$ 81.20	$ 90.87	$ 45,435.00
W8x48	192	LF	$ 54.93	$ 2.65	$ 1.63	$ 59.21	$ 66.89	$ 12,842.88
							TOTAL	$ 133,902.22
Beams								
W21x50	1480	LF	$ 57.29	$ 3.72	$ 1.72	$ 62.73	$ 71.25	$ 105,450.00
W21x57	648	LF	$ 75.00	$ 3.27	$ 1.64	$ 79.91	$ 90.05	$ 58,352.40
W12x87	150	LF	$ 105.00	$ 2.38	$ 1.59	$ 108.97	$ 121.86	$ 18,279.00
W18x40	20	LF	$ 48.50	$ 3.53	$ 1.77	$ 53.80	$ 61.15	$ 1,223.00
							TOTAL	$ 183,304.40
Steel Decking								
2" Galvanized, Composite Steel Decking	17056.8	SF	$ 1.50	$ 0.46	$ 0.04	$ 2.00	$ 6,822.40	$ 40,936.00
							TOTAL	$ 40,936.00
Structural Steel Tubing								
HSS 10x8x3/8 (14' sections)	40	Ea.	$ 1,200.00	$ 49.00	$ 32.50	$ 1,281.50	$ 1,445.50	$ 57,820.00
HSS 10x8x1/2 (14' sections)	26	Ea.	$ 1,200.00	$ 49.00	$ 32.50	$ 1,281.50	$ 1,445.50	$ 37,583.00
HSS 8x8x3/8 (14' sections)	16	Ea.	$ 645.00	$ 47.00	$ 31.50	$ 723.50	$ 825.50	$ 13,208.00
HSS 8x8x5/8 (14' sections)	25	Ea.	$ 645.00	$ 47.00	$ 31.50	$ 723.50	$ 825.50	$ 20,637.50
							TOTAL	$ 129,248.50
							TOTAL ESTIMATE:	**$ 545,211.12**

Appendix D

Detailed Project Schedule

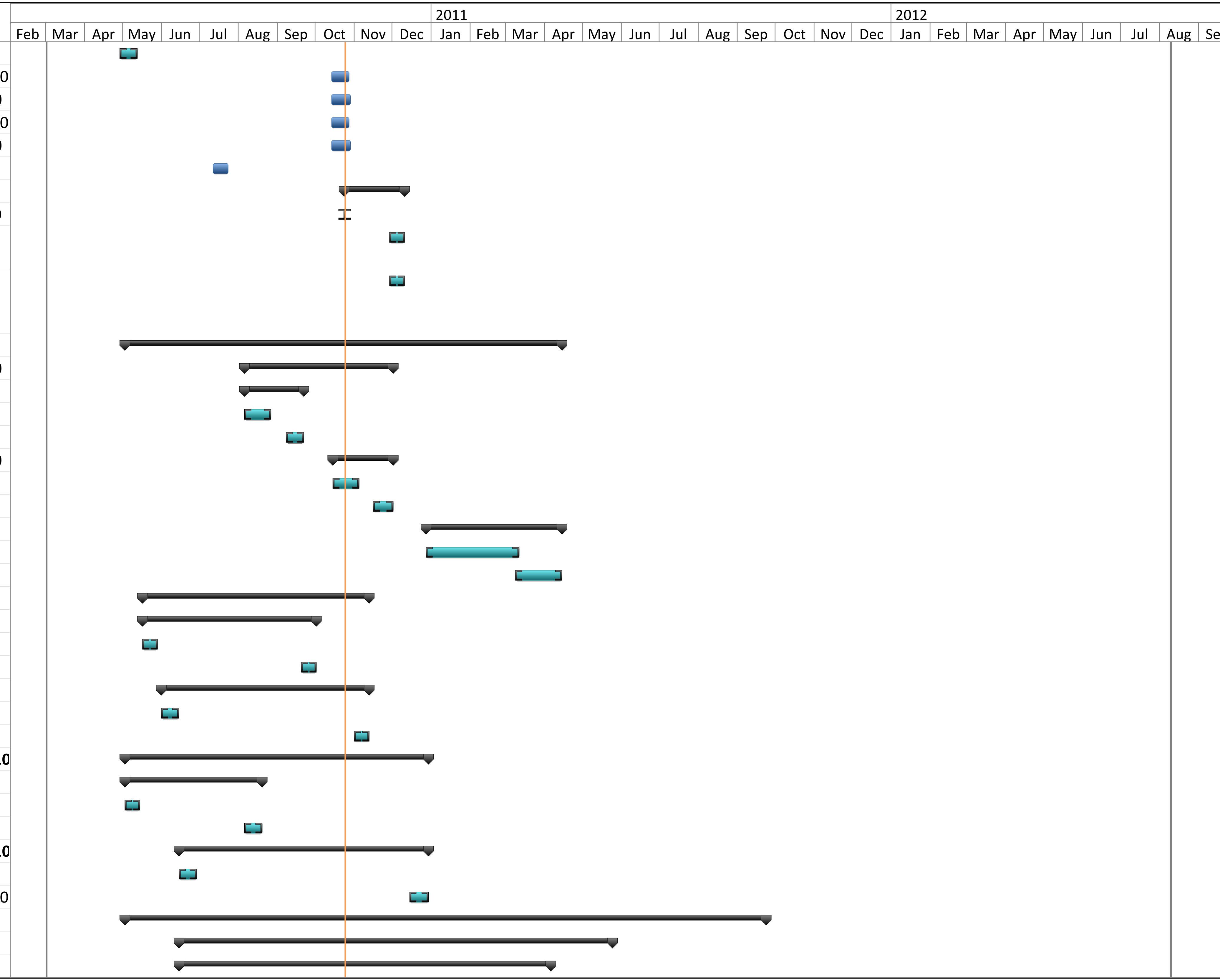
ID	Task Name	Start	Finish
1	**Project Start-up**	**Tue 3/2/10**	**Tue 7/27/10**
2	**Mobilization**	**Tue 3/2/10**	**Tue 7/27/10**
3	Notice to Proceed	Tue 3/2/10	Tue 3/2/10
4	Mobilize	Tue 3/2/10	Mon 5/17/10
5	Electrical Sub Mobilize	Tue 3/2/10	Mon 4/5/10
6	Procure/Buyout Major Subs	Tue 3/2/10	Fri 4/30/10
7	Install Temp. Lighting	Tue 3/16/10	Mon 4/12/10
8	Demo. Sub Mobilize	Tue 3/16/10	Mon 3/29/10
9	Obtain Public Space Permit	Tue 4/6/10	Wed 5/12/10
10	Procure/Buyout Interior Finish Subs	Mon 5/3/10	Tue 7/27/10
11	Plan/Coordinate MEP Equipment	Mon 5/3/10	Fri 5/28/10
12	Site Fencing	Thu 5/13/10	Wed 5/19/10
13	**Demolition**	**Thu 4/29/10**	**Thu 4/14/11**
14	**Sub-Basement**	**Thu 4/29/10**	**Tue 8/10/10**
15	Demo SB Concrete and CMU Walls	Thu 4/29/10	Mon 5/10/10
16	Cut CMU/Conc. Wall Openings	Thu 4/29/10	Mon 5/10/10
17	Demo Doors/Frames/CMU	Thu 4/29/10	Mon 5/10/10
18	Demo all Lighting Fixtures and Recpt.	Thu 4/29/10	Mon 5/10/10
19	Cut/Cap Mechanical	Tue 6/29/10	Tue 7/13/10
20	Demo Electrical	Wed 7/14/10	Tue 8/10/10
21	Demo (abandoned) Chillers 1 and 2	Wed 7/14/10	Tue 8/10/10
22	Demo Non-Essential Mech/Elec.	Wed 7/14/10	Tue 8/10/10
23	**Basement**	**Mon 7/26/10**	**Wed 10/27/10**
24	Demo Basement	Mon 7/26/10	Fri 8/13/10
25	**Parking Garage/Ramp**	**Mon 8/16/10**	**Wed 10/27/10**
26	Demo Doors, Fixtures, & CMU	Mon 8/16/10	Fri 8/27/10
27	Remove MEP	Mon 8/16/10	Wed 10/27/10
28	Demo Topping and Concrete	Mon 8/30/10	Mon 9/13/10
29	**Penthouse**	**Tue 5/4/10**	**Thu 6/17/10**
30	Demo Mech/Elec.	Thu 5/20/10	Thu 6/3/10
31	Demo Existing Phase 1 Cooling Towers	Fri 6/4/10	Thu 6/17/10
32	Demo Existing Phase 2 Cooling	Tue 5/4/10	Mon 5/10/10
33	**Roof (Main Roof & Penthouse Roof)**	**Fri 6/4/10**	**Wed 11/17/10**
34	Demo Rooftop Equip./Assemblies	Fri 6/4/10	Thu 6/17/10
35	Demo Conc. Slab	Fri 6/4/10	Thu 6/17/10
36	Cut opening for Atrium Skylight	Thu 11/4/10	Wed 11/17/10
37	**Sixth Floor**	**Thu 4/29/10**	**Wed 5/12/10**
38	Demo Doors/Frames, MEP	Thu 4/29/10	Wed 5/12/10
39	Demo Concrete Walls	Thu 4/29/10	Wed 5/12/10



Project: Office Building - Detailed
Date: Mon 10/25/10

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

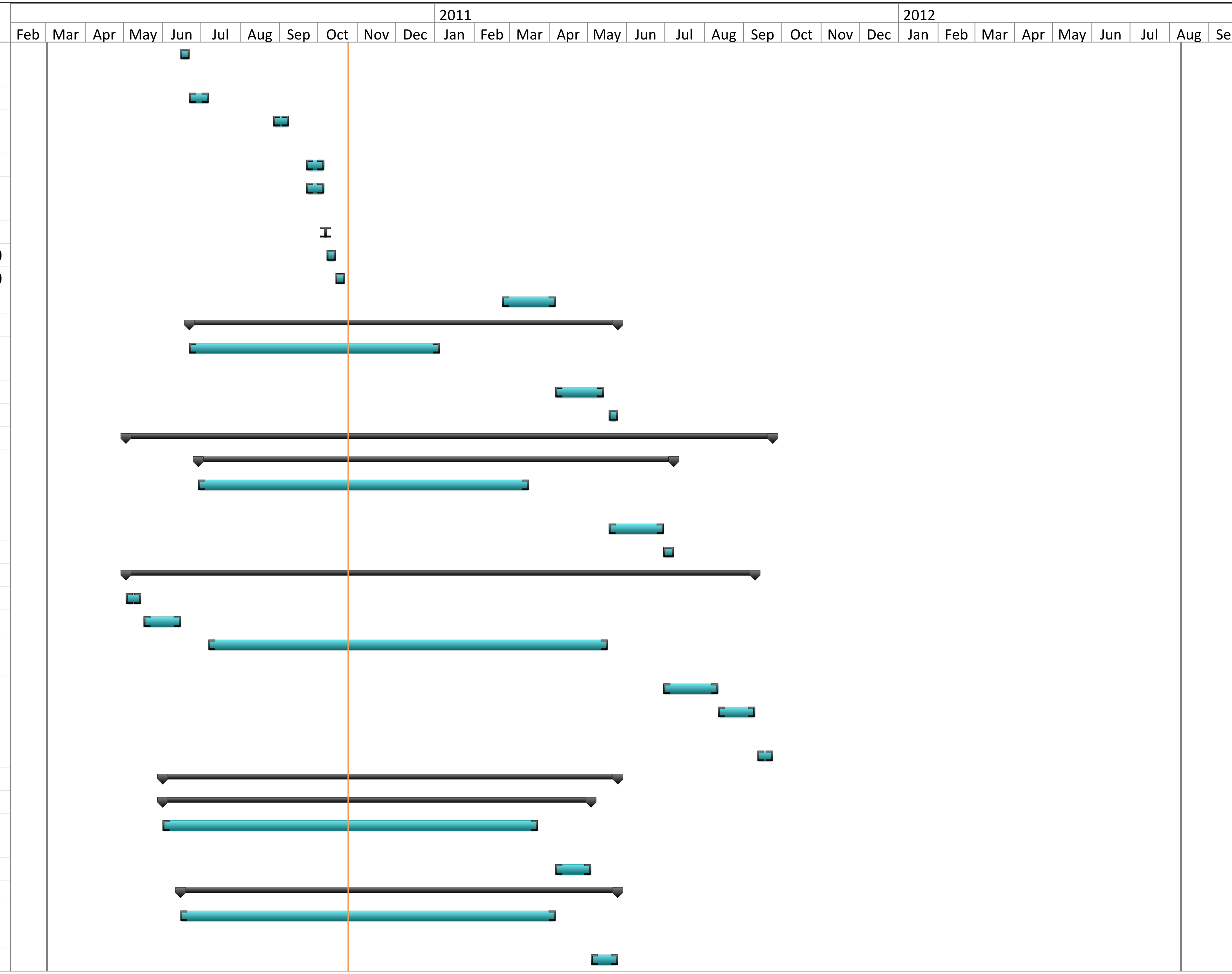
ID	Task Name	Start	Finish
40	Remove Topping	Thu 4/29/10	Wed 5/12/10
41	Fifth Floor	Thu 10/14/10	Wed 10/27/10
42	Fourth Floor	Thu 10/14/10	Thu 10/28/10
43	Third Floor	Thu 10/14/10	Wed 10/27/10
44	Second Floor	Thu 10/14/10	Thu 10/28/10
45	First Floor	Mon 7/12/10	Fri 7/23/10
46	**Elevators**	**Sun 10/24/10**	**Fri 12/10/10**
47	Mobilize Elevators (1,2,3)	Sun 10/24/10	Sun 10/24/10
48	Remove existing elev. Cabs, doors, sills, trim & block	Mon 11/29/10	Fri 12/10/10
49	Remove Cmu walls and handrail/guardrails in the Mach. Room	Mon 11/29/10	Fri 12/10/10
50	**Exterior Demolition**	**Mon 5/3/10**	**Thu 4/14/11**
51	**West Elevation**	**Fri 8/6/10**	**Wed 12/1/10**
52	**Southwest Quadrant**	**Fri 8/6/10**	**Tue 9/21/10**
53	Demo Stone Veneer/Conc. Wall	Fri 8/6/10	Thu 8/26/10
54	Demo Existing Conc. Column	Wed 9/8/10	Tue 9/21/10
55	**Northwest Elevation**	**Fri 10/15/10**	**Wed 12/1/10**
56	Demo Stone Veneer/Conc. Wall	Fri 10/15/10	Thu 11/4/10
57	Demo Existing Conc. Column	Tue 11/16/10	Wed 12/1/10
58	**East Elevation**	**Tue 12/28/10**	**Thu 4/14/11**
59	NE Quadrant	Tue 12/28/10	Fri 3/11/11
60	SE Quadrant	Wed 3/9/11	Thu 4/14/11
61	**North Elevation**	**Mon 5/17/10**	**Fri 11/12/10**
62	**NW Quadrant**	**Mon 5/17/10**	**Fri 10/1/10**
63	Demo Existing Stone Band	Mon 5/17/10	Fri 5/28/10
64	Demo Windows, Panels	Mon 9/20/10	Fri 10/1/10
65	**NE Quadrant**	**Tue 6/1/10**	**Fri 11/12/10**
66	Demo Existing Stone Band	Tue 6/1/10	Mon 6/14/10
67	Demo Windows, Panels	Mon 11/1/10	Fri 11/12/10
68	**South Elevation**	**Mon 5/3/10**	**Wed 12/29/10**
69	**SW Quadrant**	**Mon 5/3/10**	**Thu 8/19/10**
70	Demo Existing Stone Band	Mon 5/3/10	Fri 5/14/10
71	Demo Windows, Panels	Fri 8/6/10	Thu 8/19/10
72	**SE Quadrant**	**Tue 6/15/10**	**Wed 12/29/10**
73	Demo Existing Stone Band	Tue 6/15/10	Mon 6/28/10
74	Demo Windows, Panels	Wed 12/15/10	Wed 12/29/10
75	**Exterior Construction**	**Mon 5/3/10**	**Fri 9/23/11**
76	**West Elevation**	**Tue 6/15/10**	**Tue 5/24/11**
77	**Southwest Quadrant**	**Tue 6/15/10**	**Tue 4/5/11**



Project: Office Building - Detailed
Date: Mon 10/25/10

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

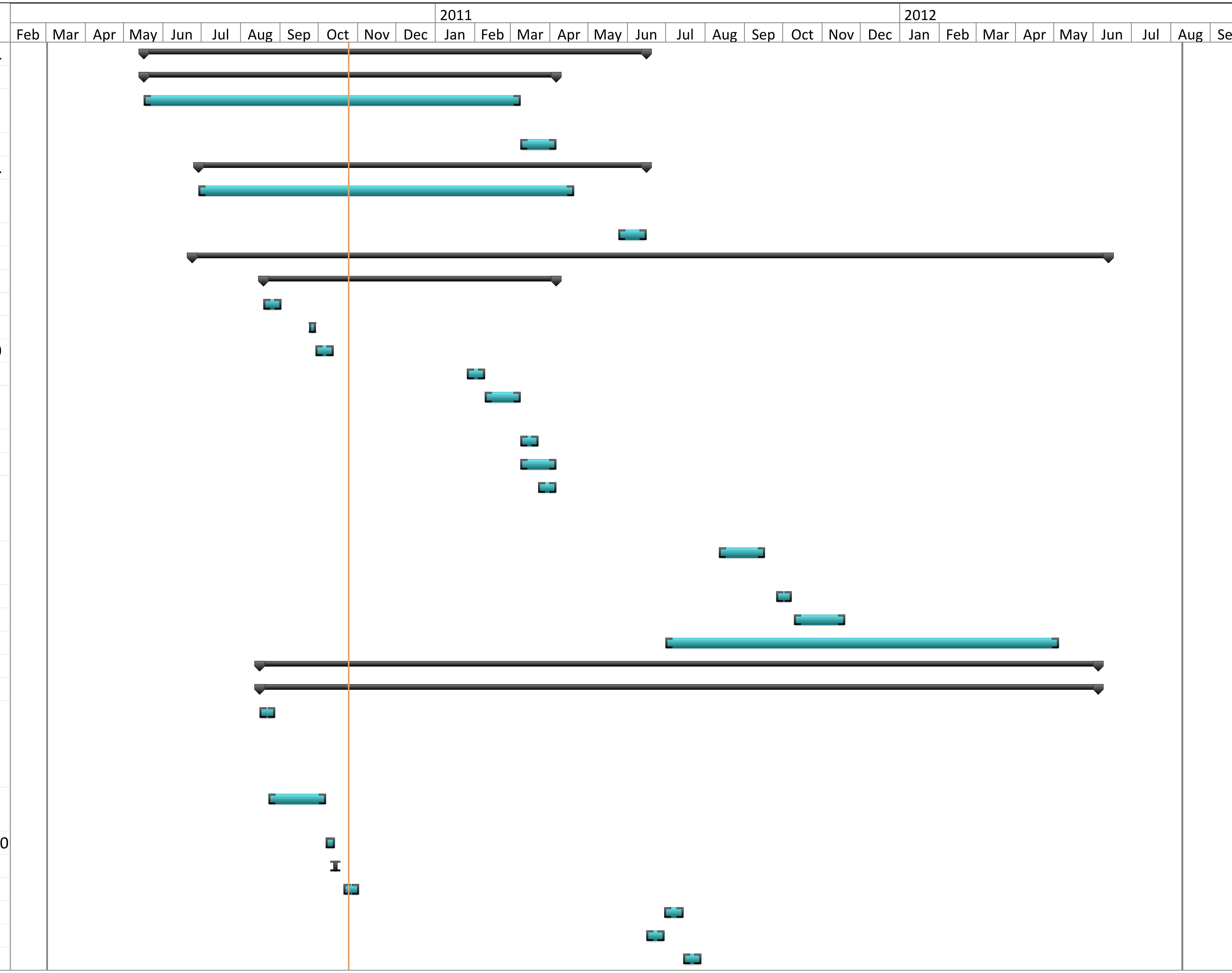
ID	Task Name	Start	Finish
78	Excavate Foundation at Curtain Wall	Tue 6/15/10	Mon 6/21/10
79	FRP Foundation Wall @ 1st Floor	Tue 6/22/10	Tue 7/6/10
80	Install Steel Columns/Beams/Drypack	Fri 8/27/10	Tue 9/7/10
81	Install Steel Moment Connections	Wed 9/22/10	Tue 10/5/10
82	Install Cantilevered Beams/Metal Deck	Wed 9/22/10	Tue 10/5/10
83	Imbeds for Curtainwall	Wed 10/6/10	Thu 10/7/10
84	FRP Concrete Infill Slab	Fri 10/8/10	Thu 10/14/10
85	Washdown Exterior	Fri 10/15/10	Thu 10/21/10
86	Install Curtain Wall System	Wed 2/23/11	Tue 4/5/11
87	**Northwest Elevation**	**Tue 6/22/10**	**Tue 5/24/11**
88	Prepare NW Quadrant for Curtain Wall	Tue 6/22/10	Tue 1/4/11
89	Install Curtain Wall System	Wed 4/6/11	Fri 5/13/11
90	Install Glass/Metal Canopy @ West	Wed 5/18/11	Tue 5/24/11
91	**East Elevation**	**Mon 5/3/10**	**Fri 9/23/11**
92	**Northeast Quadrant**	**Tue 6/29/10**	**Thu 7/7/11**
93	Prepare NE Quadrant for Curtain Wall	Tue 6/29/10	Tue 3/15/11
94	Install Curtain Wall System	Wed 5/18/11	Wed 6/29/11
95	Install Glass/Metal Canopy @ East	Thu 6/30/11	Thu 7/7/11
96	**Southeast Quadrant**	**Mon 5/3/10**	**Fri 9/9/11**
97	Erect Scaffolding	Mon 5/3/10	Fri 5/14/10
98	Salvage Stone	Mon 5/17/10	Mon 6/14/10
99	Prepare SE Quadrant for Curtain Wall	Wed 7/7/10	Mon 5/16/11
100	Install Curtain Wall System	Thu 6/30/11	Thu 8/11/11
101	Areaway Steel Supports and Grating	Fri 8/12/11	Fri 9/9/11
102	Exterior Punchout	Mon 9/12/11	Fri 9/23/11
103	**North Elevation**	**Tue 6/1/10**	**Tue 5/24/11**
104	**Northwest Quadrant**	**Tue 6/1/10**	**Tue 5/3/11**
105	Prepare NW Quadrant for Curtain Wall	Tue 6/1/10	Tue 3/22/11
106	Curtain Wall Framing/Glazing	Wed 4/6/11	Tue 5/3/11
107	**NE Quadrant**	**Tue 6/15/10**	**Tue 5/24/11**
108	Prepare NE Quadrant for Curtain Wall	Tue 6/15/10	Tue 4/5/11
109	Curtain Wall Framing/Glazing	Wed 5/4/11	Tue 5/24/11



Project: Office Building - Detailed
Date: Mon 10/25/10

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

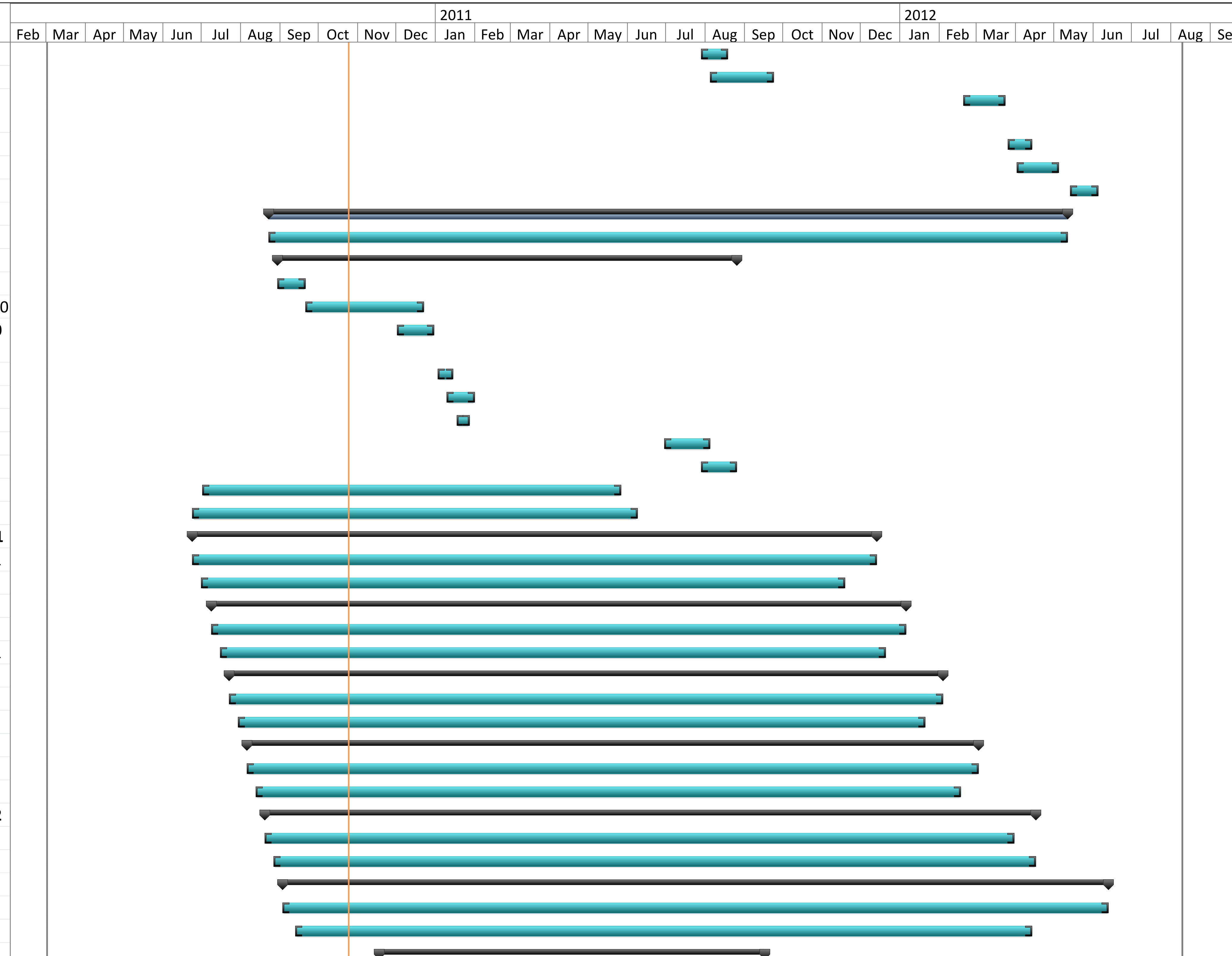
ID	Task Name	Start	Finish
110	**South Elevation**	**Mon 5/17/10**	**Wed 6/15/11**
111	**SW Quadrant**	**Mon 5/17/10**	**Tue 4/5/11**
112	Prepare SW Quadrant for Curtain Wall	Mon 5/17/10	Tue 3/8/11
113	Curtain Wall Framing/Glazing	Wed 3/9/11	Tue 4/5/11
114	**SE Quadrant**	**Tue 6/29/10**	**Wed 6/15/11**
115	Prepare SE Quadrant for Curtain Wall	Tue 6/29/10	Tue 4/19/11
116	Curtain Wall Framing/Glazing	Wed 5/25/11	Wed 6/15/11
117	**Interior Construction**	**Thu 6/24/10**	**Tue 6/12/12**
118	**Sub-Basement**	**Thu 8/19/10**	**Tue 4/5/11**
119	Repair Control Jt./Floor Topping	Thu 8/19/10	Wed 9/1/10
120	MEP Pre Hangers	Fri 9/24/10	Tue 9/28/10
121	Install MEP Risers	Wed 9/29/10	Tue 10/12/10
122	Set AHU	Wed 1/26/11	Tue 2/8/11
123	MEP Rough-In/Set new MEP Equipment	Wed 2/9/11	Tue 3/8/11
124	Elec./Fire Alarm/Telecom Rough-in	Wed 3/9/11	Tue 3/22/11
125	Connect Mech. Equipment	Wed 3/9/11	Tue 4/5/11
126	Pull Power/Lighting/FA/Comm/Data/Securit Wires	Wed 3/23/11	Tue 4/5/11
127	Insulate Int./Ext. Walls, Drywall, Tape & Finish, Prime & Paint	Fri 8/12/11	Fri 9/16/11
128	Install Plumbing Fixtures	Mon 9/26/11	Fri 10/7/11
129	Miscellaneous Finishes	Mon 10/10/11	Fri 11/18/11
130	Phase 2 of Sub-Basement	Fri 7/1/11	Fri 5/4/12
131	**Basement**	**Mon 8/16/10**	**Mon 6/4/12**
132	**East Core Areas**	**Mon 8/16/10**	**Mon 6/4/12**
133	Install Metal Decking/Prep Slab and Walls/Install New Beams/Steel Framing for Central Atrium Opening	Mon 8/16/10	Fri 8/27/10
134	Repair Concrete Floor & Fill Openings in Slab	Mon 8/23/10	Wed 10/6/10
135	Misc. CMU/Fireproof Steel	Thu 10/7/10	Wed 10/13/10
136	MEP Risers	Wed 10/13/10	Fri 10/15/10
137	Layout Track/Mech. Pre Hangers	Thu 10/21/10	Mon 11/1/10
138	MEP Rough-In	Thu 6/30/11	Thu 7/14/11
139	Set AHU	Thu 6/16/11	Wed 6/29/11
140	Elec./Fire Alarm/Telecom In-Wall	Fri 7/15/11	Thu 7/28/11



Project: Office Building - Detailed
Date: Mon 10/25/10

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

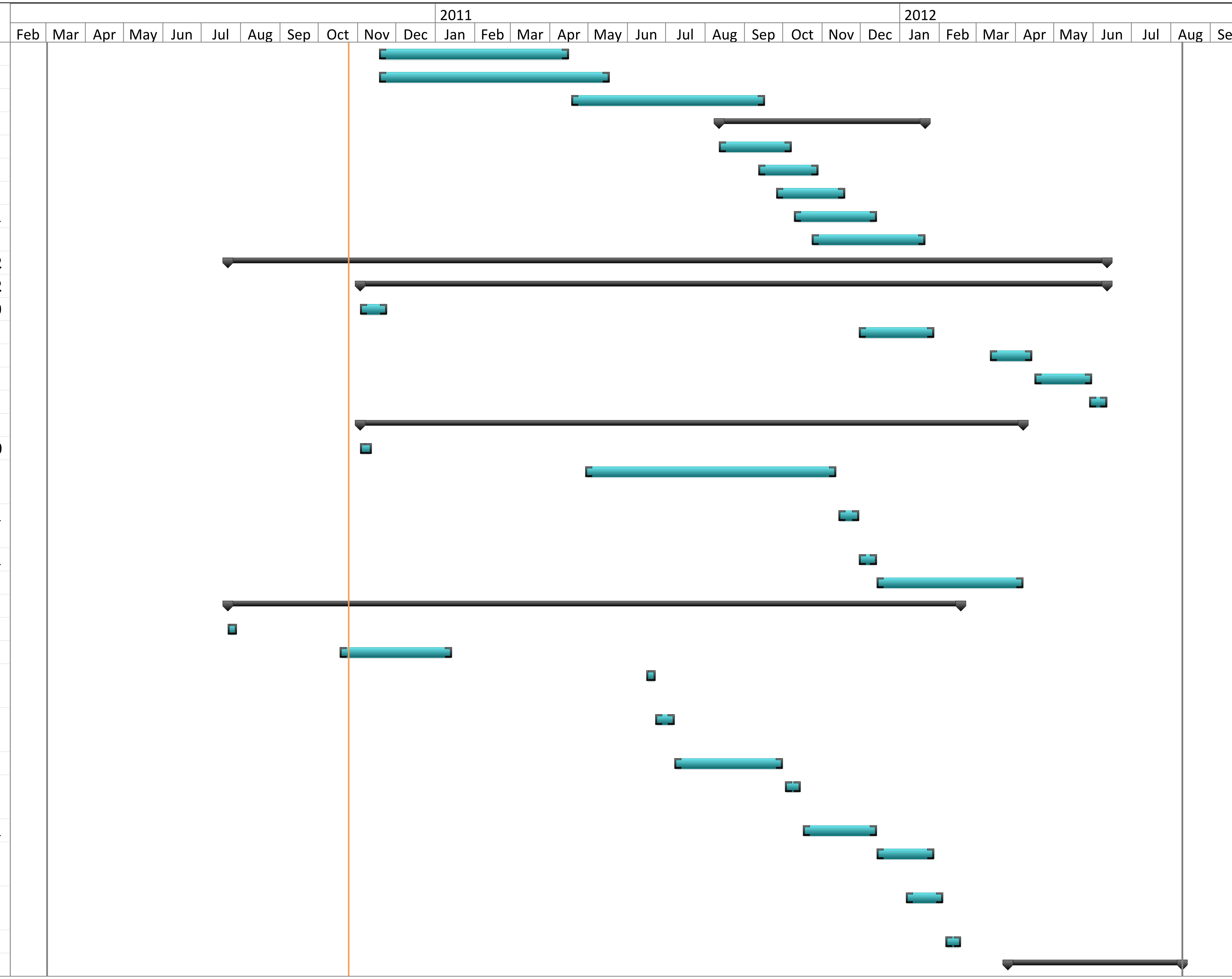
ID	Task Name	Start	Finish
141	Pull Telecom/Security Wires	Fri 7/29/11	Thu 8/18/11
142	Install Electrical Equipment	Fri 8/5/11	Fri 9/23/11
143	Insulate Int./Ext. Walls, Drywall, Tape & Finish, Prime & Paint	Mon 2/20/12	Fri 3/23/12
144	Ceiling Grid	Mon 3/26/12	Fri 4/13/12
145	Install Plumbing Fixtures	Mon 4/2/12	Fri 5/4/12
146	Miscellaneous Finishes	Mon 5/14/12	Mon 6/4/12
147	**West Core Areas**	**Mon 8/23/10**	**Fri 5/11/12**
148	Same as East Core Areas	Mon 8/23/10	Fri 5/11/12
149	**Parking Garage/Ramp**	**Mon 8/30/10**	**Thu 8/25/11**
150	Steel Jacket Reinforcement	Mon 8/30/10	Mon 9/20/10
151	FRP Parking Garage Concrete	Tue 9/21/10	Wed 12/22/10
152	Waterproof Swm Vault/Install Filter Media/Conc. Curb	Thu 12/2/10	Thu 12/30/10
153	Install Doors and Lifts	Mon 1/3/11	Fri 1/14/11
154	Rough-In Overhead Door Controls	Mon 1/10/11	Mon 1/31/11
155	HC Lift/Dock Bumpers	Tue 1/18/11	Thu 1/27/11
156	MEP Rough-In	Thu 6/30/11	Thu 8/4/11
157	Miscellaneous Finishes	Fri 7/29/11	Thu 8/25/11
158	Roof (Main Roof & Penthouse Roof)	Fri 7/2/10	Thu 5/26/11
159	Penthouse	Thu 6/24/10	Wed 6/8/11
160	**Sixth Floor**	**Thu 6/24/10**	**Tue 12/13/11**
161	East Core Areas	Thu 6/24/10	Tue 12/13/11
162	West Core Areas	Thu 7/1/10	Fri 11/18/11
163	**Fifth Floor**	**Fri 7/9/10**	**Thu 1/5/12**
164	East Core Areas	Fri 7/9/10	Thu 1/5/12
165	West Core Areas	Fri 7/16/10	Tue 12/20/11
166	**Fourth Floor**	**Fri 7/23/10**	**Fri 2/3/12**
167	East Core Areas	Fri 7/23/10	Fri 2/3/12
168	West Core Areas	Fri 7/30/10	Fri 1/20/12
169	**Third Floor**	**Fri 8/6/10**	**Fri 3/2/12**
170	East Core Areas	Fri 8/6/10	Fri 3/2/12
171	West Core Areas	Fri 8/13/10	Fri 2/17/12
172	**Second Floor**	**Fri 8/20/10**	**Mon 4/16/12**
173	East Core Areas	Fri 8/20/10	Fri 3/30/12
174	West Core Areas	Fri 8/27/10	Mon 4/16/12
175	**First Floor**	**Fri 9/3/10**	**Tue 6/12/12**
176	East Core Areas	Fri 9/3/10	Tue 6/12/12
177	West Core Areas	Mon 9/13/10	Fri 4/13/12
178	**Elevators**	**Thu 11/18/10**	**Fri 9/16/11**



Project: Office Building - Detailed
Date: Mon 10/25/10

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

ID	Task Name	Start	Finish
179	Elevators 1, 2, 3	Thu 11/18/10	Fri 4/15/11
180	Elevators 7 and 8	Thu 11/18/10	Tue 5/17/11
181	Elevators 4, 5, 6	Mon 4/18/11	Fri 9/16/11
182	**Stairs**	**Fri 8/12/11**	**Fri 1/20/12**
183	Sub-Basement & Basement Stairs	Fri 8/12/11	Fri 10/7/11
184	Stairwell #1	Mon 9/12/11	Fri 10/28/11
185	Stairwell #2	Mon 9/26/11	Fri 11/18/11
186	Stairwell #3	Mon 10/10/11	Tue 12/13/11
187	Stairwell #4	Mon 10/24/11	Fri 1/20/12
188	**Entry Pavilion/Atrium**	**Thu 7/22/10**	**Mon 6/11/12**
189	**South Entrance Lobby**	**Wed 11/3/10**	**Mon 6/11/12**
190	Place New Slab & CMU Blast Walls	Wed 11/3/10	Tue 11/23/10
191	Install Canopy	Wed 11/30/11	Fri 1/27/12
192	Drywall & Limestone Walls	Mon 3/12/12	Fri 4/13/12
193	Install Floor & Doors	Mon 4/16/12	Wed 5/30/12
194	Final Paint/Touch-up	Tue 5/29/12	Mon 6/11/12
195	**Entry Pavilion/Atrium**	**Wed 11/3/10**	**Fri 4/6/12**
196	New Conc. Slab/Slab Openings	Wed 11/3/10	Thu 11/11/10
197	Install Steel Framing/Curtain Wall Anchors	Fri 4/29/11	Fri 11/11/11
198	Install Rainwater Collection, Ext. Lighting, Hot Water Supply Risers	Mon 11/14/11	Tue 11/29/11
199	Install Diffusers and Interior Lights	Wed 11/30/11	Tue 12/13/11
200	Install Granite Floor & Walls	Wed 12/14/11	Fri 4/6/12
201	**Central Atrium**	**Thu 7/22/10**	**Fri 2/17/12**
202	FRP 6" Curb BSM for Stairs	Thu 7/22/10	Wed 7/28/10
203	Install Central Atrium Stairs	Mon 10/18/10	Thu 1/13/11
204	Install Clips for Curtain Wall & Anchors for Window Washing System	Thu 6/16/11	Wed 6/22/11
205	Install Glazed Storefront and Steel Channel Support	Thu 6/23/11	Thu 7/7/11
206	Install Glazed Curtain Wall - Atrium	Fri 7/8/11	Fri 9/30/11
207	Install Metal Panels @ 1st Floor Ceiling	Mon 10/3/11	Fri 10/14/11
208	Install Glass/Mtl Railings @ Stairs	Mon 10/17/11	Tue 12/13/11
209	Place Stone at Atrium Columns and Install Doors	Wed 12/14/11	Fri 1/27/12
210	Marble/Granite Floor Central Atrium Lobby	Fri 1/6/12	Fri 2/3/12
211	Install Window Washing System	Mon 2/6/12	Fri 2/17/12
212	**Project Close-out**	**Mon 3/26/12**	**Thu 8/9/12**



Project: Office Building - Detailed
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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 Name	Start	Finish
213	GC Submit O&M's	Mon 3/26/12	Fri 4/20/12
214	Test and Balance	Mon 5/14/12	Fri 5/25/12
215	Fire Alarm Testing	Mon 5/21/12	Mon 6/4/12
216	MEP Commissioning	Tue 6/5/12	Thu 8/9/12
217	Owner Training	Tue 6/5/12	Mon 7/2/12
218	Submit Record Drawings	Tue 6/5/12	Mon 7/2/12

2011: Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2012: Jan Feb Mar Apr May Jun Jul Aug Sep

Project: Office Building - Detailed
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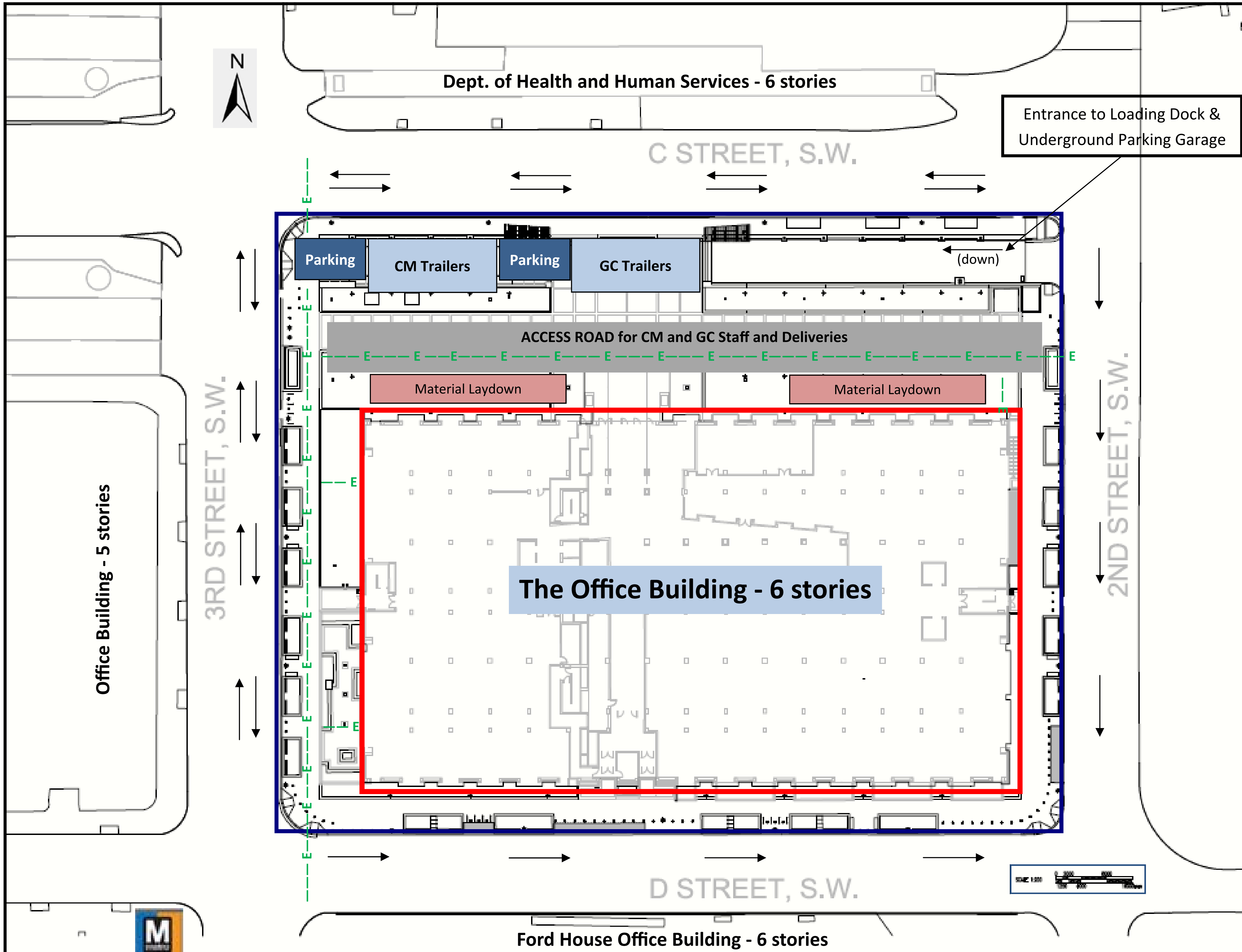
Task, Split, Milestone, Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, Deadline, Progress

Appendix E

Site Layout Plan



Building Perimeter
Traffic Flow
Property Line/Construction Fence
Electric Line
Temporary Trailers
Staff Parking
Metro Federal Center SW Station
Material Laydown

Lynn Appel

Technical Assignment #2

Site Layout Plan

Demolition & Construction Phases

Appendix F

General Conditions Estimate

Project Staff

Line Item	Unit Rate	Unit	Quantity	Cost
Operations Manager	$ 2,100	Wks	131	$ 275,100
Project Executive	$ 2,100	Wks	65.5	$ 137,550
Accountant	$ 1,600	Wks	131	$ 209,600
Cost Engineer	$ 1,125	Wks	131	$ 147,375
Project Manager	$ 1,850	Wks	131	$ 242,350
Project Engineer	$ 1,300	Wks	131	$ 170,300
Field Engineer	$ 1,125	Wks	131	$ 147,375
Adminstration	$ 365	Wks	131	$ 47,815
General Superintendent	$ 1,950	Wks	131	$ 255,450
Superintendent	$ 1,700	Wks	131	$ 222,700
Safety Manager	$ 1,400	Wks	131	$ 183,400
$				2,039,015

Construction Facilities and Equipment

Line Item	Unit Rate	Unit	Quantity	Cost
Trailers (2) 50'x10'	$ 330	Mos.	26	$ 8,580
Office Equipment	$ 150	Mos.	29	$ 4,350
Office Supplies	$ 95	Mos.	29	$ 2,755
Office Furniture	$ 1,000	Ea.	5	$ 5,000
Construction Site Fence	$ 600	Mos.	29	$ 17,400
Copiers	$ 2,000	Mos.	29	$ 58,000
Scanners/Color Printer	$ 5,000	Ea.	2	$ 10,000
Network Equipment	$ 50	Mos.	29	$ 1,450
Mobile Phones	$ 325	Mos.	29	$ 9,425
Personal Protective Equipment	$ 100	Mos.	29	$ 2,900
Signage	$ 2,600	Ls.	1	$ 2,600
Dumpsters (6)	$ 550	Mos.	29	$ 95,700
$				218,160

Temporary Utilities

Line Item	Unit Rate	Unit	Quantity	Cost
Field IT/Network Set-up	$ 15,000	LS	1	$ 15,000
Field Telephone Hook-up	$ 1,500	LS	1	$ 1,500
Field Telephone Service	$ 100	Mos.	13	$ 1,300
High Speed Internet	$ 1,250	Mos.	29	$ 36,250
Temporary Water/Sanitary Supply	$ 2,100	LS	1	$ 2,100
Temporary Toilets (10)	$ 975	Mos.	29	$ 282,750
Potable Water	$ 60	Mos.	29	$ 1,740
$				340,640

Miscellaneous Costs

Line Item	Unit Rate	Unit	Quantity	Cost
Public Space Permit	$ 1,000	Ls.	1	$ 1,000
Progress Photographs	$ 475	Mos.	29	$ 13,775
Document Reproduction	$ 35,000	Ls.	1	$ 35,000
Clean-up Expenses	$ 490	Wks.	131	$ 64,190
Misc. Field Expenses	$ 1,000	Mos.	65.5	$ 65,500
Construction Sign	$ 2,500	Ls	1	$ 2,500
$				181,965

General Conditions Summary

Line Item	Unit Rate	Unit	Quantity	Cost
Project Staff	$ 15,565	Week	131	$ 2,039,015
Construction Facilities & Equipment	$ 1,665	Week	131	$ 218,160
Temporary Utilities	$ 2,600	Week	131	$ 340,640
Miscellaneous Costs	$ 1,389	Week	131	$ 181,965
$				2,779,780

Appendix G

Product Data Cut Sheets for PV Panels and Inverters bp solar

220 Watt Photovoltaic Module

BP 3220

The BP 3220 is an advanced polycrystalline 220W solar module that incorporates antireflective coated cells and glass to generate more energy (more kWh per kWp) in your installation.
This module has undergone the most rigorous testing to ensure reliable long term performance and is certified to comply with the latest safety standards (IEC61730 & UL1703).
Six bypass diodes mounted on our IntegraBus™ circuit board and laminated in the module provide effective protection of the solar cells from overheating when shaded and ensure long term reliability.
All interconnections are made using lead free soldering making these modules even friendlier with the environment.

BP 3220 scale 1:14

Performance

Performance	BP3220
Rated Power	220W
Tolerance	±3%
Module efficiency	13.2%
Nominal voltage	24V
Warranty*	90% power output over 12 years 80% power output over 25 years Free from defects in materials and workmanship for 5 years.

*Refer to BP Solar's Warranty document for terms and conditions.

Configuration

BP 3220N	Clear Universal frame, Wirehold IP67 potted junction box with pre-installed output cables fitted with polarized connectors (Multi-Contact III connectors).

Qualification Test Parameters

Temperature cycling range	-40°C to +85°C for 200 cycles
Damp heat test	85°C and 85% relative humidity for 1000h
Front & rear load test (eg: wind)	2400Pa (equivalent to 245kg/m^2 load distributed)
Front load test (eg: snow and wind)	5400Pa* (equivalent to 550kg/m^2 load distributed)
Hailstone impact test	25mm hail at 23m/s from 1m distance
Impulse voltage test	8000V waveform impulse according to high voltage test techniques IEC 60060-1 standard.
Reverse current overload test	135% of the overcurrent protection rating for two hours

*When mounted in accordance with BP Solar's installation instructions

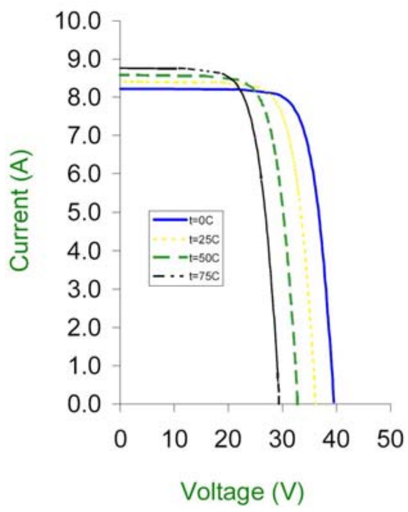
Efficiency (%)

9-11 | 11 -12 | 12-13 | 13-14 | 14-15

Quality and Safety

- Certified according to the extended version of the IEC 61215:2005 (Crystalline silicon terrestrial photovoltaic modules – Design qualification and type approval)
- Certified according to IEC 61730-1 and IEC 61730-2. (Photovoltaic module safety qualification, requirements for construction and testing.
- Listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating).
- Module electrical measurements are calibrated to World radiometric reference via third party international laboratories.
- Manufactured in ISO 9001 certified factories.

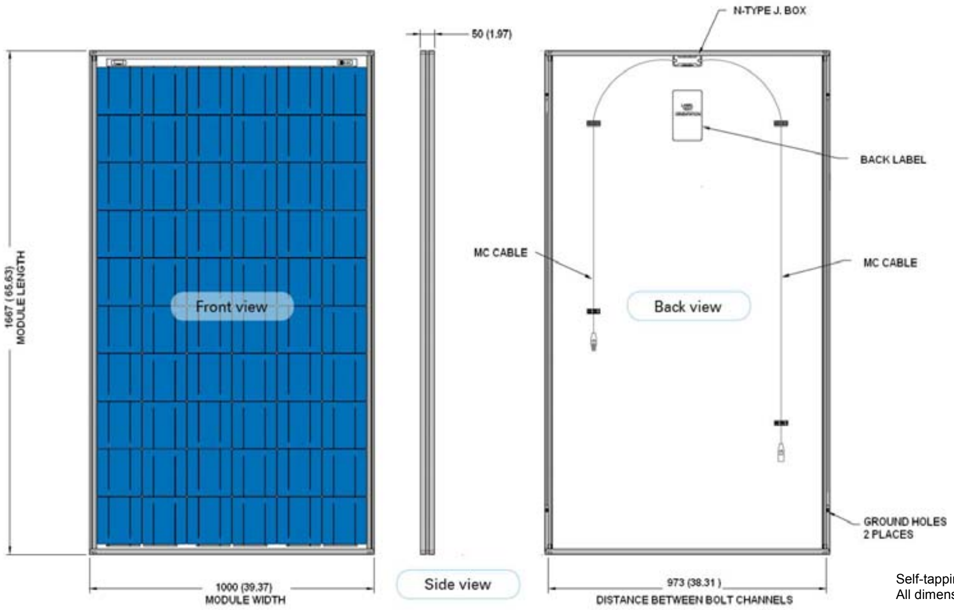
BP 3220N I-V Curve

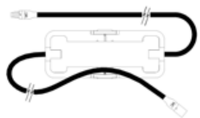


220 Watt Photovoltaic Module

BP 3220

Module Diagram





N TYPE JUNCTION BOX
(with wire-hold feature)

JUNCTION BOX DETAIL

Self-tapping grounding screw, included with each module.
All dimensions in millimetres, figures in brackets in inches.

Electrical Characteristics

	1000W/m² (STC[1])	800W/m² (NOCT[2])
Maximum Power (P_{max})	220W	158.4W
Voltage at MPP (V_{mpp})	29.0V	25.8V
Current at MPP (I_{mpp})	7.6A	6.1A
Short circuit current (I_{sc})	8.4A	6.8A
Open circuit voltage (V_{oc})	36.2V	32.9V

Efficiency at 1000W/m²	13.2%
Efficiency reduction at 200W/m²	< 5% reduction (efficiency 12.5%)
Limiting reverse current	8.4A
Temperature coefficient of I_{sc}	(0.065±0.015)%/K
Temperature coefficient of V_{oc}	-(0.36±0.05)%/K
Temperature coefficient of P	-(0.5±0.05)%/K
NOCT[3]	47± 2°C
Maximum series fuse rating	20A
Application class (According to IEC 61730:2007)	Class A Installation
Maximum system voltage (N-Type junction box)	1000V (IEC 61730) 600V (UL)

[1]STC: Standard test conditions - irradiance of 1000W/m² at an AM1.5G solar spectrum and a temperature of 25°C
[2] 800W/m², NOCT, AM 1.5G solar spectrum
[3]NOCT: Nominal Operation Cell Temperature Sun 800W/m²; Air 20°C; wind speed 1m/s

Mechanical Characteristics

Solar cells	60 polycrystalline cells (156mm x 156mm) connected in series
Front Cover	High transmission 3.2mm tempered anti reflective coated glass
Encapsulant	EVA
Back Cover	White polyester
Frame	Silver anodised aluminium.
Diodes	IntegraBus™ technology includes 6 Schottky bypass diodes - one for every 10 cells - on a printed circuit board
Junction Box Dimensions	N-Type: 39.60 x 100.60 x 13.20 (mm) / 1.56 x 3.96 x 0.52 (inch) Certified to meet UL1703 flammability test
Output Cables (N-Type)	3.3mm² cable with weatherproof MC III connectors. Asymmetrical cable lengths 1250mm/49.21inch (-) and 800mm/31.50inch (+)
Dimensions	1667±3 x 1000±3 x 50 (mm) 65.63±0.12 x 39.37±0.12 x 1.97 (inch)
Weight	19.4kg / 42.77pounds

All dimensional tolerances within ±1% unless otherwise stated

Contact:

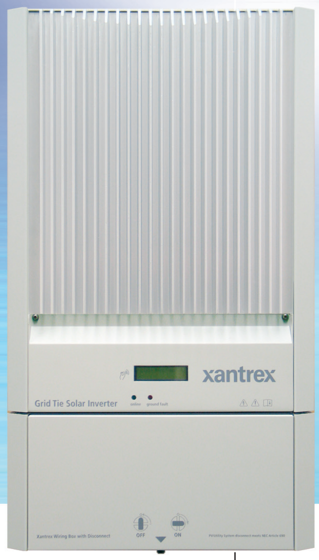
www.bpsolar.com

This data sheet complies with the requirements of EN 50380
This publication summarises product warranty and specifications which are subject to change without notice
All solar modules are individually tested prior to shipment; an allowance is made within our factory measureme to account for the typical power degradation (LID effect) which occurs during the first few days of deployment.

Smart choice for power™

xantrex™

Xantrex™ GT Series Grid Tie Solar Inverters



The Xantrex™ Grid Tie Solar Inverter (GT Series) is designed to convert photovoltaic (PV) electricity produced by solar modules into utility-grade power that can be used by the home or sold to the local electrical utility. Offering high efficiency (up to 96.0 %), clean aesthetics, high reliability, and a low installed cost, through ease of installation and integrated features, the GT Series is a proven, high-frequency design in a compact enclosure.

The GT Series may be installed as a single inverter, for a single PV array, or in a multiple-inverter configuration for large PV systems.

Technology

- An NEC compliant, integrated DC/AC disconnect, standard in the GT Series, eliminates the need for external DC (PV) disconnects, and in some jurisdictions, AC disconnects
- Large heat-sink offers extraordinary heat dispersion without the need for a cooling fan
- Liquid crystal display (LCD) provides instantaneous information – power level, daily and lifetime energy production, PV array voltage and current, utility voltage and frequency, time online “selling”, fault messages, and installer-customized screens
- LCD vibration sensor allows the tap of a finger to turn backlight on and cycle through display screens

Installation

- Flexible module selection and sizing due to wide PV input MPPT tracking voltage range
- Lightweight and versatile mounting bracket
- Easy access DC (photovoltaic) and AC (utility) terminal block simplifies wiring
- Rugged NEMA 3R inverter enclosure allows reliable indoor and outdoor installations

Performance

- Best-in-class efficiency to maximize solar system return on investment
- Accurate MPPT tracking ensures maximum energy harvest under any conditions
- FCC Part B compliance provides less external electronic interference

Serviceability

- 10-year standard warranty
- Sealed inverter enclosure can be quickly separated from the wiring box allowing DC/AC connections to remain intact in the unlikely event the inverter needs to be serviced

xantrex GT SERIES WARRANTY 10 YEARS

Standard 10-year warranty

C US UL 1741 CSA 107.1-01 PHOTOVOLTAIC POWER INVERTER

www.xantrex.com

Smart choice for power™

Xantrex™ GT Series Grid Tie Solar Inverters

Electrical Specifications - Output

Models	GT5.0		GT4.0N		GT3.8		GT3.3N		GT2.8	
Nominal output power	240 V	208 V	240 V	208 V	240 V	208 V	240 V	208 V	240 V	208 V
Maximum AC power output	5000 W	4500 W	4000 W	3800 W	3800 W	3500 W	2800 W	2700 W	2800 W	2700 W
AC output voltage (nominal)	240 V	208 V	240 V	208 V	240 V	208 V	240 V	208 V	240 V	208 V
AC output voltage range	211-264 Vac 183-229 Vac									
AC frequency (nominal)	60 Hz									
AC frequency range	59.3 - 60.5 Hz									
Maximum continuous output current	21 A	22 A	16.7 A	18.3 A	15.8 A	16.8 A	13.8 A	14.9 A	11.7 A	13.0 A
Maximum output over-current protection	30 A		25 A		20 A	25 A	20 A		15 A	
Maximum utility backfeed current	0 A									
Total harmonic distortion (THD)	< 3 %									
Power factor	> 0.99 % (at rated power), > 0.95 % (full power range)									
Utility monitoring, islanding protection	UL1741-2005 / IEEE 1547									
Output characteristics	Current source									
Output current waveform	True sine wave									

Electrical Specifications - Input

	GT5.0		GT4.0N		GT3.8		GT3.3N		GT2.8	
Maximum array open-circuit voltage	600 Vdc									
MPPT voltage range (CEC & CSA)	240 - 550 Vdc		240 - 480 Vdc		195 - 550 Vdc		200 - 400 Vdc		195 - 550 Vdc	
MPPT operating range	235 - 550 Vdc		235 - 550 Vdc		195 - 550 Vdc		200 - 550 Vdc		193 - 550 Vdc	
Maximum input current	22.0 Adc	20.0 Adc	18.0 Adc	17.0 Adc	20.8 Adc	19.5 Adc	17.5 Adc	16.5 Adc	15.4 Adc	14.9 Adc
Maximum array short-circuit current	24.0 Adc									
Reverse-polarity protection	Short-circuit diode									
Ground-fault protection	GF detection, IDIF > 1 A									
Maximum inverter efficiency	95.9%	95.5%	96.0%	95.7%	95.9%	95.6%	95.9%	95.6%	95.0%	94.6%
CEC efficiency	95.5%	95.0%	95.5%	95.0%	95.0%	95.0%	95.5%	95.0%	94.0%	93.5%
CEC part number	GT5.0-NA-240/208		GT4.0N-NA-240/208		GT3.8-NA-240/208		GT3.3N-NA-240/208		GT2.8-NA-240/208	
Night-time power consumption	1 W									

Environmental Specifications

	GT5.0	GT4.0N	GT3.8	GT3.3N	GT2.8
Operating temperature range	-13°F to 149°F (-25°C to 65°C)				
Enclosure type	NEMA 3R (outdoor rated)				
Inverter weight	58.0 lb (25.8 kg)	58.0 lb (25.8 kg)	58.0 lb (25.8 kg)	49.0 lb (22.2 kg)	49.0 lb (22.2 kg)
Shipping weight	65.0 lb (27.2 kg)	65.0 lb (27.2 kg)	65.0 lb (27.2 kg)	57.0 lb (25.9 kg)	57.0 lb (25.9 kg)
Inverter dimensions (H x W x D)	28 1/2 x 16 x 5 3/4” (72.4 x 40.3 x 14.5 cm)				
Shipping dimensions (H x W x D)	34 x 20 1/2 x 10 5/16” (86.6 x 51.8 x 26.2 cm)				

Mechanical Specifications

	GT5.0	GT4.0N	GT3.8	GT3.3N	GT2.8
Mounting	Wall mount (mounting bracket included)				
Input and output terminal	AC and DC terminals accept wires sizes of #14 to #6 AWG				
PV / Utility disconnect	Eliminates need for external PV (DC) disconnect. Complies with NEC requirements				
Cooling	Convection cooled, fan not required				
Display	Backlit, two-line, 16-character liquid crystal display provides instantaneous power, daily and lifetime energy production, PV array voltage and current, utility voltage and frequency, time online “selling”, fault messages, and installer-customizable screens				
Communications	Integrated RS232 and Xanbus™ RJ45 communication ports				
Wiring box	PV, utility, ground, and communications connections. The inverter can be separated from the wiring box.				
Warranty	10-year standard				
Model name (negative ground)	GT5.0-NA-240/208 UL-05	GT4.0N-NA-240/208 UL-05	GT3.8-NA-240-/208 UL-05	GT3.3N-NA-240/208 UL-05	GT2.8-NA-240/208 UL-05
Part number (negative ground)	864-1009	864-1008	864-1032	864-1006	864-1001
	Positive ground inverters are also available				

Regulatory Approvals

Certified to UL1741 1st Edition: 2005 version CSA 107.1-01 CSA 2 C22.2 No.107-1-01 general use power power supplies.