FINAL REPORT

CHEMISTRY BUILDING

April 7th, 2011

Michael Gallagher

Construction Management

Dr. Riley

Michael Gallagher | Construction Option | Chemistry Building

Project Team

CM Agency:	Turner Construction
Design Architect:	Hopkins Architects
Executive Architect:	Payette Associates
Engineer:	ARUP

Project Data

Occupant:	University
Size:	265,000 SF
Total Height:	4 plus Penthouse
Function:	Research Labs and Offices
Construction Dates:	9/4/2007 to 11/2/2010

Architectural Features

Exterior façade is primarily a glass curtain wall system in aluminum framing with aluminum sunscreens. There is a large four story glass atrium with bridges on each level connecting the lab and office buildings. The atrium is covered by a large glass skylight with PV trays above it for shading and aesthetics.

Construction Logistics

The first phase of construction was Demolition of the current building and parking lot onsite. Next 49,364 CY of rock were blasted to prepare for the foundation. After the foundation was complete the concrete cores were completed all the way up to the penthouse level. Then the structural steel went up and tied into the concrete cores. The exterior façade and roof were then completed which lead to the final step of the interior fit out.

Structural System

The Structural system is comprised of a steel building with six concrete cores for vertical transportation that act as shear walls. The cores have 6" concrete poured in place slabs while the steel system has composite metal decking with 4.5" of concrete topping. This adds up to a total of 1,564 tons of steel and 18,309 CY of concrete.

Mechanical and Electrical

3D Building Information Modeling was used for the coordination of the MEP systems. There are 5 AHU in the Lab penthouse which supply air to the entire lab building and exhaust 390 fume hoods. The atrium and office building are controlled by 7 AHU located in the basement. All the offices have chilled beams and the AHU have a heat recovery system and VAV boxes. The entire building receives its power, chilled water, and steam from the campus plant.

EXECUTIVE SUMMARY

Senior Thesis is meant to present the results that were found after conducting the four areas of research and analysis that were completed on the Chemistry Building throughout the spring semester. These four areas came forth through the series of technical reports completed and meeting with Dr. Riley. These practical areas were chosen, based upon the idea that they could be modified based upon critical industry issues, value engineering, constructability, and schedule reduction/acceleration.

Analysis #1: Bringing BIM into the Field (Critical Industry Issue)

After working on the Chemistry Building for two summers and being a part of the PACE roundtable discussion, it was clear that this project is a prime example of "bringing BIM into the field." The purpose of this analysis is to investigate additional ways BIM could have been used on the Chemistry Building besides MEP coordination.

Analysis #2: Lab Penthouse AHU Commissioning (Mechanical Breadth)

During the balancing and commissioning process of the lab penthouse AHU's of the Chemistry Building, it was realized these five AHU's were performing inefficiently. It was determined the cause was poor layout of duct work. The goal of this analysis is to use the BIM model to layout the duct work differently to eliminate the additional two inches of static pressure between the AHU and exhaust duct.

Analysis #3: Alternative Curtain Wall Systems

The Chemistry Building is designed to have a forty million dollar curtain wall system that is manufactured in Italy and contracted with Permasteelisa. The goal of this analysis is to determine two things. The first is to determine if breaking the contract up between multiple players can shorten lead-time and reduce the schedule. The second is to investigate other high-efficiency glazing systems to determine if a US manufacturer can produce a similar system. Glazing with PV capability will also be explored to see if it will be realistic to incorporate on the Chemistry Building.

Analysis #3: Feasibility of PV Curtain Wall System (Electrical Breadth)

Analysis #4 will be incorporated with analysis #3. Because the curtain wall is extremely expensive, a financial analysis will be conducted to determine if a PV capable glazing systems can be substituted. The goal is to find a system that can help with the energy consumption of the building with a short payback period.

ACKNOWLEDGEMENTS

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Industry Acknowledgements:

Turner Construction

Schuco USA

Vela Management Systems

Hopkins Architects

Special Thanks To:

Turner Construction Project Teams

Project Architects and Engineers

PACE Industry Members

The Owner

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PROJECT OVERVIEW

Building name: Chemistry Building
Building Occupant Name: University
Occupancy or Function Type: Half of the building is Lab and Research space and the other half is offices
Size: 265,000 SF
Number of stories above grade / total levels: 4 floors plus a penthouse

Turner Construction www.turnerconstruction.com
Construction Manager

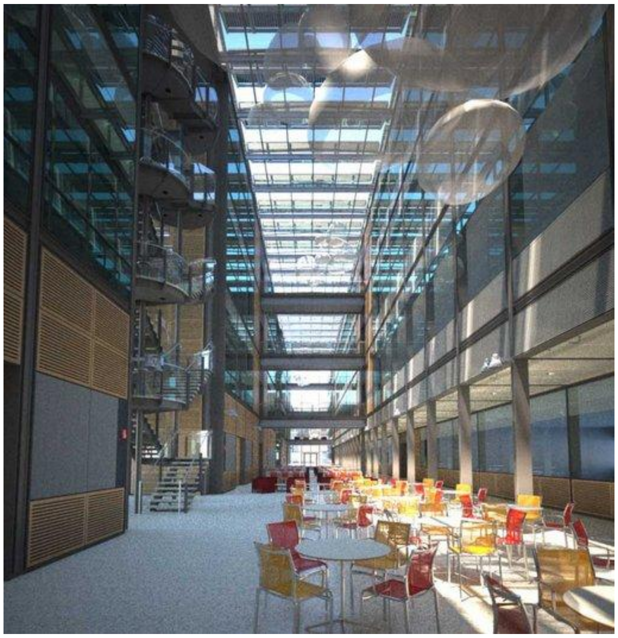
Payette Associates www.payette.com
Architect on Record

Hopkins Architects (UK) www.hopkins.co.uk
Executive Architect

ARUP www.arup.com
Engineer

Dates of construction (start—finish): 9/4/2007 – 11/2/2010

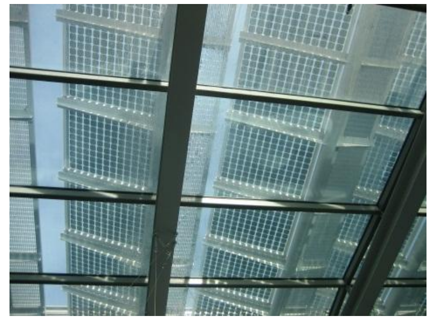
Introduction



The Chemistry Building is designed to separate the building into separate spaces. The East side of the building is four stories of research and teaching labs. The West side of the building is four stories of offices. These two spaces are then connected by a large 4 story glass atrium with 3 bridges spanning across the large open space for access from one building to the other. The picture on the right is taken from inside the atrium looking north.

This 265,000 SF University Building was constructed as a result of their outdated and confined current facilities. The funding for this project came from a percentage of profit from a cancer drug discovered at this university.

There are six concrete cores for vertical transportation which break each building into sections. The lab building has three of the concrete cores which separate this part of the building into 4 main lab spaces. On the office side the cores are within each main pod which separates the office into only 3 main spaces on each floor. Besides the concrete cores where the elevators are located the architect used the rest of the vertical transportation as an aesthetic feature. On the lab building there are three stair towers enclosed in glass on the exterior of the building. They are a major part of the exterior design of the building and can be seen in the picture on the left. On the inside in the atrium there are also two large staircases which are and architectural feature. They can be seen in the picture above on the left side and help give the building an open feel. Going along with the open feel the end walls of the atrium are comprised of all glass and the entire roof on the atrium is a glass skylight.



Also the sides of the office building and lab building that face the atrium are all glass. Above the skylight are PV trays which are custom made for this building. They are not a traditional looking panel and are almost all clear glass allowing sunlight to make it through them and still naturally light the atrium. This can be seen in the picture on the right in the top center.

The Building façade is a curtain wall system. All the glass was produced in Italy. There are shading devices for each floor that also add to the aesthetics as well as function of the building. All the glass for the end walls on the atrium, skylight, office building, and lab building are tinted glass. The egress stair towers have a different type of glass. The end walls on the office and lab buildings are a granite stone. On the office side every room has a sliding door the height of the room with a screen for when the door opens. Because of safety and code requirements there is also a railing on the exterior covering the opening so no one falls out. All the penthouses have louvers that were produced in Mexico. These were chosen for their overall look as long with being function with the mechanical systems.

The university that owns this building has its own sustainable requirements for all the buildings on campus. Because of this, a lot of green aspects are incorporated in this building. The major one that can be seen when looking at the building is the PV trays on the roof. However these were done as more of an aesthetic feature and really do not produce too much energy. There is also a grey-water system that collects water and uses it to flush the toilets. All the lights and rooms have occupancy sensors which help reduce energy consumption. Because the building has a lot of glass it allows for a lot of natural lighting. The bad part about all of the glass though is it affects the mechanical system, which is why the windows were tinted and shading devices were incorporated on the façade. To also help with the mechanical system the AHU have a heat recovery system and VAV boxes.

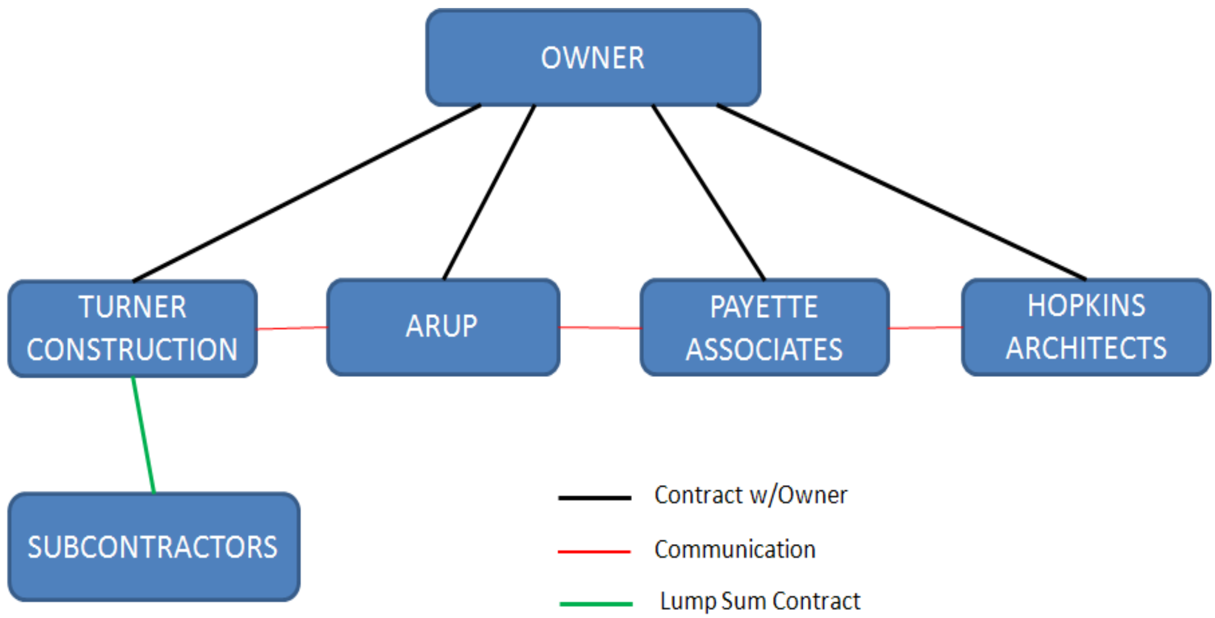
Project Location

Due to the Owner's request, the building location and name will not be discussed due to security reasons and Owner's preferences.

Client Information

The current Chemistry building was built in 1927 and was not up to date with today's technology. The current labs were small and already cramped so there was no room to implement the new technology in the current labs. Because of this it was a must to build a new building. By building this new high-tech facility it was also a way to lure in more renowned researchers due to the fact they were looking to hire five more researchers. The Chemistry Building was funded by a percentage of the profits from an anti-cancer drug that was developed at the previous chemistry building. The owner was interested most in constructing a building that has the best technology and satisfies the needs and desires of the researchers in order to have a successful facility and team. This was clearly show by the number of times the design of the labs changed. When each new faculty member was hired they reviewed the lab designs and were able to make changes or add anything to the lab they would be working in. The original contract schedule showed the building was to be completed on November 2nd, 2010. However, after the contract was formed the owner decided they wanted the turnover to happen sooner. Because of this Turner worked extremely hard to achieve the TCO on July 13, 2010 and substantial completion in a short time after this. The owner wanted to start moving in on August 2nd, 2010, but would be phased and continue until April 5th, 2011. The keys to completing the project to the owner's satisfaction are to have the highest quality, state of the art facility and be completed on time.

Project Delivery System



The project was a design-bid-build and started off with Hopkins Architects for the design process. This firm is a well-recognized London based UK Company. Their headquarters is a glass and steel building with a large courtyard and glass skylight covering it which is located right next to Parliament. This is a similar type style the owner was looking for. The main reason for choosing this firm is because of their expertise in designing high-efficiency and sustainable buildings. Turner construction was then brought on for preconstruction and worked with the owner, Hopkins, and engineers for 2 years before actual construction started. Payette associates were also brought on as the executive architect. With their expertise on design of high-end laboratories they did most of the interior design. ARUP did the engineering for the MEP and Structural systems of this building. The owner had individual contracts with Turner Construction, ARUP, Hopkins Architects, and Payette Associates. Even though there were no contracts between the CM firm, Architects, Engineers they all worked together through preconstruction and throughout the project. The owner and Turner Construction have a GMP contract. Turner then hired subcontractors, which were all approved by the owner, and they all had lump sum contracts. Turner also has a CCIP which covered all the subcontractors working onsite.

Staffing Plan

The Chemistry building was a very large and unique project which resulted in Turner construction having a large project team. The building was broken into sections and assigned members to manage. Each section had a project engineer and engineering team, a superintendent, and an assistant superintendent. The sections were the basement, office building, lab building, the project site, and the exterior façade and roof of the building. This was a more efficient way to manage the project instead of their typical approach where each team was in charge of certain subcontractors. It was a lot easier to coordinate because there were less people involved in the communication process to complete a certain task. For example, if a bathroom needed to be completed it was easier for one superintendent to contact the electrical contractor, carpenters, plumbing contractor, and floor contractor and coordinate the work between those trades. If the job was being managed by staff being assigned to certain trades there would have to be multiple superintendents involved in the communication and coordination process along with all the trades. It is more efficient, takes less time, and there are better results when the task is communicated directly to the subcontractor instead of being communicated through multiple people. Also, because the project was insured as a CCIP it was required to have a safety manager and EMS person on staff.

DESIGN AND CONSTRUCTION OVERVIEW

Building Systems

- **Demolition**
  The building that was torn down in order to build the Chemistry Building was an armory. When it was originally built it was a barn with horse stables. Before its demolition its use was storage for ROTC, clubs, and other university organization's equipment. There was a large asphalt parking lot that also needed to be demoed in order to build the Chemistry Building. The material that was hauled off-site from this demo comprised mostly of wood and asphalt.

- **Structural Steel**
  The building has structural steel framing. The entire atrium is framed with structural steel. The Lab building is broken up into 4 different steel framing systems separated by three concrete cores that act as shear walls. The office building is split up into three different steel framing systems and each framing system contains a concrete core that acts as a shear wall. All the steel has composite metal decking with 4000psi concrete topping. In the Office building the beams and girders are both wide flanges with a depth of 27". The beams along the curtain walls on the office side are wide flanges with a depth of 21". The beams and girders in the Lab building are all 24" depth wide flanges. Just like the Office building the beams along the curtain wall are 21" depth wide flanges. All the connections with the columns are moment connections.

- **Cast-In-Place Concrete**
  The foundation walls and concrete cores are all reinforced 5000psi cast in place concrete. The concrete cores and foundation walls required vertical formwork. The formwork used for this job are reusable forms. One level was completed and the forms were removed and the installed on the next level for the next pour. This can be seen in the picture below. The first floor of the building is also a cast in place slab. Scaffolding from the basement level held up the formwork to place this concrete on Level A. Some areas of the building were capable of being placed directly from the concrete truck and the rest of the concrete was placed using a pump truck.

- **Mechanical System**

  The mechanical system for the lab building is located in the penthouse on top of the building. This part of the building houses five air handler units with a heat recovery system and VAV boxes. The return system for the fume hoods exits the building through six exhaust towers on top of the lab penthouse roof. The entire east side of the basement is mechanical rooms. One of the rooms is for a greywater system for the building that is hooked up to a 12,000 gallon tank. The northwest corner of the basement contains another seven air handler units that service the rest of the building. These all also have a heat recovery system and all the offices are tempered by chilled beams and individual thermostats. These twelve air handler units produce a total of 478,160cfm. The building also has a sprinkler system throughout the entire building. By code the exterior colonnade is required to be sprinkled and as a result there are wet and dry systems incorporated in this building. The Atrium is a large open space and 4 stories high the three penthouses on top of the office building each have a large fan that sucks the all the smoke and air out of this space. Once the smoke alarm goes off and these fans start up the smoke hatch that each fan's ductwork hooks up to pops open.

- **Lighting / Electrical Systems**

  The electrical system has an emergency generator with a max rating of 1000 kw, 480/277 volts. It is also sized to connect (4) 400 amp connectors per phase, (4) 400 amp cam connectors for neutral and (1) 400 amp cam connector to grounded. All the panel boards are 3 phase, 4 wires. The building also has PV trays covering the atrium skylight and occupancy and daylight sensors to help reduce the electricity usage of the building.

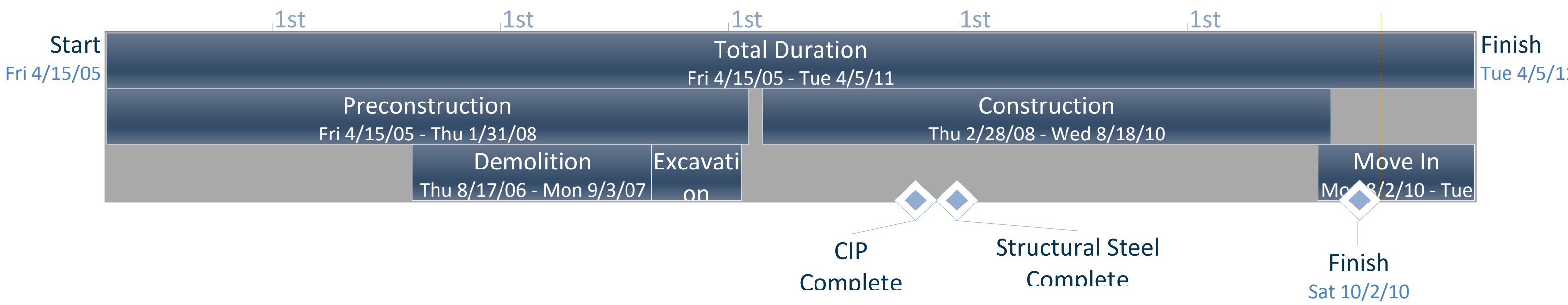
  The way this building is designed there is a lot of natural lighting. Every light in the building is also hooked up to an occupancy sensor to help conserve energy. Each room also has daylight sensors to adjust the lighting based upon the natural light coming into the building.

- **Curtain Wall System**
  The curtain wall system is composed of aluminum framing with glazing. The glazing was designed based upon a wind speed of 100 mph, an importance factor of 1.15, and in the Exposure B category. The glazing is a high efficient glass manufactured just outside of Venice, Italy. Curtain wall consultants, Hopkins Architects, and members in charge of the sustainable design decided on this type of glass and how it was going to be installed. The glass picked by a crane and then installed by workers in a boom lift. Each piece of glass was fastened down with toggles. It was then tightened down to the correct torque and a gasket and caulking were installed. The device that was attached to the crane to pick the glass was shaped in an X and each arm had two suction cups on it. Two similar ones are pictured below.

Detailed Project Schedule

*See Appendix A for complete detailed project schedule

The Chemistry Building's schedule was broken down into different phases. The phases were preconstruction, demolition, excavation, construction, and move-in. The durations of these phases can be seen in the timetable below.



Looking at the above chart, the components that make up the preconstruction part are selecting the project team and the design process. The project started off with the Owner choosing Hopkins Architects to be the design Architect. Soon after they were selected, Turner Construction was brought on for preconstruction planning. The owner, Hopkins Architects, Turner Construction, and ARUP worked together for roughly two years before construction started.

The next phase was Demolition. Even though the timetable above shows demolition taking over a year, it only involved Turner Construction for about the last month of it. The majority of the time consisted of the owner clearing out the building. Next, the utilities to the armory were cut and capped before Turner Construction demolished the building and large parking lot.

Finally demolition was complete on 9/3/07 and excavation began. Because the geotechnical reports showed there was a lot of shallow bedrock, blasting was required in order to complete the foundation. Almost 50,000 CY or rock were blasted and hauled off site. This was a long and complex process because blasts were only permitted to take place during a one hour time frame each day. It was also required that any dynamite placed in the ground needed to be blasted that day and could not remain in the ground and active overnight.

Once the sheeting and Shoring were installed, the construction process began on February 28th, 2008. The first part of the critical path for this portion was pouring the footers and foundation. Just like the excavation, the foundation work started at the south end of the building and worked north. The superstructure started on March 3rd, 2008 with the erection of the south concrete cores and south CIP columns. The concrete worked continued moving south to north completing the CIP Columns, CIP Beams, and CIP Concrete Cores. Because the concrete cores act as shear walls and the structural steel ties into them, steel erection could not begin until September 15th, 2008 when the south cores were complete.

One of the first milestones during the construction process was the completion of the cast in place concrete on October 24th, 2008. The steel quickly topped out after on December 29th, 2008.

The next part of the schedule is broken down into portions of the building. Because the lab and office portions of the building are completely independent once the superstructure is complete, two separate schedules were formed for this point forward. The schedule formed by Turner Construction broke the schedule down even further and resulted in around 36,000 items. Because the detailed schedule in Appendix C was limited to 200 items, the furthest it was broken down into was by floor. Included in this is framing the walls, rough in, inspections, closing the walls, and MEP.

The next milestone for the Chemistry Building was the Exterior Façade and Roof were completed on December 18th, 2009.

The building turnover process was in phases and began on August 2nd, 2010. Moving in would then continue until April 5th, 2011. By Contract the Chemistry Building was to be completed by October 2nd, 2010.

Project Cost

The Costs presented below are based on the GMP costs from the information provided by Turner Construction.

	COST $	COST $/SF
Excavation & Foundation	6,170,000	23.28
Structural Frame	32,600,000	123.02
Exterior Wall	45,772,000	172.72
Interior Finishes	37,465,000	141.38
Lab Casework & Equipment	13,984,000	52.77
Roofing	3,388,000	12.78
Plumbing	17,302,000	65.29
HVAC	31,235,000	117.87
Electrical	24,552,000	92.65
Controls	4,919,000	18.56
Sitework	3,929,000	14.83
GC's and GR's	25,802,000	97.37
Elevators	2,790,000	10.53
Fire Protection (Sprinkler System)	2,740,000	10.34
Furniture	4,865,000	18.36
Total	**257,513,000**	**971.75**

Site Layout

*See Appendix B for Site Layout Plans

During the demolition of the parking lot and armory building there were two ways in and out of the site. One is located on the Northwest corner of the site and the other is located on the Northeast of the site. Both of these gates were in use for the excavation process and for about a year into the construction process. The Chemistry Building was eventually constricted to one entrance and exit gate due to the start of construction of a bridge spanning the main road to the west of the building. The Northeast gate was used as the only gate to the site until the bridge was completed in the summer of 2010. When the Northwest gate reopened the Northeast gate was then closed because construction started on a neighboring building along this road.

All excavation and erection started at the South end of the site and worked its way towards the North. The way the building is setup the lab and office parts were erected separately and then connected by the atrium steel. Typically there were at least two cranes onsite and multiple crews. One crane worked on the lab building while the other was working on the office side. All areas around the site were stable and suitable for a crane to be positioned. Mobile cranes were used for this project and they were typically around 100 tons.

The loading dock and hoisting lifts were located on the Northeast corner of the building. They were positioned where the north exterior stair tower is located and connected onto the North lab concrete core. The hoist was a two car system. One was used for materials and the other was used for the workers. This was erected once the north concrete core was finished and cured and stayed until the elevators for the building were operable. The reason for this location is it was closest to the Northeast gate, which was the only gate for majority of the construction process. It was also located in a position where tractor trailers with deliveries could easily turn around, back into the loading dock, and then exit the site.

The trailers were all positioned in the Northeast corner of the site by the entrance gate. Next to the trailers is a small parking lot for the Tuner employee's onsite. There is a large parking lot about a mile down the road from the site where the rest of the workers parked. A bus constantly ran back and forth transporting the workers. Each subcontractor was permitted to have a small trailer and/or an equipment trailer onsite until the landscaping and finishing site work around the site needed to start.

The dumpsters were located next to the loading dock for easy access.

*Note: No site layout plan was provided by the contractor to critique. Also due to the fact that the location cannot be revealed surrounding buildings and road names or a zoomed out location of the site are not included.

General Conditions Estimate

*See Appendix C for complete estimate

The estimate for the general conditions for the Chemistry Building is summarized in the table below. The way this project was contracted it was broken down into general conditions and general requirements. This estimate below does not represent actual amounts contracted between the owner and Turner Construction. Most of the information used to calculate these figures came from RS Means Cost Works.

Item	Unit Rate	Unit	Total Units	Total Cost ($)
Preconstruction General Conditions	14,143,50	Weeks	104	1,470924.00
General Conditions	79,089.70	Weeks	165	13,049,800.00
General Requirements	61,733.33	Weeks	165	10,186,000.00
Total	**154,996.53**		**159.43**	**24,706,724.00**

The Chemistry Building is a highly unique and sophisticated building which is shown by the extremely high cost per square foot of $971.74 / SF. Because of this a wide variety of expertise was required to build this project which resulted in a very large project team. The total cost for staffing this project based on RS Means cost works and the schedule of the project was $11,103,100.

This project had two years of preconstruction where Turner Construction worked with the owner, architect, and engineers. The costs associated with this are included in the total staff budget above and summary table above. Although there was a small staff and not too many other general condition costs associated with the preconstruction process, it increased the total cost for this section by about 6.64%.

The general conditions and general requirements comprise of about 9.64% of the total cost of this $257,508,998 building. This percentage is a reasonable number and 8-10% of the total building cost is usually typical. An interesting part about these particular general conditions that differs from typical projects is the owner pays for all the temporary utilities during construction. This includes gas, electric, chilled water, etc. This is a substantial cost considering the project is just over three years and would drive the 9.64 percentage up. However, not many projects have two years of preconstruction which is why this value is reasonable.

BRINGING BIM INTO THE FIELD (Critical Industry Issue)

Problem Identification

The Chemistry Building produced a Building Information Model which was used for 3D MEP coordination. After attending the "Carrying BIM to the Field" breakout session of the PACE roundtable conference, it was clear the Chemistry Building was a prime example of this topic. Some of the main topics discussed were tablets, barcode scanning, paperless jobs, tracking progress, and improving efficiency. Through my experience working on this project for two summers, I have noted additional ways the BIM model could have been used on the Chemistry Building. The costs to use tablets, barcode scanning, etc. are minimal compared to the large upfront cost of building the model. These minimal costs could save time on the project, organize information, and help track progress. Loading the model with manufacture information and warranty information could also be beneficial for the owner throughout the lifecycle of the building and its maintenance.

Research Goal

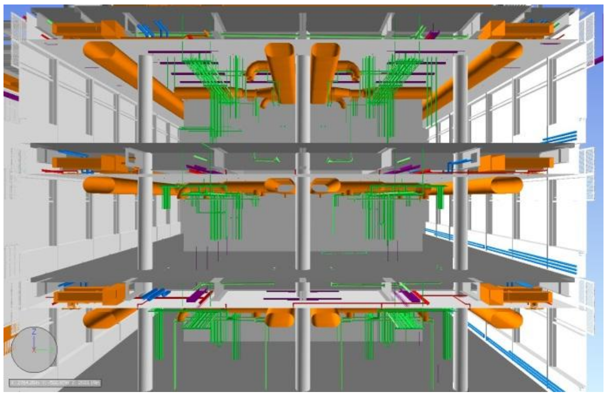
The goal of this analysis is to show the benefits of BIM and how it can be utilized more on a project. The goal of this analysis is also to tie all my analysis's together and be an underlying theme for my senior thesis project.

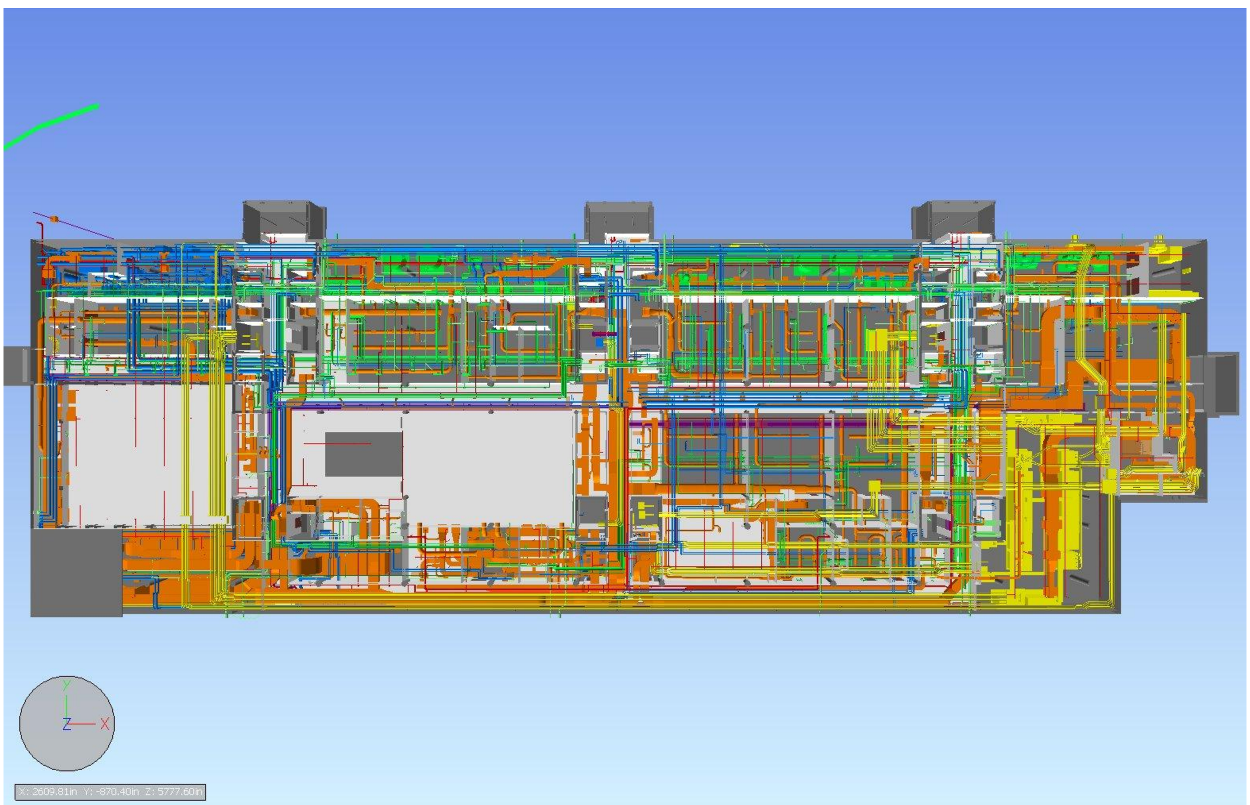
Methodology

- Research projects that have used BIM to its fullest potential
- Explore case studies associated with BIM
- Interview select industry members regarding BIM
- Compare research gathered to my experience and project team's experience on the Chemistry Building
- Draw conclusions based upon comparison
- Develop summary of findings and associate cost and project impacts to them

Background Information

The Chemistry Building is comprised of an office side, 4-story atrium, and lab side. These three differing spaces made the mechanical systems very complex and difficult to design. In order to get the most efficient and highest quality system, changes were constantly taking place. There were so many changes that a period of six months passed and there was no progress. As a result Turner's parent company, Hochtief AG based in Germany, built a 3D mechanical and structural model. In order to make up for the lost time, Turner decided to release the sheet metal orders for the duct work based on the 3D Model.





This extensive model was extremely valuable to the planning and construction process for the Chemistry Building. The delays the project faced due to mechanical changes were going to result in major delays. Therefore, being able to release the sheet metal orders for the duct work based on the 3D model was crucial in making up lost time to curtail the delay. Some of the additional benefits of this model were improved coordination between trades, reduction of problems / changes during construction, and fewer change orders.

It is clear that Building Information Modeling was beneficial to this project, but the question is, are there any additional ways BIM could have been used to benefit the Chemistry Building more? After attending the PACE conference breakout session of “Carrying BIM to the Field,” the research I have conducted, and my experience working on the project, the answer is yes.

PACE: Carrying BIM to the Field Recap

The key points touched upon during this discussion are as follows: uses, paperless jobs, tablets, computer limitations, and benefits.

BIM has been a huge topic in the construction industry. There has been a substantial amount of news presenting BIM as the tool that can do almost anything. This is true to a certain extent but the biggest problem is educating people how to properly use the resource of BIM. A prime example of this came forth when a student shared an experience he had while on a jobsite this past summer. The student approached a supervisor in the field using a tablet as a resource and asked him what exactly he used the tablet for. The supervisor responded by saying he likes it because it is easier to take notes and organize them while on the jobsite. This expensive piece of equipment and valuable resource is being wasted. The tablet, if used properly, can bring up drawings, schedules, or basically any information about the job. This eliminates the need to walk back to the jobsite trailer to search for answers or information, thus saving time. Tracking commissioning and job progress are easier and more accurate when using the tablet. Another benefit is having the ability to look at the 3D model as your standing in that space. This helps the superintendents notice problems sooner. Although the costs of tablets are expensive, the implementation of them could result in paperless jobs to even out the costs. Two other interesting features associated with BIM and the tablets are the uses of barcodes/tagging and using the model with the total station. Using barcodes makes a project more organized and provides management with the information of where a piece is located during transit and where it belongs on the job. The New Meadowlands stadium had great success doing this. Using the model with the total station also has huge advantages for renovations and new construction. Asbuilts can be taken using the total station and laser then uploaded into the model.

There are two downfalls associated with BIM and carrying it to the field. The expensive cost to produce the model and constantly update it is a huge deterrent. Although it may save you money throughout the job, many owners do not consider this and only look at the high upfront cost. The next major problem is not everyone is properly educated how to use this technology. If the knowledge is not there BIM will not be beneficial.

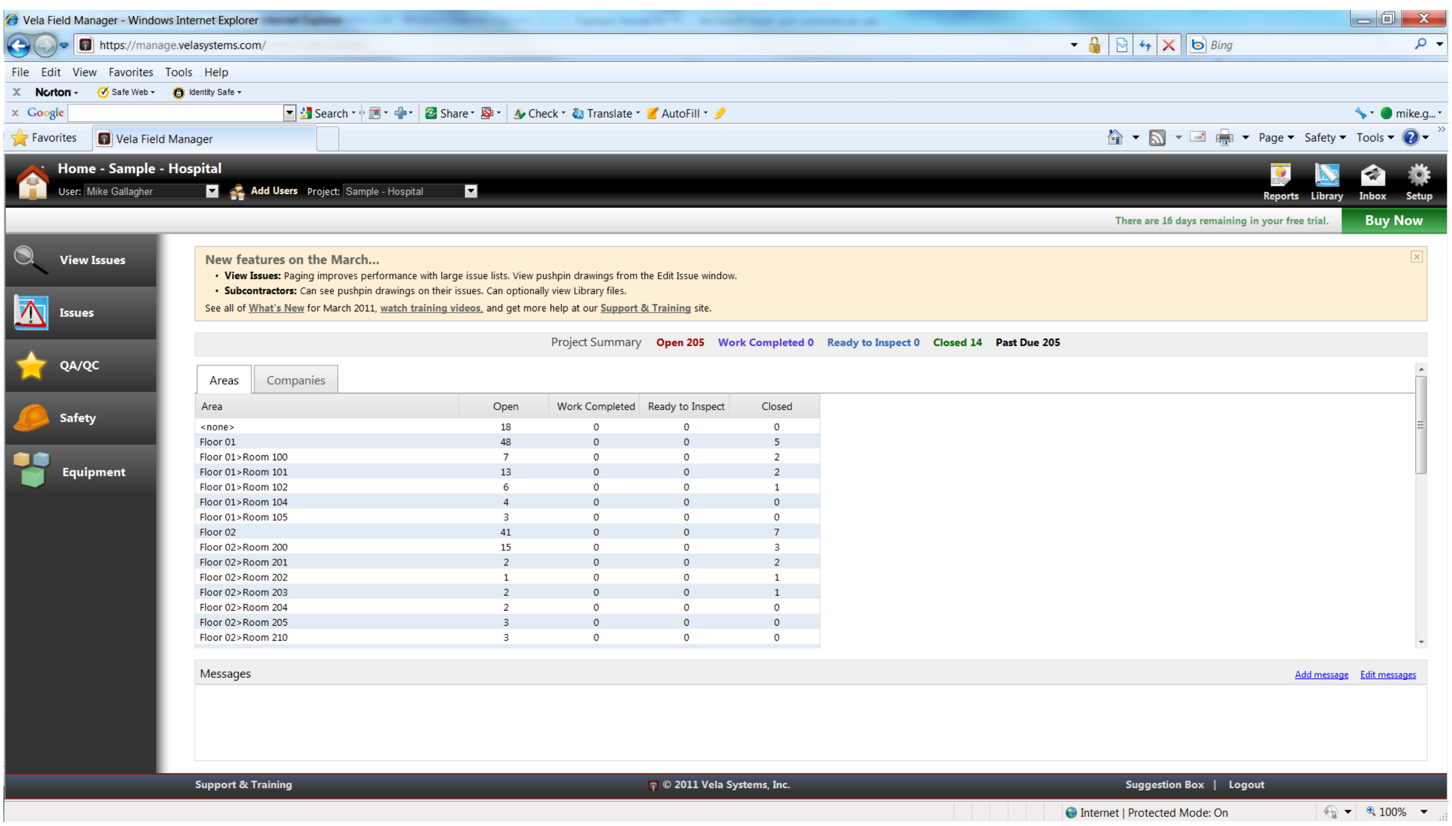
New Technology

While researching ways of bringing BIM into the field successfully, I came across a couple of software programs that help manage this process. The three major ones I found are Vico Software Integrating Construction, Trimble, and Vela Systems.

VICO Software and Trimble have a partnership to work together in Carrying BIM to the Jobsite. This is possible because VICO is software is used in the modeling process and uses Vico's Construction to help build the model. Trimble is a company that is known for its GPS, Laser, Optics, and Positioning Hardware / Software. When you combine these two programs, you can take the 3D model and export the information in it to Trimble Field Layout Solution. This information can then be printed out and given to the workers constructing the building. As a result, the workers are supplied with extremely accurate information and everything should get erected in the correct location. Besides being able to print out a layout drawing for the workers, Trimble allows you to use GPS and a total station for layout. The main purpose for this is everything is placed with precision to eliminate errors. This is very beneficial for excavation, formwork, superstructure erection, and MEP layout.

Vela Systems is a tool that is involved in more than just BIM. The goal of this tool is to help manage and make the entire construction process easier and more organized. Vela Systems has gone as far as making a mobile application to access and manage this system from your phone. Vela Systems trademark phrase is "Construction happens in the Filed – **Mange it**" which is the main theme for this system. The purpose of Vela Systems is to have all the drawings, documents, Models, ASI's, RFI's, QA / QC, Safety, commissioning, tracking progress, closeout, etc. in the program. When this program is purchased, an unlimited number of accounts can be linked to the project and anyone that has an account can upload information to the system. A really nice feature for this system is the reports function. With this you can quickly get a 2 week look ahead for the entire project, a particular trade, or a portion of the building. As a result, the subcontractors should always know what they should be working on and what is to be completed next. The superintendents then can go through and QA & QC the areas when a subcontractor closes the item. In doing this, the superintendent can approve the area and completely close it out or make comments and even upload pictures. This can then be printed as another report and clearly documented. This is a function that many owners like because they can see what is being QA & QC and see that they are getting the quality building they paid for.

Vela Systems also is very customer friendly. Everyone I talked to when researching this software was very helpful and tried to supply as much information as possible. A benefit about this is you know what you are paying for upfront before you make any purchases. There is a free 30 day trial that is the actual system that you would be purchasing. The free trial version has every feature that the software you will be purchasing has. It is not a company that tries to lure you in with a preview and you need to purchase the product to see how it really works. The free trial version is also loaded in with two sample projects so you can see how it actually functions. You can even set up your own project for 30 days. Besides being able to visualize the software program first hand, there are support & training videos online that are very useful and help you use the software. Below is a picture of what the system looks like.



Case Studies and Industry's Opinion of Vela Systems

Vela Systems is being implemented on smaller projects to projects like the nine hundred ninety-eight billion dollar New Meadowlands Stadium. It is also being used by small regional companies to larger global companies. Overall, it has received a very positive review and has been shown to save time, money, and improve the overall construction experience.

On the Vela Systems website, there is a list of Industry member's thoughts about Vela Systems after using it. After reading some of the quotes, it is clear this is an extremely beneficial tool and should be implemented on more projects.

Besides people's opinions about the software, there is documented proof of how this software improved certain projects. Skanska used Field BIM Solution to save one million dollars on the New Meadowlands Stadium. They did this by tracking the 3,200 precast concrete panels used in erecting the stadium. This was done by placing a radio frequency identification tag on all the precast at the fabrication facility. By doing this, Skanska could easily tell which stage of production every piece was in at any moment. It could then be easily coordinated which pieces of precast needed to be delivered to the jobsite on a particular day and time. Skanska estimated that using this technology resulted in roughly a one million dollar savings based on the ten days that were saved on the construction schedule.

Barton Malow used Vela Systems on the Maryland General Hospital in Baltimore, Maryland. The case study associated with the project shows how using this software improves the efficiency of contractor's work, decreases the owner's cost for maintaining the building, and decreases the time associated with the handover process, thus saving money. Typically in a project there are thousands of papers that range from reports from the commissioner to project manuals, to QA & QC of the equipment. These papers are typically all organized in a binder. It takes a lot of time to organize all of this information and make sure it is in a format that the owner's maintenance team can successfully use to keep the equipment running at optimal performance. Vela Systems helps manage and simplify this process. Using BIM, Vela systems generates an equipment list and then all the manuals, maintenance information, commissioning reports, warranty information, and system data is linked to this piece of equipment. For maintaining the building, the maintenance team can run a report to find out when they need to change filters for particular equipment. This eliminates the need to search through binders of pages to find maintenance information. In some cases if the information is not organized well, the maintenance team does not know what equipment requires necessary upkeep. If this happens eventually equipment is not running at optimal performance resulting in wasting energy and even equipment breakdown. Besides the benefits of maintaining the building, the model being loaded with information expedites the commissioning process. Vela systems can be used to see what equipment is installed and ready to be commissioned. When the commissioner arrives onsite, they will then know exactly which equipment they can commission and also do not need to waste time searching through data to figure out the information they need for commissioning. They can simply bring up all the information about the equipment and how it is supposed to perform through their tablet or laptop in the field. Overall this case study shows that loading the BIM through Vela Systems reduces wasted time searching for information or spending time organizing information. Vela Systems organizes the information for the project. It is even capable to link photos or videos to certain equipment.

An additional case study is one conducted by Turner Construction regarding QA/QC. This was done successfully on the two following projects: 10 Rittenhouse Square, Philadelphia, PA and Hampton Roads Naval Housing, Norfolk, VA. This case study makes the quality control and quality assurance process smoother and better sequenced. A superintendent brings a tablet or iPad into the field and inputs information on this while walking around. There is a set form to fill out in Vela Systems for this. You choose the trade, area of the building, what is being inspected, and then if it conforms or is in non-conformance. If the iPad or tablet is hooked up wirelessly, this information is uploaded immediately and everyone on the project can see it. This eliminates the time taken going back to the trailer, filling out a paper copy, scanning this form into the computer, emailing the trade notifying them if there is a problem, and then filing this information. Vela systems properly documents everything and everyone has access to the information. If a trade has issues that are non-conformant with the specs or design, when this information is uploaded a notification message can then be sent to that trade. The 5 step process before that required going back to the trailer now can all be done on one step while standing in the field. A picture of the non-conformance can even be taken and linked to this issue. Bob Wunderlich, Quality Control Manager for Turner Construction Company said “We pick up a day of time on schedule every week or so. You continue to pick up a day here and there and pretty soon it adds up.”

Impacts of Implementing Vela Systems on the Chemistry Building

It is very difficult to associate a time or cost savings of implementing this system, but after ready the case studies, it clearly shows Vela Systems benefits a project. The case studies I chose to include in this report are also areas that were challenging in managing the Chemistry Building. The communication between the architects, superintendents, and trades about closeout and punchlist items was very difficult. First off, the architects were from London and only visited the jobsite for a couple days every other week. With that, the time for the architect, superintendent and Forman to walk around for inspections was limited. The architects in an excel sheet would note areas that needed to be touched up. When I was standing in the building it was difficult sometimes trying to find some of the locations and descriptions of areas that needed to be fixed. Because of this, there was a lot of time wasted searching for those locations and getting other superintendents involved in trying to find particular locations. Because the locations were not always clear, when this information was given to a Forman, there were usually calls asking where certain areas where. Also items on the punchlist were missed because no one could find the locations. This then resulted in a 2 week delay in closing particular items on the punchlist because of the wait time for the architect to return. Besides the superintendents and Forman having difficulty finding locations, the architects many times had difficulty finding areas members wanted them to locate. Overall the communication between all parties involved was not always clear which resulted in wasted time. This was a similar case in some of the case studies and Vela Systems helped improve it. By having a set naming convention for locations based, the locations marked on a plan or elevation drawing, and a picture linked to this issue, this would eliminate the wasted time described with the Chemistry Building. Although for some areas of the building, punchlist work went smoothly and there was little to no wasted time, implementing Vela Systems would help organize this process and make it easier for everyone involved.

From the Skanska case study, I feel the tracking system used for the precast would have been very beneficial if it was used for the Chemistry Building's curtain wall system. Because the curtain wall system was produced in Italy and the high costs associated with shipping materials, it was very common for shipments to contain a variety of building materials. If glass was being shipped for the south endwall and a couple pieces of glass were ready to ship for the north egress stair tower, all this glass would be combined in one crate. As a result, you never knew what material was going to show up onsite or when materials you needed were going to show up. Therefore, it took time to sort through each shipment to figure out what portions of the building were included in this delivery. There were instances where a piece of glass was broken and it was part of the critical path of drying in the building. A new piece then needed to be ordered and it was common that no one would ever know the status of that lite. Weeks would go by and superintendents didn't know if it was still in fabrication, in shipping, in customs, or on a truck on its way to the site. Because of this, it was difficult to coordinate with other trades or adjust the schedule accordingly to still be productive while waiting for material. If the barcode tracking system linked to Vela Systems was implemented, all these problems would be eliminated. By simply clicking on a piece of glass in the model or scanning a barcode, you would know exactly where and what stage a particular material was in.

Vela Systems benefits associated with commissioning would also be useful to the Chemistry Building based on challenges that were faced during construction. This will be talked about in the analysis of Lab Penthouse AHU Commissioning (Mechanical Breadth #1).

Recommendations and Conclusions

Taking my experience of working on this project for two summers into account, the challenges the project faced, information from the project team, reading case studies regarding Vela Systems, and the additional research I did, I feel Vela Systems would improve the construction process of the Chemistry Building. The reasons for this statement can easily be understood after reading the *Impacts of Implementing Vela Systems on the Chemistry Building*. In addition to this, Turner used Vela Systems to help manage dormitory buildings on the same university's campus. The site manager for Turner Construction on the Chemistry Building said they were considering using this system on this project also, but the timing did not work out. The start dates for the two projects were fairly close and by the time Vela Systems was running smoothly and clearly was going to be valuable for the neighboring project, the Chemistry Building was too far along to implement Vela Systems. Taking this into consideration, if the timing was different, Vela Systems very well could have been used on this project.

LAB PENTHOUSE AHU COMMISSIONING (Mechanical Breadth 1)

Problem Identification

During the balancing and commissioning process of the lab penthouse AHU's of the Chemistry Building, it was realized these five AHU's were performing inefficiently. It was determined the cause was poor layout of ductwork. Two inches of static pressure were being lost between the AHU and the exhaust duct. As a result, the fans needed to run at a higher rpm in order to achieve the required CFM of air flow. Therefore, the fans were using a lot more energy, thus making the system inefficient.

Research Goal

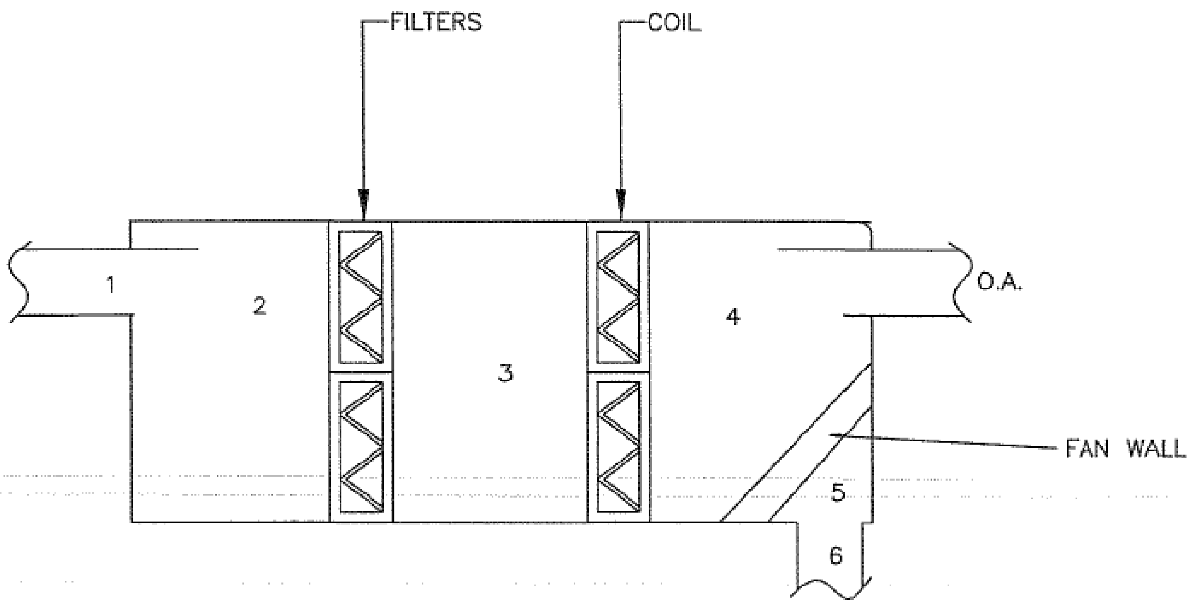
The goal of this analysis is to use BIM to layout the ductwork differently in order to reduce the static pressure drop. This will reduce the fan speed and save energy.

Methodology

- Determine how this happened
- Use current fan speed and CFM to calculate out energy consumption
- Use the BIM model to layout ductwork differently
- Calculate out the CFM and fan speed based on new ductwork layout
- Calculate energy savings based on new fan speed from changed ductwork
- Construction Impacts

Background Information

The air handler units were custom made for the Chemistry Building by Ventrol. The five AHU's in the lab penthouse are designed where the exhaust is forced out of the building through an axial fan wall. The airflow through all of the units must be 75,000 cfm in order to meet the exhaust requirements for the lab. These units were also designed to have an ESP of 3.2 IN WC and TSP of 7.8 IN WC. However it was notice this was not the case during the balancing and commissioning process. Looking at the plan view of the AHU from above notice hose the fan wall blows into the corner of the unit. If you then look at the elevation view in the BIM model of this area, you can see that there is a small exhaust duct on the one side of this corner. The problem is the exhaust ductwork is too small and cuts down the air flow. The air bounces around in that corner because the duct is too small. Because of this, the fans need to work harder and have a higher rpm in order to force the air into that small exhaust duct. This is where the additional 2" of static pressure is located. This can be seen in plan view and data provided below for the five AHU's.



Static Profile

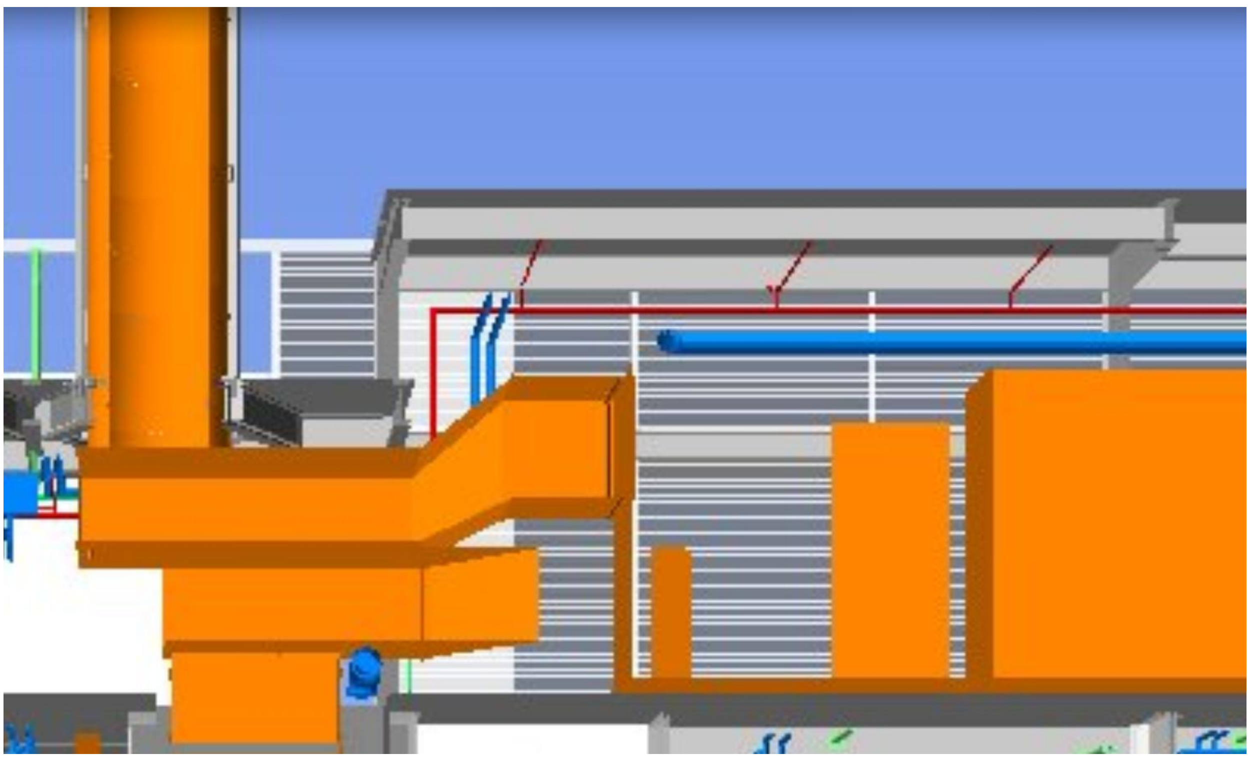
	1	2	3	4	5	6
AHU—1	−1.54	−1.52	−1.68	−2.69	+3.22	+1.18
AHU—2	−1.0	−1.17	−1.29	3.52	−2.75	.85
AHU—3	−1.04	−1.20	−1.39	−2.26	−3.74	+1.76
AHU—4	−.98	−1.0	−1.22	−2.43	3.23	+1.09
AHU—5	−1.65	−1.73	−2.6	−3.27	+2.60	+1.39

EXHAUST SYSTEM STATIC PRESSURES - DWG: sketch

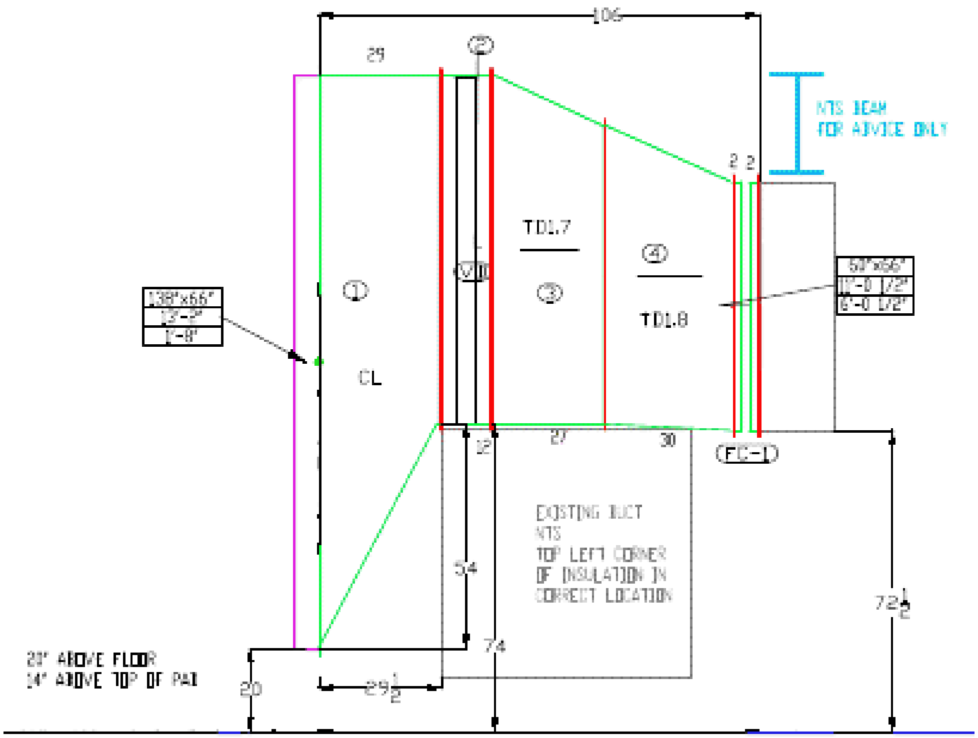
For the purpose of this analysis, we are only going to look at AHU – 1. Looking at this diagram above, you can see that there is 2.04" of static pressure between location 5 and 6.

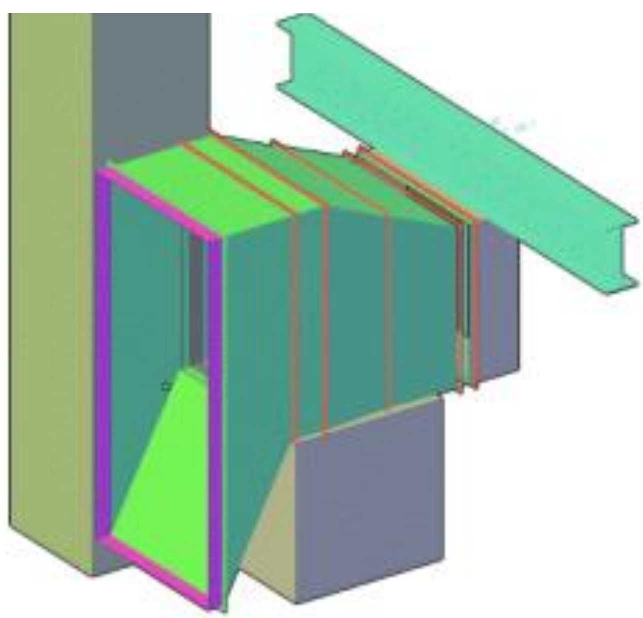
Corrective Work

After examining the 3D model and this problem in the field, the only real option to correct this problem was cut out the exhaust ductwork, make the exhaust ductwork larger, and cut a larger hole in the side of the AHU to connect the exhaust duct. This was the only way to have minimal impacts on other systems. Looking at the image below which was taken from the model, you can see the supply duct is below the exhaust duct and there are steel beams limiting the exhaust ductwork to the height it is currently at. As you can also see in the image there is a little bit of room to make the exhaust duct larger where it connects to the AHU and then transition down to the smaller ductwork which just fits between the steel beams and supply duct.



The image below shows the dimensions and an elevation layout of the new ductwork. The AHU is on the left of this image where the pink line is. The image below that is a 3D diagram of the space and the new ductwork. Once again the pink line represents where this ductwork ties into the AHU.





Based on this new design, I calculated out what the change in static pressure would be for this new ductwork. In doing this I solved for the friction factor for the total length of the duct, which is 106 inches. Next knowing that the change in static pressure = component losses + friction losses, I solved for the pressure drop. In order to do this, I needed to break up the exhaust duct into five different components in order to use the ASHRAE book and solve for the loss coefficient. The five sections are as follows:

1. The fan wall to the Exhaust duct
2. Elbow between fan wall and exhaust duct. (I added this in because there is a turn from the fan wall to where the air enters the exhaust duct)
3. The AHU exit ductwork transitioning up to the damper
4. The Damper
5. Transition back down to the ductwork between the supply duct and steel beam.

After figuring out the loss coefficient for these 5 areas and multiplying it by the velocity pressure and adding them all up in addition to the pressure drop associated with the friction factor for the duct, I received a total pressure drop of 0.3310 in wg. This seems very reasonable to the original static pressure drop of 2.04 in wg for this same section.

Please see Appendix D to see the equations used and calculation that were conducted in order to achieve the value of 0.3310 in wg.

However when this design was actually implemented, the drop in pressure was 0.87 in wg. While conducting this analysis and using the ASHRE book, I came across a section that talked about Duct Systems Effect. After reading this, it was clear that this was taking place for this situation. Duct Systems Effect is when there is a series of losses that are close together they have an effect on each other and result in additional losses. Due to the design of the fan wall blowing into the corner and the exhaust duct only on one side

Schedule Impacts

Looking at the detailed schedule in Appendix A. you can see balancing the Lab AHU's took place from 6/3/10 through 8/18/11, 55 days total. This process includes commissioning and is partially adjusted for the issue presented in this analysis. The original schedule showed this process taking almost half this time. Because balancing and commission had to stop, this area needed to be redesigned, new ductwork needed to be fabricated and installed, then finally balancing and commissioning could begin again, this resulted in major delays. This entire process took over twice the time it should have and didn't finish until after 8/18/10. Because this was one of the final steps for the MEP superintendent, this also resulted in additional costs. This superintendent was supposed to be finished with this project and move to another job but now needed to stay at the Chemistry Building and be an additional general conditions cost.

Cost Impacts

ORIGINAL DESIGN
(Before Corrective Work)

$$KW = \frac{V \cdot A \cdot PF}{1000}$$

using a power factor of 0.6 for an Axial FAN

Volts = 450
AMPS = 12.8

$$KW = \frac{(450)(12.8)(0.6)}{1000}$$

= 3.456 KW ← running 24 hrs/day for 1 year

(3.456)(8760) = 30,274.56

30,274.56 kWh/year per FAN

5 Units each w/ 12 Fans = 60 FANS

(30,274.56)(60)

= 1,816,473.6 kWh/year for all the fans constantly running at PEAK POWER/SPEED

x $0.1312/kwh = **$238,321.34/year ALL FANS RUNNING 24 hrs/day for 1 year**

$79,440.45/year ALL FANS RUNNING ONLY 8 hrs/day for 1 year 605,491.2 kWh/year

REDESIGN

$$KW = \frac{V \cdot A \cdot PF}{1000}$$

ALSO USING A PF of 0.6

NEW
VOLTS = 415
AMPS = 11.0

$$KW = \frac{(415)(11.0)(0.6)}{1000}$$

= 2.739 kw

(2.739)(8760) = 23,993.64

23,993.64 kWh/year per FAN

5 UNITS EACH w/ 12 FANS = 60 FANS

(23,993.64)(60)

= 1,439,618.4 KWh/year for all fans constantly running at PEAK POWER/SPEED

x $0.1312/kwh

$188,877.94/year ALL FANS RUNNING 24 hrs/day for 1 year

$62,959.32/year ALL FANS RUNNING ONLY 8 hrs/day for 1 year 479,872.8 kwh/year

Following the calculations on the previous page, you can see for the absolute worst case scenario of all 12 fans in all 5 units running at peak power constantly for an entire year, the redesigned duct work saves 376,855.2 kWh worth of energy in one year. Based on the cost of energy for the location of this building being $0.1312/kWh for December of 2010, this results in a $49,443.41 savings per year. Using a 1% increase in energy costs per year the savings to date from this change would be as follows:

Number of Years	Savings to Date
5	$252,211.00
10	$517,287.40
20	$1,088,694.00
25	$1,396,440.00
50	$3,187,279.00
80	$6,015,854.00

Recommendations and Conclusions

In conclusion, this was a necessary change. An additional 2” of static pressure is a huge amount and when this is the case for 5 air handler units, you can clearly see this drives the amount of energy required to run this equipment way up very quickly. The corrections made ultimately reduced the amount of energy used per year by 376,855.2 kWh. This was done by modifying the ductwork and its connection into the AHU, thus reducing the additional 2” of static pressure down to 0.87” of static pressure. Although redesigning this area delayed the commissioning and balancing process and required additional costs for new materials, labor to demo and install the new design, and personnel to manage this process, these costs were minimal to the ultimate savings this redesign achieved.

ALTERNATIVE CURTAIN WALL SYSTEMS

Problem Identification

The Chemistry Building Currently has a forty million dollar curtain wall system that is manufactured in Italy. As a result, there were many problems associated with lead time and tracking pieces needed for construction. Because the scope of this work was so large, there were not many bidders due to the fact that a company could use the same amount of resources to bid four projects. Another problem associated with the curtain wall was engineering showed the three exterior glass stair towers only needed to be heat strengthened on the exterior pane. During construction a large percentage of the glass was broken.

Research Goal

The goal of this analysis is to show that breaking the curtain wall system contract up could improve the construction and management of constructing the curtain wall system. An additional goal is to find alternative systems that will work for the Chemistry Building and have potential to reduce schedule or cost. With the idea of value engineering in mind, a glazing system with PV capabilities will also be investigated. The goal is to find another system that costs less and/or is able to incorporate PV into it.

Methodology

- Contact manufactures for alternative glazing systems
- Find examples of similar projects where contract was split up
- Develop cost comparison between alternative systems and current system
- Develop schedule comparison between alternative systems and current system
- Draw conclusions and determine if alternate systems make sense
- Draw conclusions on how breaking up contract would improve project
- Electrical Breadth based upon PV glass system (explained in next analysis)

Background Information

The curtain wall is comprised of a glass façade with aluminum framing. The first challenge associated with this was the lead time. Because of the size of the glass, the only place that was capable of producing it was Italy. Due to the amount of time to produce and ship, the lead time did not allow time to finalize the contract drawings. As a result early design assist with the subcontractor, Permasteelisa, was implemented. This allowed for early production. Lead time also became a problem for replacement glass for pieces that were defective or broken during installation. After ordering a piece of glass it took approximately two months to end up onsite. With the challenges of lead time and getting the curtain wall onsite, Turner Construction had to build temporary walls to enclose the building in order for the mechanical rough in process to continue.

The next challenge pertaining to the curtain wall was the glass on the three exterior stair towers. The original design called for heat strengthened glass on the interior and exterior panes. Permasteelisa's engineers showed with calculations based on the design the inside pane did not have to be heat strengthened. During installation the interior pane of the glass started to crack around the edges. The first action taken was to change the toggles that were torqued down to hold the glass in place. The original toggles would pinch the glass against the framing causing it to crack. After the toggles were changed, the breakage percentage of the glass decreased. However, a percentage of the glass was still breaking. The final solution was to widen the gap between each piece of glass which would give the installer more room to torque down the toggles. In addition to that, all the glass was replaced with the original design of heat strengthened panes on the interior and exterior. Changing out the glass required a lot of logistics planning between Permasteelisa, the owner, and Turner. The stair towers are located along a road that needs to stay open during normal business hours. This was crucial because it affected the type of crane used, the crane location, and the days/hours the crew would work. One option was to bring in a tower crane that could reach all the towers and allow the road to stay open while work was completed during normal working hours. Each stair tower comprised of 115 pieces resulting in a total of 345 pieces to be replaced. With the rate for removal and installation on an estimated average of 7 pieces/day, it would take about 50 days or 400 hours to complete this task. Based on those numbers, if this work was completed only on off hours or weekends, it would take almost half a year to complete. This activity would also take a crane, boom lift, lull, and six workers to complete. Therefore, it was an expensive problem to solve.

An agreement between the three was to rip out finished site work and pour a pad for a mobile crane to sit on. The pad's location allowed the crane to reach all three towers, work normal hours, and complete the work the best based on time and cost. Below are pictures to better visualize the curtain wall and stair towers.

Breaking up the Contract

The curtain wall system for the Chemistry Building was such a large package that almost no contractors would bid the work. The reason for this is, these contractors could bid 3 or 4 projects with the amount of resources and personal it would take to bid the Chem. Building. Because of this there was no competitive bidding to drive the price down. Permasteelisa was the only contractor that bid the project therefore they were awarded the contract.

When talking with the project executive more about this and further investigating this, it would be difficult to break up the contract. The only possible way to break it up would be take the atrium skylight and wood paneling out of this bid package. There would be almost no problem in taking the wood paneling out, but the atrium skylight might be a little bit of a problem. In order for all the glass to match how the architect designed it, it would be extremely difficult for the glass to match with two different contractors both supplying glass. This would be the same case for the exterior stair towers. That was a separate phase of construction the curtain wall, but the fritted glass used on the stair towers match the fritted glass on the rest of the façade. The stair tower work was a little over 3 million dollars, the wood panel work was around 4 million dollars, and the skylight was around 4 million dollars, therefore this would still be roughly a 30 million dollar plus bid package. Thirty million dollars for a curtain wall system is still a really big bid package, especially considering an entire 100,000 SF multistory office building can be built for 30 million dollars.

As a result, unless it was acceptable to have slightly different glass for different areas of the building, it would be extremely difficult to break down this contract enough to achieve competitive bidding. Even if this was achieved, the savings from the competitive bidding could potentially not be as beneficial as one may think. The problem with having multiple contractors owning little pieces of a certain wall system is coordinating between them. If coordination between these contractors is not successful, it is very possible for leaks to occur due to poor connection between one another's work. In many cases one contractor work will be schedule dependent on another contractor's work which results in a higher risk for delays by adding more tasks / contractors onto the critical path.

Schuco Systems

While searching for different curtain wall systems, I came across a system manufactured by Schuco that contains photovoltaic glazing incorporated in the curtain wall system. This system is known as the Schuco E^2 façade. This line of curtain wall systems is known for supplying a complete system that can allow for building ventilation, PV energy production, sun shading, and a very low amount of heat loss. The goal of this product line is to drastically improve the performance of buildings and continue to drive the industry to build greener buildings.

This system really caught my attention because it is one of the few manufactures that markets a complete system. This system includes the glass, aluminum, gaskets, mullions, steel supports, electrical wiring, and everything a normal glass and aluminum curtain wall contains. Many systems supply only the PV glass and then you need to find a manufacture that produces a framing system for this panel and then find another contractor to hook up the electrical system for the PV, which requires a lot of coordination. It also takes a lot of time to find all the components that will properly work together and result in a well-functioning building. With the Schuco system you do not need to worry about this, because everything is included.

After realizing Schuco was a unique system and a high quality curtain wall system with PV incorporated could all be completed by working with a single contractor, I knew this was the system I wanted to implement on the Chemistry Building.

Once I decided this was the best system for fulfilling the goal of finding a curtain wall system with PV capabilities, I contacted the customer service department of Schuco. They put me in contact with a person that deals with preconstruction, working with the installers, and knows the technical information about majority of the systems. Within the first couple minutes of the phone call with this Schuco representative, he informed me this system has not been used on any buildings in the US yet. Because of this, his knowledge about the system was limited. However, he did give me a very rough estimate of the curtain wall system costing anywhere from $180 to $280 per SF and then an additional $120 per SF for pieces that were photovoltaic. The only way to get more accurate pricing is if this system was actually out to bid. Even if this was the case it would still be difficult because Schuco is a German based company and this system has yet to be used in the United States. Schuco also only started doing work in the United States 3 years ago; therefore they are still trying to expand in the United States. Because of this, some of the Schuco representatives I talked to informed me they just changed departments recently and did not know a lot of information I was after. Everyone one of them gave me the same contact, which they felt would be able to help me. This was the person who provided me with the pricing represented above. Even though I provided the total SF of glazing the building has, along with all the sizes of the glass used and the quantities of each size, he could not give me more accurate pricing. In addition to the sizes I provided him, I noted that I was curious how much savings there would be if a smaller glass was used. Each piece of glass is roughly 10.5’ wide and one of my research goals was to find out how much of a premium you were paying for the larger glass. In doing so I proposed to reduce the width of the glass in half. Although this would affect the architectural look of the building, I wanted to present the cost savings associated with reducing the glass size to the owner and architect. If there was a significant savings you could present the argument is it really worth X amount of money to reduce the amount of mullions or does increasing the number of mullions really change the architectural appearance of the building that much? In reducing the glass size besides the fact of the actual fabrication of the glass being cheaper, the system very well could then be produced in the United States. The current sizes of the glass required this system to be produced overseas which account for roughly 2.65 million dollars in shipping and packing.

In addition to the information I received from talking on the Phone with Schuco representatives, I was provided with the project data sheet for the E^2 façade system I have chosen to implement. This product data sheet can be viewed in Appendix E.

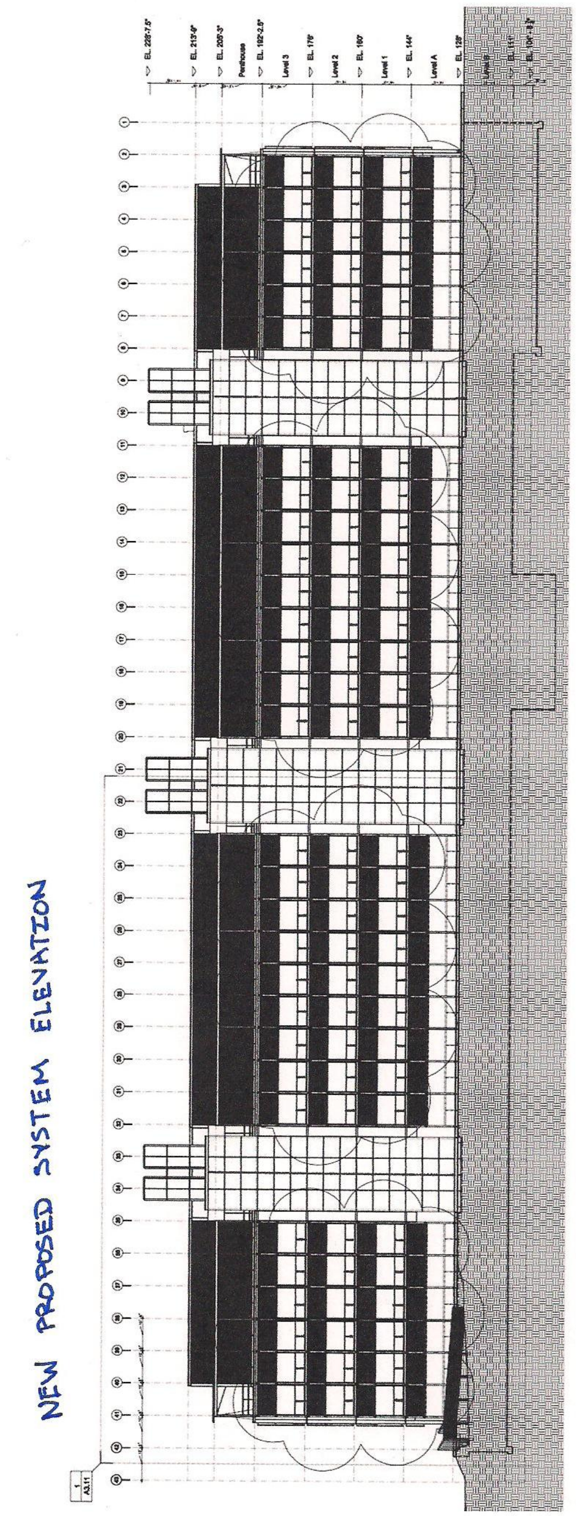
The project data sheet is where I got the majority of the information about the system. From the data sheet, I chose to use transparent PV glass with monocrystalline photovoltaic cell system which typically produces 140 W/m^2. I also found out that you could request a color of the cells; therefore I could keep the same green color of the glass used on the fritted glass. By doing this, I can maintain the same architectural look. Another important feature I looked at was the U-value for this system. The U-Value for the current system meets the specs that requires a value that is not more than 0.45 BTU/SF x h x degree F (2.56 W/m^2 x K) for vertical glass and not more than 0.54 BTU/SF x h x degree F (3.07 W/m^2 x K) for horizontal glass. Looking at the project data sheet, this system is capable of meeting those standards.

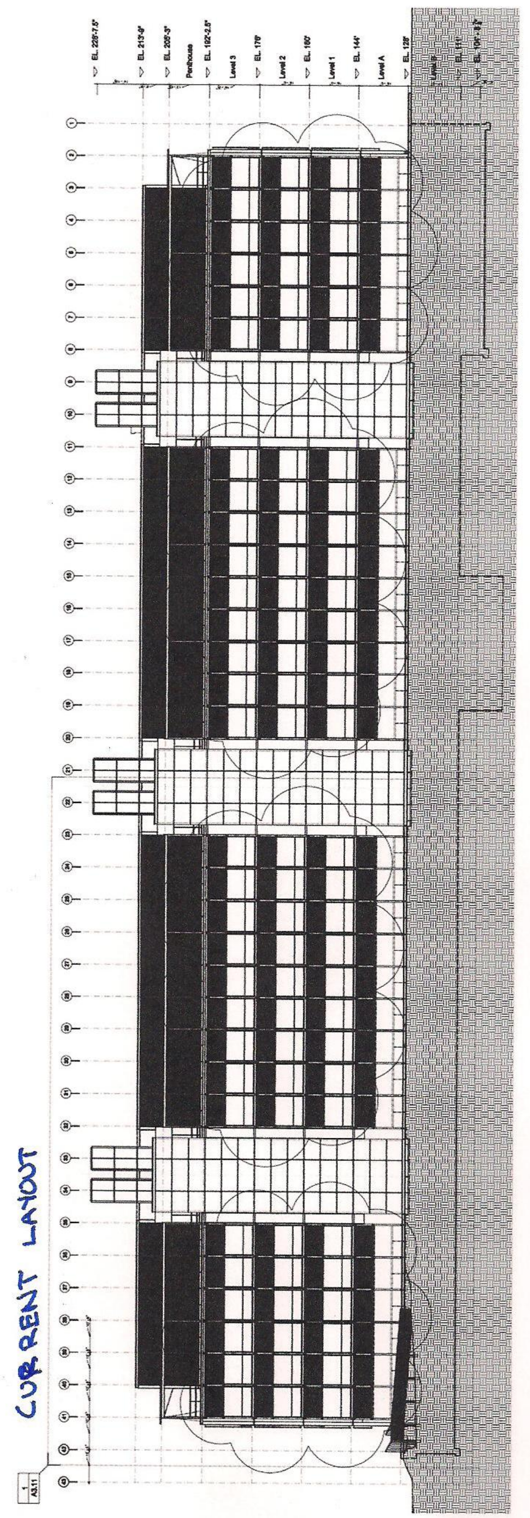
Proposed Designs for Alternative Curtain Wall Systems

After reviewing that this system has met all the performance standards in the specs and met the criteria of the system I was looking to implement, I began to design out my system. In doing so, I have proposed 3 different scenarios.

1. Maintain larger glass size and assume higher price and implement PV where fritted glass is located on exterior façade that is not covered by sun shades
2. Reduce glass size and assume lower price and implement PV where fritted glass is located on exterior façade that is not covered by sun shades
3. Reduce glass size and assume lower price. Maintain fritted glass and does not incorporate PV.

The new elevation that incorporates the changes to the façade in Scenario #1 which will be the proposed scenario to implement because of the minimal architectural changes and cost comparison results is presented on the next page.


NEW PROPOSED SYSTEM ELEVATION


CURRENT LAYOUT

Cost Impacts

The current glazing system / curtain wall system for the purpose of this analysis is roughly $20 million dollars. Note, this price only includes the price of the glass, aluminum extrusions, steel structures, gaskets and silicone, hoisting, and installation. All costs associated with the following things have been eliminated from the cost of the curtain wall system for the purpose of this analysis: wood panels, sun shades, design assist, mock ups, testing, stone cladding, insurance, preconstruction design, and other miscellaneous items. I have done this because it was very unclear of what was included in the rough pricing provided by Schuco. This reason for this is because they did not review all the drawings, specs, or fully estimate out this project. Therefore they could not commit to even a rough price or really say what was included or not included in the price. The price was simply based on the representative's experience.

The total SF of glass on the building is roughly 79,000 SF.

Scenario #1

($280/SF) (79,000 SF) + ($1,593,480)

(cost of PV glass found in the analysis of Feasability of PV curtain wall system)

= $23,713,480

For LARGE same size glass as current system and PV glass replacing exterior fritted glass

Scenario #2

($180/SF) (79,000 SF) + ($1,593,480)

= $15,813,480

For smaller glass and PV glass replacing exterior fritted glass

Scenario #3

$(\$180/SF)(79{,}000\ SF) = \$14{,}220{,}000$ For smaller glass and maintaining Fritted Glass

$(\$180/SF) \times 10\%$ Increase for fritted glass $= \$18/SF$

≈25,000 SF of Fritted Glass

$(\$14{,}220{,}000) + (\$18/SF)(25{,}000\ SF) = \$14{,}670{,}000$

From the calculations above scenario #1 is approximately $3,713,480 more expensive than the current system. Scenario #2 is roughly $4,186,520 less expensive than the current system. Scenario #3 is roughly $5,330,000 less expensive than the current system. It makes sense that scenario #2 and #3 are both a lot less expensive because both of these scenarios reduced the size of the glass. This eliminated the premium that is paid for the increased glass size, thus reducing the overall cost substantially. The cost of scenario #1 is not that much greater than the original cost and a solid argument can be made to implement this system. Half of this additional cost is related to the expense of adding PV glass into the system. Please see Cost Comparison / Payback Period for the analysis of *Feasibility of PV Curtain Wall System* for additional cost analysis and argument for implementing this system.

Egress Stair Tower Glass

As discussed in the problem identification and background information, all of the stair tower glass was replaced. This totaled up to just over 400 lites of glass. There were many other costs associated with replacing the glass besides the cost of the new heat-entrained glass. The other costs are as follows

- Ripping out the landscaping
- Building Pad for crane
- Paying for landscaper to come back and redo work

- Labor
- Crane and Lull
- Additional time to remove glass before installing new glass
- Removal of old glass

The initial cost of the glass was roughly $480,000. It is roughly an additional cost of 10% to heat-entrain the glass. Therefore, if an additional $48,000 were spent up front this problem may have been avoided. Although on paper, the calculations showed the glass was strong enough if it was not heat-entrained, this was not the case when it was constructed. It is unfortunate that if that additional money was spent up front it may have eliminated about $1.51 million dollars which was estimated as the cost to solve this problem.

All the glass on the stair towers is fritted glass and contains the majority of the glass that I have proposed to implement Schuco's photovoltaic glass on. The three stair towers contain about 13,490 SF of the 18,970 SF of fritted glass that is going to be replaced. See Cost Comparison / Payback Period for the analysis of *Feasibility of PV Curtain Wall System* for proposed cost impacts. Also see the Design portion for how this system will visually look.

Reduction to Cost and Schedule by Manufactured in the U.S.

In addition to reducing the size of the glass to reduce cost of material, another goal of reducing the size was to be able to produce in the United States. It cost roughly $2.65 million dollars to package and ship all the materials from Italy to the jobsite. As discussed in the problem identification and background information the main reason for the material being produced in Italy was because the size of glass did not allow it to be produced in the U.S. Therefore by reducing the size of the glass could result in a U.S. manufacturer producing all of the material. This would make the cost of shipping and packaging become a faction of what it currently is.

Besides the cost savings, manufacturing in the U.S. could save time on the schedule. Drying in the building is a key milestone date and is crucial to the start of interior finishes. If the building is not dried in, interior finishes get delayed because if the majority of them get wet they are ruined. There was a long lead time to receive materials onsite. The major reason for this was the time it took for the material to travel across the ocean on a boat, and then go through customs, then picked up from the shipping yard and delivered to the site. This added roughly an additional two weeks to a normal lead time. If certain pieces were more crucial, they were shipped by plane, but still typically took over a week to arrive onsite. If the materials were manufactured in the U.S. it is possible the additional two weeks to the lead time could be eliminated.

Architectural Impacts

Reducing the size of the glass would be a major architectural impact. There could be huge cost savings and schedule savings as a result of reducing the size of the glass. Therefore the architect and owner would need to consider if the current design is worth the additional time and cost. The purpose of this is solely for value engineering and presenting the facts to the owner and architect to make the appropriate decision based upon their desires.

An additional architectural impact would be implementing the photovoltaic glass. The max size this glass can be is 8' x 7' and majority of the glass on this building is 10.5' wide. This should not be a major impact on the East façade of the Lab building because from the exterior there will be a small joint between the glass. The changes on the interior will not be visible because the additional mullion will be behind an aluminum panel that covers the bottom 3' of the wall. The major impact for implementing this system would be an additional mullion in the middle lites of glass on the exterior egress stair towers. This glass is 10.5' and would simply be cut in half and match the size of the rest of the glass used on these towers. The final architectural impact is also associated with the PV glass. The color of the cellular array will match the color of the fritted glass; however the layout of the cellular array does not match the layout of the fritted glass.

Recommendations and Conclusions

In order to maintain the architectural look the least, scenario #1 should be implemented. Although the cost is a little bit more, this system incorporates PV glass which is the majority of the additional cost. In the *Feasibility of PV Curtain Wall System* analysis the Cost Comparison / Payback Period shows that it makes sense to incorporate the PV glass system. If this was the case, it would also eliminate the challenges faced with the exterior egress stair tower's glass because it will be replaced with the new system.

Although it will not likely be accepted, it would also be advised to present the cost savings and possible schedule reductions associated with reducing the glass size to the owner and architect. The purpose of this would solely be for value engineering and not at all intended to criticize the architect's design.

FEASABILITY OF PV CURTAIN WALL SYSTEM (Electrical Breadth)

Problem Identification

As discussed above, there were many problems associated with the curtain wall system. While exploring other curtain wall systems, it seems practical to explore a glass with PV capabilities. Besides the large cost of the curtain wall, about two million dollars' worth of custom PV trays cover the glass atrium skylight. This is an impractical cost considering they are used mainly for an architectural feature and produce minimal energy.

Research Goal

The goal of this analysis is to find a PV capable glazing system that can be implemented on the Chemistry Building.

Methodology

- Contact manufacturers that produce glazing systems with PV capabilities
- Determine the total cost of this system
- Determine energy usage of the building and its cost
- Electrical Design
- Determine how much energy the system produces and electrical equipment required to utilize the energy produced by this system
- Perform feasibility analysis based on cost of current system and payback period

Background Information

As discussed in the previous analysis, the curtain wall system has an extremely high cost. Because of this, I have chosen to investigate alternative systems. In doing so, I came across a system manufactured by Schuco that contains photovoltaic glazing incorporated in the curtain wall system. This system is known as the Schuco E^2 façade. This line of curtain wall systems is known for supplying a complete system that can allow for building ventilation, PV energy production, sun shading, and a very low amount of heat loss. The goal of this product line is to drastically improve the performance of buildings and continue to drive the industry to build greener buildings.

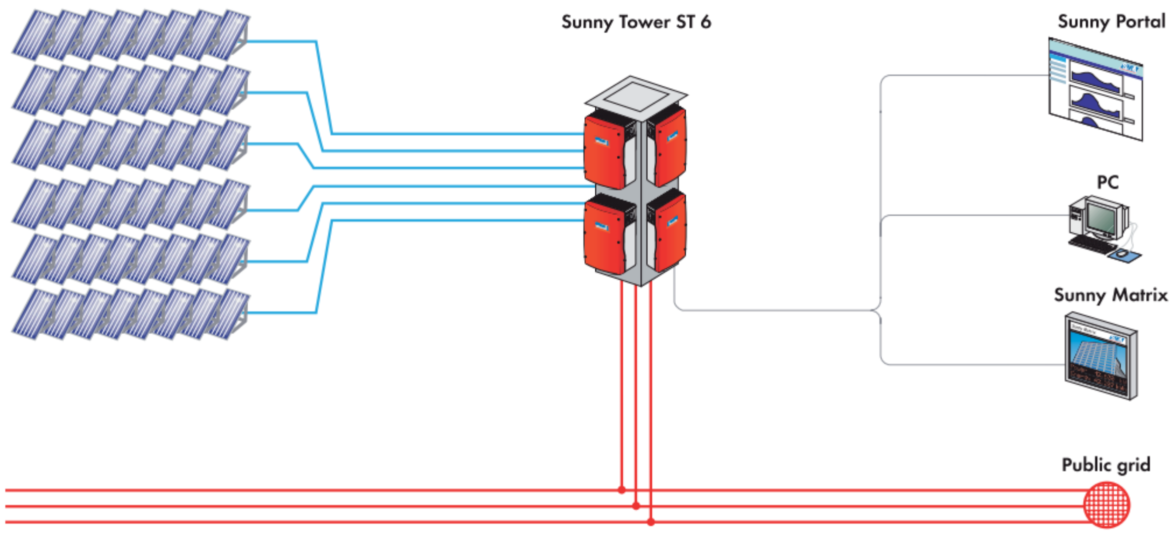
The E^2 façade works by placing a film with PV modules in it that is on the exterior of the glass. The modules are laid out in either a translucent or transparent design. Based on the images of the two, which can be seen in the product data sheet, the transparent version is closer to looking like the fritted glass on the Chemistry Building.

Design

All three of the exterior stair towers located on the East side of the building are comprised of fritted glass and will all be replaced with this system. There is fritted glass all over the building; however it does not make since to replace all of it with the photovoltaic system. This is because a lot of the fritted glass is behind sun shades or located on the interior of the building. As a result the only other glass that will be replaced with this system is the fritted glass that is on the exterior of the building and not covered with sun shades.

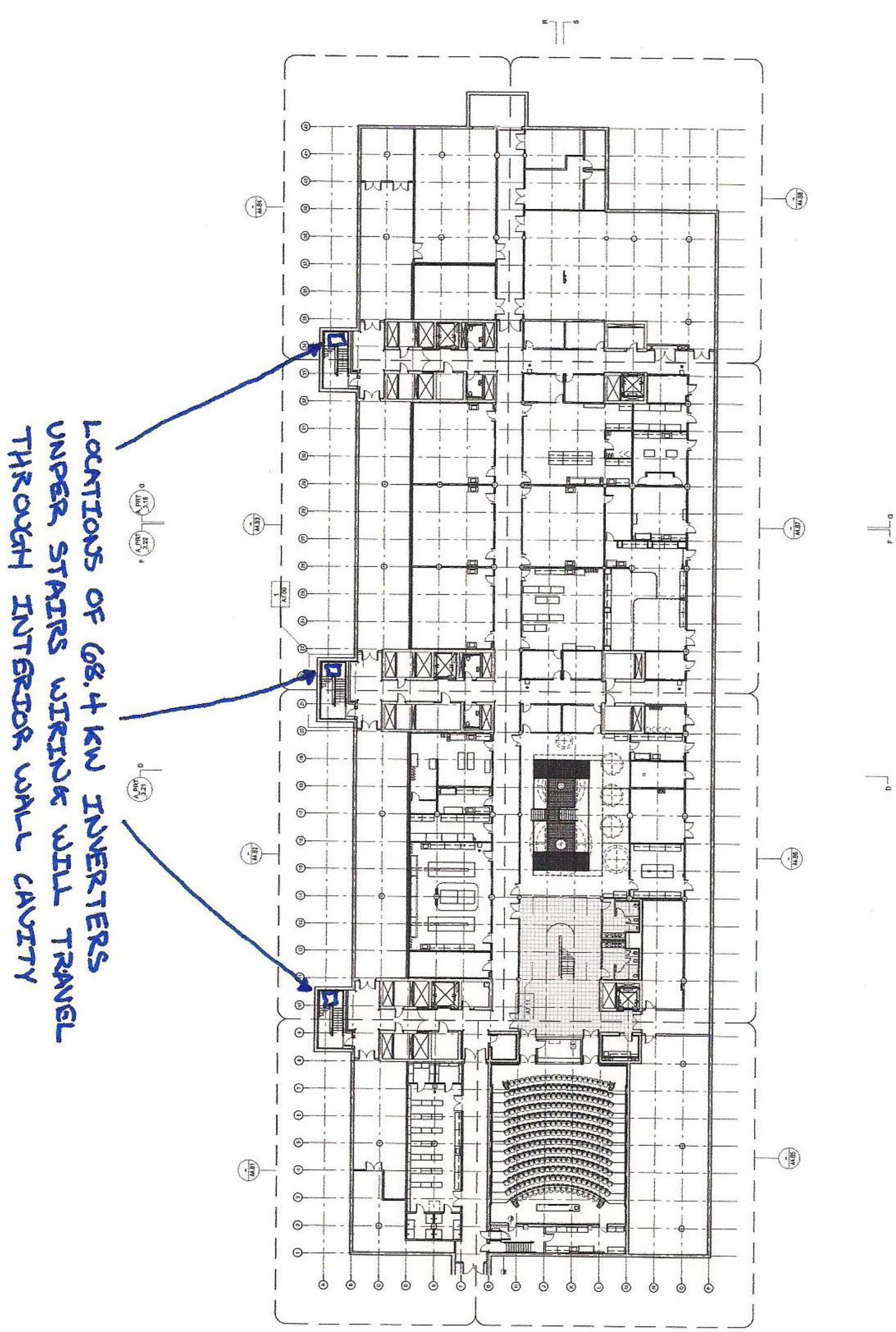
In total there will be about 18,970 SF of fritted glass that will be replaced with the E^2 photovoltaic glass façade. From the product data sheet, this photovoltaic system produces an average of 140 W/m^2 per day. With that, this system will produce 246.736 kWh for the Chemistry Building. In order to utilize this energy though, inverters must be used. Based upon the locations of the photovoltaic glass and locations of the building where there is space to place these inverters, this system will use 3 – 68.4 kW inverters and 1 – 49.6 kW inverter. The 3 larger inverters will be located in the basement under the exterior stair towers. There is then enough space in the switchgear room for the smaller inverter. Each 68.4 kW inverter will be connected about 24 lites on the East side of the building and a stair tower's lites. This produces almost exactly 68.4 kW. The 49.6 kW inverter carries the rest of the energy produced.

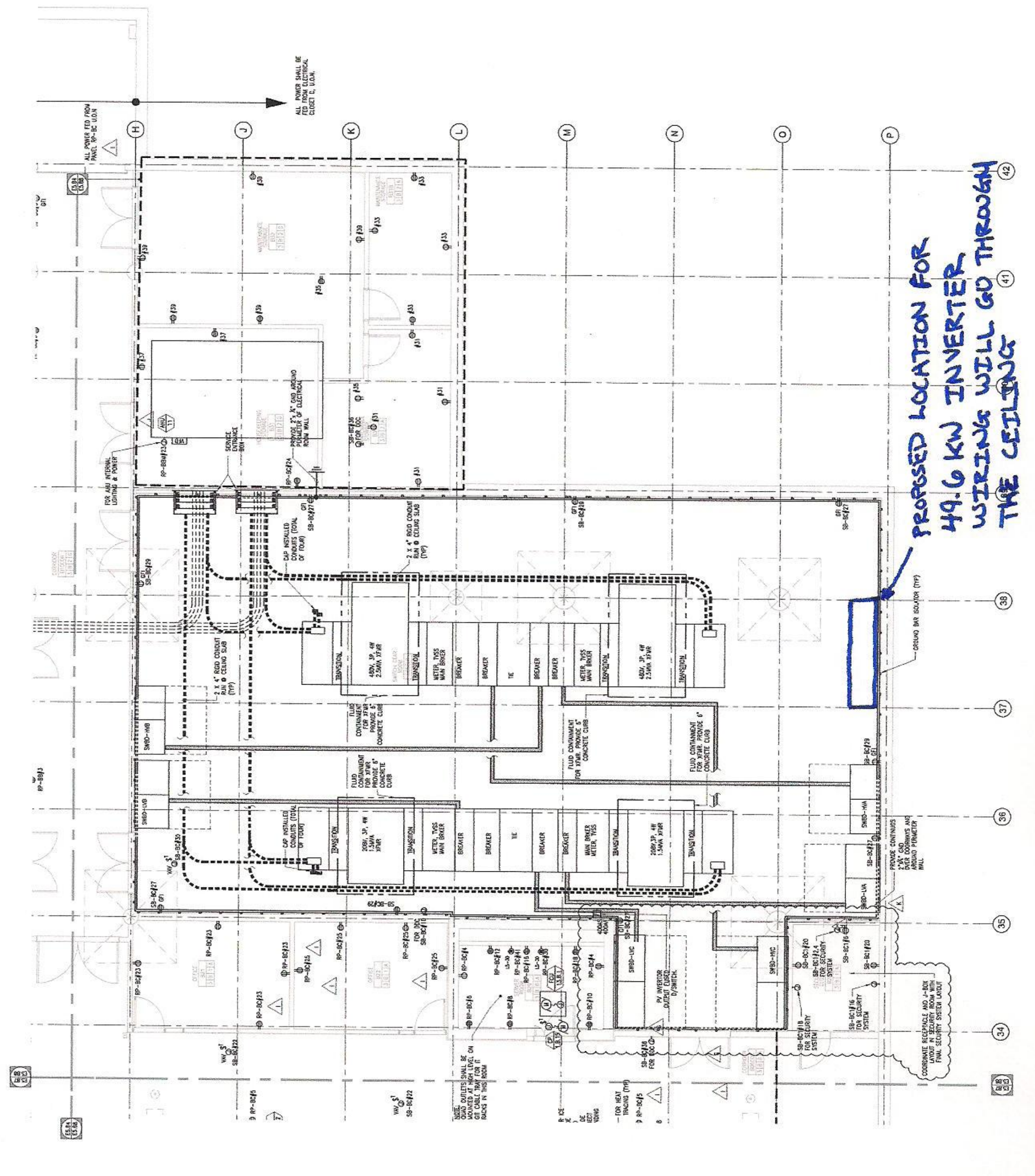
The inverters I chose to use were a Sunny Tower with 6 Sunny Mini Central 8000TL and a Sunny Tower with 6 Sunny Mini Central 11000TL. I chose to use these inverters for multiple reasons. The first being the sizes of these units were optimal for the total kW's produced by my system. The other reasons are they are easy to install and both are highly efficient with an efficiency rating of 98%.

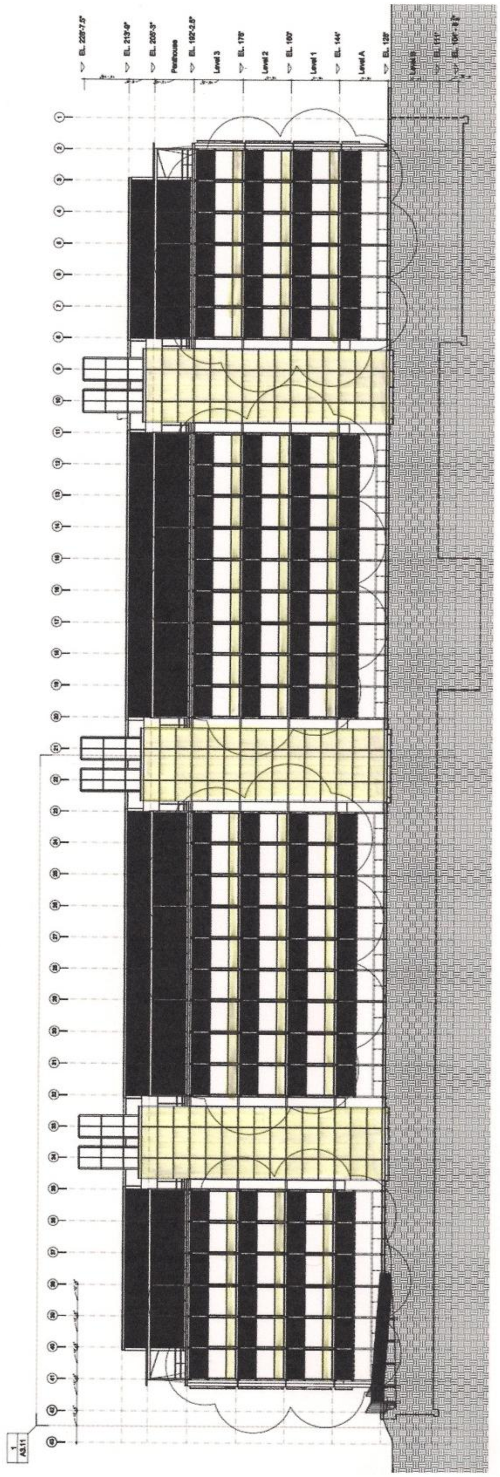


See Appendix F. for the product data sheets of these two inverters.

Based upon the design pictures on the next two pages, this system will need approximately 1940 ft of DC wire and 345 ft of AC wire.


LOCATIONS OF 68.4 KW INVERTERS
UNDER STAIRS WIRING WILL TRAVEL
THROUGH INTERIOR WALL CAVITY


PROPOSED LOCATION FOR 49.6 KW INVERTER, WIRING WILL GO THROUGH THE CEILING



All the glass that is yellow in the picture above represents that glass that will now be photovoltaic glass.

Payback Period

The cost of energy used below is the local cost for December 2010 which was found from the U.S. Energy Information Administration.

SOLAR GLASS

THE GLASS PRODUCES 140 W/m² OF ENERGY

TOTAL SF = 18,970
= 1,762.4 m²

(140 W/m²)(1,762.4 m²) = 246,736 watts/day
= 10,280.67 watts/hr
= 10.281 kw/hr
= 90,061.56 kwh's a year

1 year = 8760 hours

cost = $0.1312/kwh
COST OF ENERGY INCREASES BY 1% PER YEAR

COST OF SYSTEM = ($120/SF)(18,970 SF) = $2,276,400

FEDERAL TAX REBATE OF 30%

($2,276,400)(0.7) = **$1,593,480 = TOTAL SYSTEM COST**

STATE TAX CREDIT/year = $0.675/KWH

($0.675/kwh)(90,061.56 kwh) = $60,791.553 savings per year

year 21 TOTAL SAVINGS TO DATE = $1,551,218.71
year 22 TOTAL SAVINGS TO DATE = $1,626,572.30

FROM INTERPOLATION, THIS SYSTEM WILL BE PAID OFF IN 21.56 years. A LITTLE LESS THAN 21 YEARS and 7 MONTHS.

Please see Appendix G. for the excel file used to calculate these values

Recommendations and Conclusions

A little over a twenty one and half year payback period is a little long but it is not awful. Considering the pervious Chemistry Building was used for over 80 years and buildings on this campus typically have a really long life, it seems to be worth the investment. Another argument for implementing this system would be the client spent around $2 million dollars on custom PV trays that produce only 85 KV or 68 kWh per day. With that in mind, the system I propose to implement produces just over 246 kWh per day and had an initial cost of just over $2.276 million dollars. Note, these cost are before tax rebates have been incorporated, but the Schuco E^2 system produces just over 3.6 times as much energy as the PV trays above the atrium skylight. The Schuco system also only costs 13.8% more. From this comparison, it is clear that the Schuco system is a better value. From this information, it seems practical to incorporate the Schuco E^2 system into the Chemistry Building.

RECOMMENDATIONS AND CONCLUSIONS

After conducting a series of technical reports and building statics reports throughout the fall semester I gained a lot of knowledge about the Chemistry Building and understood it a lot better. After spending a semester learning about this building, it was time to apply the knowledge I have learned throughout the classes I have taken here at Penn State. In order to do this, with the help of my consultant, Dr. Riley, I identified four analyses that I would conduct on the Chemistry Building of areas that could have been done differently. The goal of the first analysis was based on a critical industry issue to carry BIM into the field. The goal of the second analysis was based on the mechanical information I was taught and meant to save energy by modifying ductwork in order to reduce fan speed while maintaining the same CFM. The third analysis was my depth analysis which related to the biggest challenges that were faced during construction. The goal of this analysis was to find an alternative curtain wall system that either cost less without reducing performance or a system that performed better by incorporating PV glass into the system. The fourth and final analysis is based on what I have learned in my electrical classes. The goal of this analysis was related to the previous analysis and was meant to design out the electrical system necessary in order to utilize the energy produced by the PV glass.

After conducting the first analysis, I have concluded the following. Taking my experience of working on this project for two summers into account, the challenges the project faced, information from the project team, reading case studies regarding Vela Systems, and the additional research I did, I feel Vela Systems would improve the construction process of the Chemistry Building. The reasons for this statement can easily be understood after reading the *Impacts of Implementing Vela Systems on the Chemistry Building*. In addition to this, Turner used Vela Systems to help manage dormitory buildings on the same university's campus. The site manager for Turner Construction on the Chemistry Building said they were considering using this system on this project also, but the timing did not work out. The start dates for the two projects were fairly close and by the time Vela Systems was running smoothly and clearly was going to be valuable for the neighboring project, the Chemistry Building was too far along to implement Vela Systems. Taking this into consideration, if the timing was different, Vela Systems very well could have been used on this project.

Analysis number two showed that modifying the ductwork resulted in major savings. An additional 2" of static pressure is a huge amount and when this is the case for 5 air handler units, you can clearly see this drives the amount of energy required to run this equipment way up very quickly. The corrections made ultimately reduced the amount of energy used per year by 376,855.2 kWh. This was done by modifying the ductwork and its connection into the AHU, thus reducing the additional 2” of static pressure down to 0.87” of static pressure. Although redesigning this area delayed the commissioning and balancing process and required additional costs for new materials, labor to demo and install the new design, and personnel to manage this process, these costs were minimal to the ultimate savings this redesign achieved.

The third and fourth analysis determined the best alternative system was to maintain the current glass size but use the Schuco E^2 Façade system to incorporate PV glass into the curtain wall. Although this resulted in a slightly higher cost, the final analysis showed there is a practical payback period and the system should be implemented.

Overall, all four of these analyses showed the construction industry is constantly evolving and incorporating new technology. When the Chemistry Building started construction, a large majority of new technology was incorporated to help manage this project. The critical industry issue shows how technology and many software programs have evolved / improved over the past 4 years. The alternative curtain wall systems analysis and feasibility of implementing a PV curtain wall system analysis both show how materials have progressed. When the design of this building was started almost seven years ago photovoltaic panels were just starting to become popular and implemented on some projects. At that time you wouldn’t have thought when this project was finishing up that photovoltaic capabilities would be incorporated in the glazing of curtain wall systems. These analyses show that we need to continue to evolve our construction and design abilities with the constantly improving technology. This will allow new buildings to continue be greener and more energy efficient as time progresses.

RESOURCES

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Schuco-USA Connecticut Office Representatives

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Turner Construction Team

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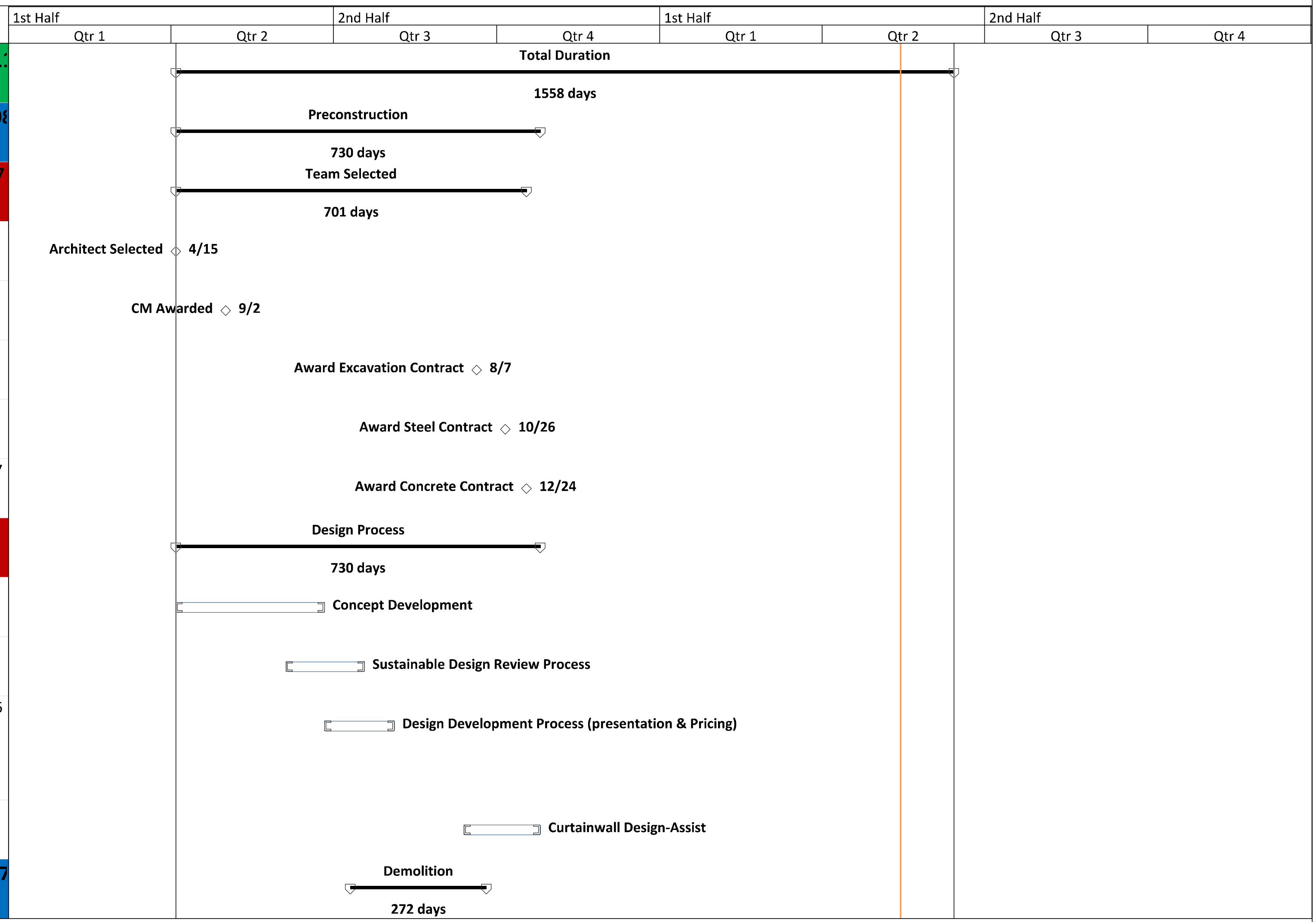
APPENDIX A – DETAILD PROJECT SCHEUDLE

Chemistry Building

Michael Gallagher
Construction Option

Tech Two - Detailed Schedule Summary
October 27, 2010

Task Name	Duration	Start	Finish
Total Duration	**1558 day**	**Fri 4/15/0**	**Tue 4/5/1**
Preconstruction	**730 days**	**Fri 4/15/05**	**Thu 1/31/08**
Team Selected	**701 days**	**Fri 4/15/05**	**Mon 12/24/07**
Architect Selected	0 days	Fri 4/15/05	Fri 4/15/05
CM Awarded	0 days	Fri 9/2/05	Fri 9/2/05
Award Excavation Contract	0 days	Tue 8/7/07	Tue 8/7/07
Award Steel Contract	0 days	Fri 10/26/07	Fri 10/26/07
Award Concrete Contract	0 days	Mon 12/24/07	Mon 12/24/07
Design Process	**730 days**	**Fri 4/15/05**	**Thu 1/31/08**
Concept Development	297 days	Fri 4/15/05	Mon 6/5/06
Sustainable Design Review Process	157 days	Sat 2/18/06	Mon 9/25/06
Design Development Process (presentation & Pricing)	140 days	Tue 6/6/06	Mon 12/18/06
Curtainwall Design-Assist	154 days	Mon 7/2/07	Thu 1/31/08
Demolition	**272 days**	**Thu 8/17/0**	**Mon 9/3/07**

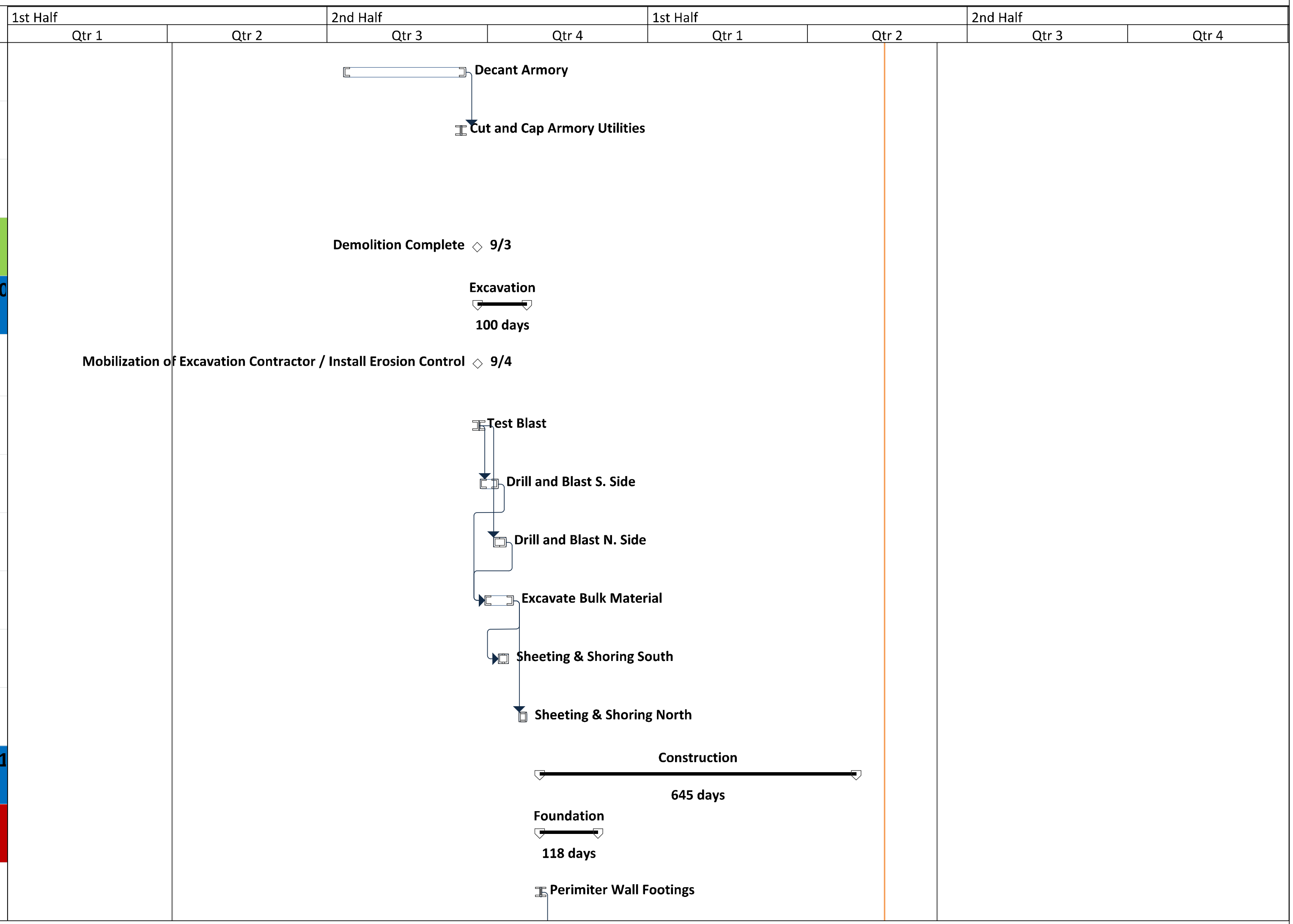


Scheduled Tasks | Milestones | Total Duration

Chemistry Building | **Michael Gallagher** | **Tech Two - Detailed Schedule Summary**

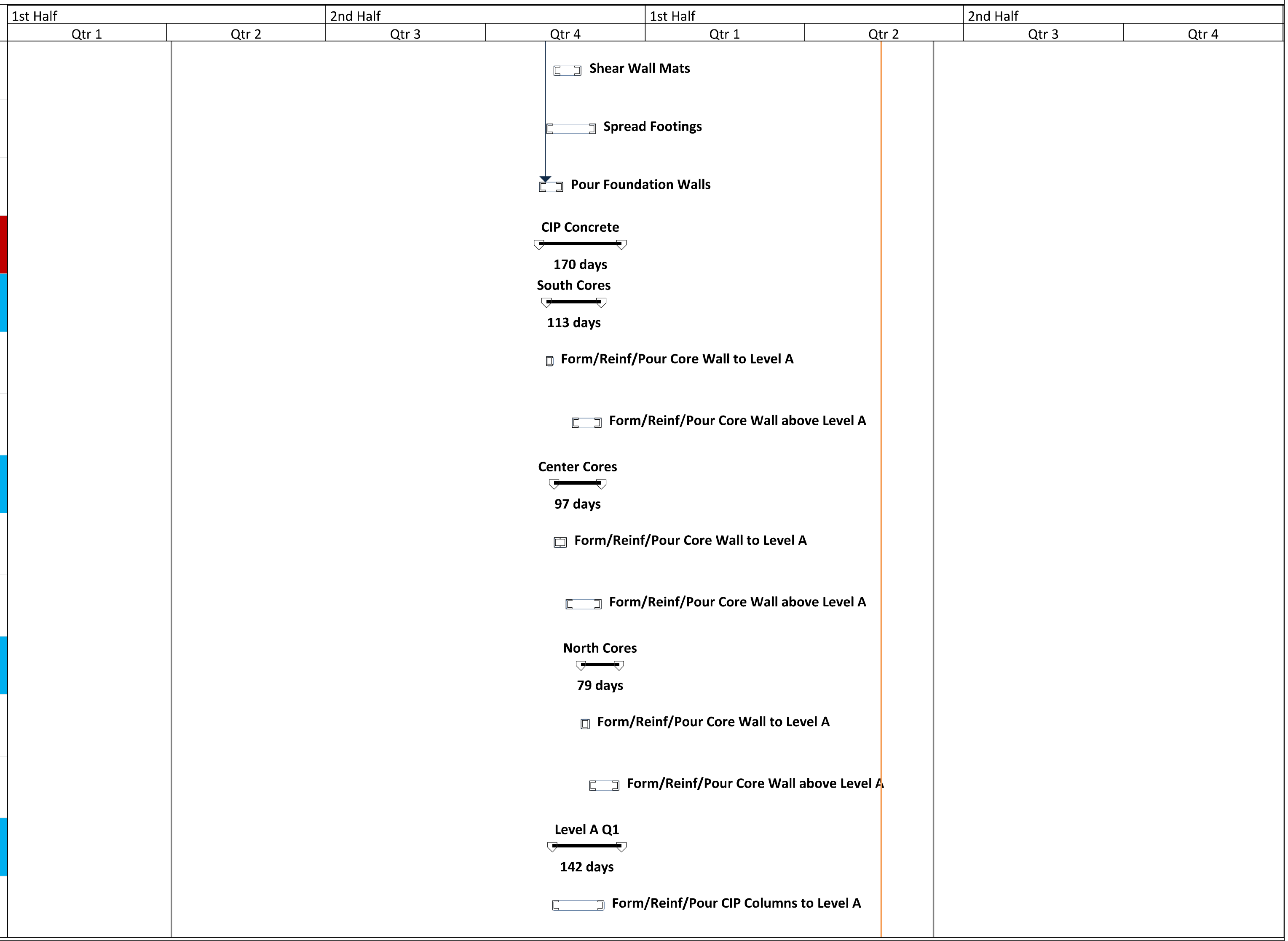
Construction Option | **October 27, 2010**

Task Name	Duration	Start	Finish
Decant Armory	249 days	Thu 8/17/06	Tue 7/31/07
Cut and Cap Armory Utilities	5 days	Mon 7/16/07	Fri 7/20/07
Demolish Armory	24 days	Tue 7/31/07	Fri 8/31/07
Demolition Complete	0 days	Mon 9/3/07	Mon 9/3/07
Excavation	**100 days**	**Tue 9/4/07**	**Mon 1/21/0**
Mobilization of Excavation Contractor / Install Erosion Control	0 days	Tue 9/4/07	Tue 9/4/07
Test Blast	1 day	Fri 9/7/07	Fri 9/7/07
Drill and Blast S. Side	38 days	Tue 9/11/07	Thu 11/1/07
Drill and Blast N. Side	26 days	Fri 10/19/07	Fri 11/23/07
Excavate Bulk Material	60 days	Mon 9/24/07	Fri 12/14/07
Sheeting & Shoring South	21 days	Fri 11/2/07	Fri 11/30/07
Sheeting & Shoring North	16 days	Mon 12/31/07	Mon 1/21/08
Construction	**645 days**	**Thu 2/28/0**	**Wed 8/18/1**
Foundation	**118 days**	**Thu 2/28/08**	**Mon 8/11/08**
Perimiter Wall Footings	4 days	Thu 2/28/08	Tue 3/4/08



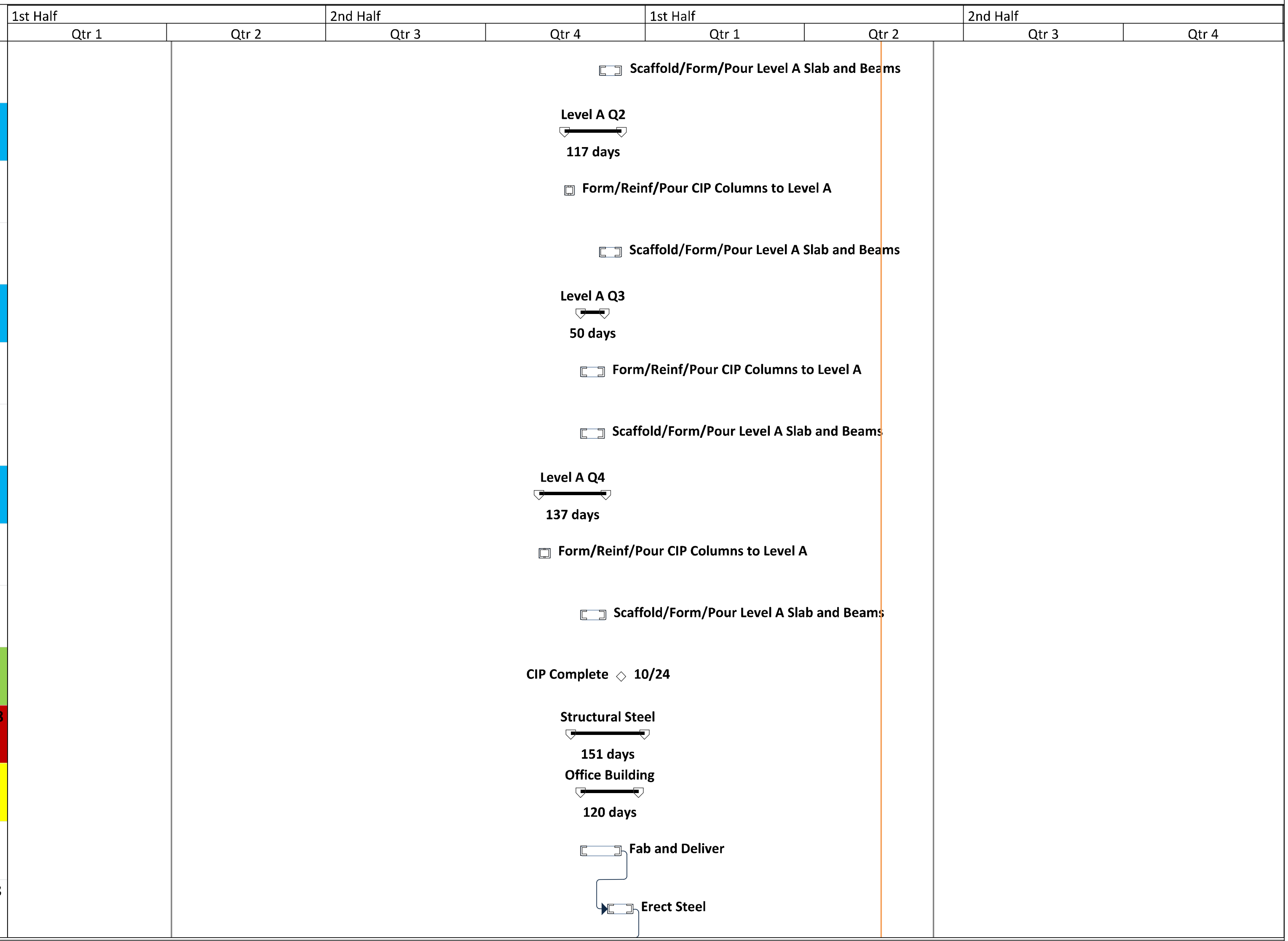
Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Shear Wall Mats	56 days	Mon 4/14/08	Mon 6/30/08
Spread Footings	101 days	Mon 3/24/08	Mon 8/11/08
Pour Foundation Walls	49 days	Tue 3/4/08	Fri 5/9/08
CIP Concrete	**170 days**	**Mon 3/3/08**	**Fri 10/24/08**
South Cores	**113 days**	**Mon 3/24/08**	**Wed 8/27/08**
Form/Reinf/Pour Core Wall to Level A	15 days	Mon 3/24/08	Fri 4/11/08
Form/Reinf/Pour Core Wall above Level A	59 days	Fri 6/6/08	Wed 8/27/08
Center Cores	**97 days**	**Tue 4/15/08**	**Wed 8/27/08**
Form/Reinf/Pour Core Wall to Level A	25 days	Tue 4/15/08	Mon 5/19/08
Form/Reinf/Pour Core Wall above Level A	73 days	Mon 5/19/08	Wed 8/27/08
North Cores	**79 days**	**Tue 7/1/08**	**Fri 10/17/08**
Form/Reinf/Pour Core Wall to Level A	18 days	Tue 7/1/08	Thu 7/24/08
Form/Reinf/Pour Core Wall above Level A	61 days	Fri 7/25/08	Fri 10/17/08
Level A Q1	**142 days**	**Thu 4/10/08**	**Fri 10/24/08**
Form/Reinf/Pour CIP Columns to Level A	106 days	Thu 4/10/08	Thu 9/4/08



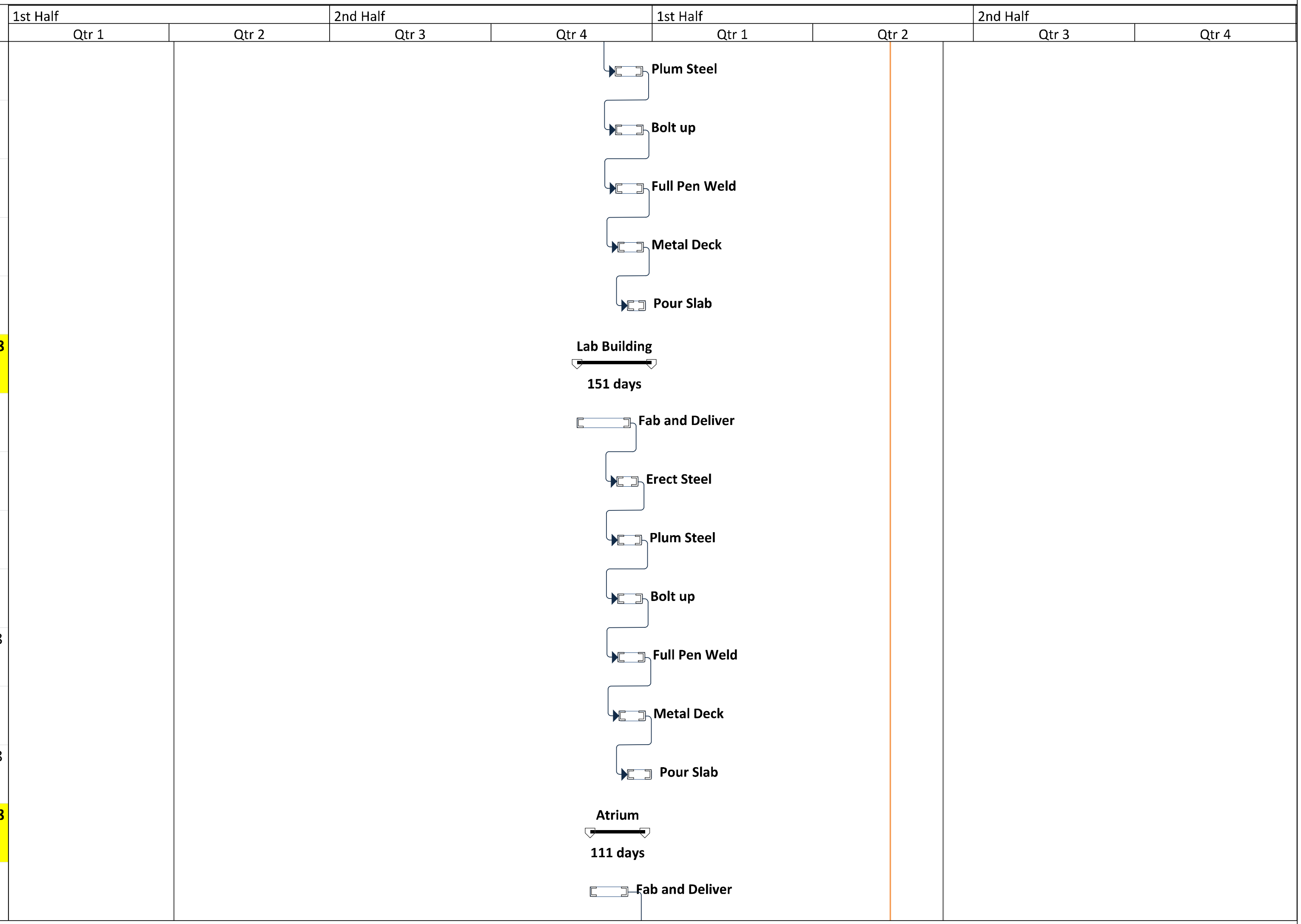
Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Scaffold/Form/Pour Level A Slab and Beams	46 days	Sat 8/23/08	Fri 10/24/08
Level A Q2	**117 days**	**Thu 5/15/08**	**Fri 10/24/08**
Form/Reinf/Pour CIP Columns to Level A	20 days	Thu 5/15/08	Wed 6/11/08
Scaffold/Form/Pour Level A Slab and Beams	46 days	Sat 8/23/08	Fri 10/24/08
Level A Q3	**50 days**	**Mon 6/30/08**	**Fri 9/5/08**
Form/Reinf/Pour CIP Columns to Level A	50 days	Mon 6/30/08	Fri 9/5/08
Scaffold/Form/Pour Level A Slab and Beams	50 days	Mon 6/30/08	Fri 9/5/08
Level A Q4	**137 days**	**Mon 3/3/08**	**Tue 9/9/08**
Form/Reinf/Pour CIP Columns to Level A	24 days	Mon 3/3/08	Thu 4/3/08
Scaffold/Form/Pour Level A Slab and Beams	52 days	Mon 6/30/08	Tue 9/9/08
CIP Complete	0 days	Fri 10/24/08	Fri 10/24/08
Structural Steel	**151 days**	**Mon 6/2/08**	**Mon 12/29/08**
Office Building	**120 days**	**Mon 6/30/08**	**Fri 12/12/08**
Fab and Deliver	84 days	Mon 6/30/08	Thu 10/23/08
Erect Steel	53 days	Mon 9/15/08	Wed 11/26/08



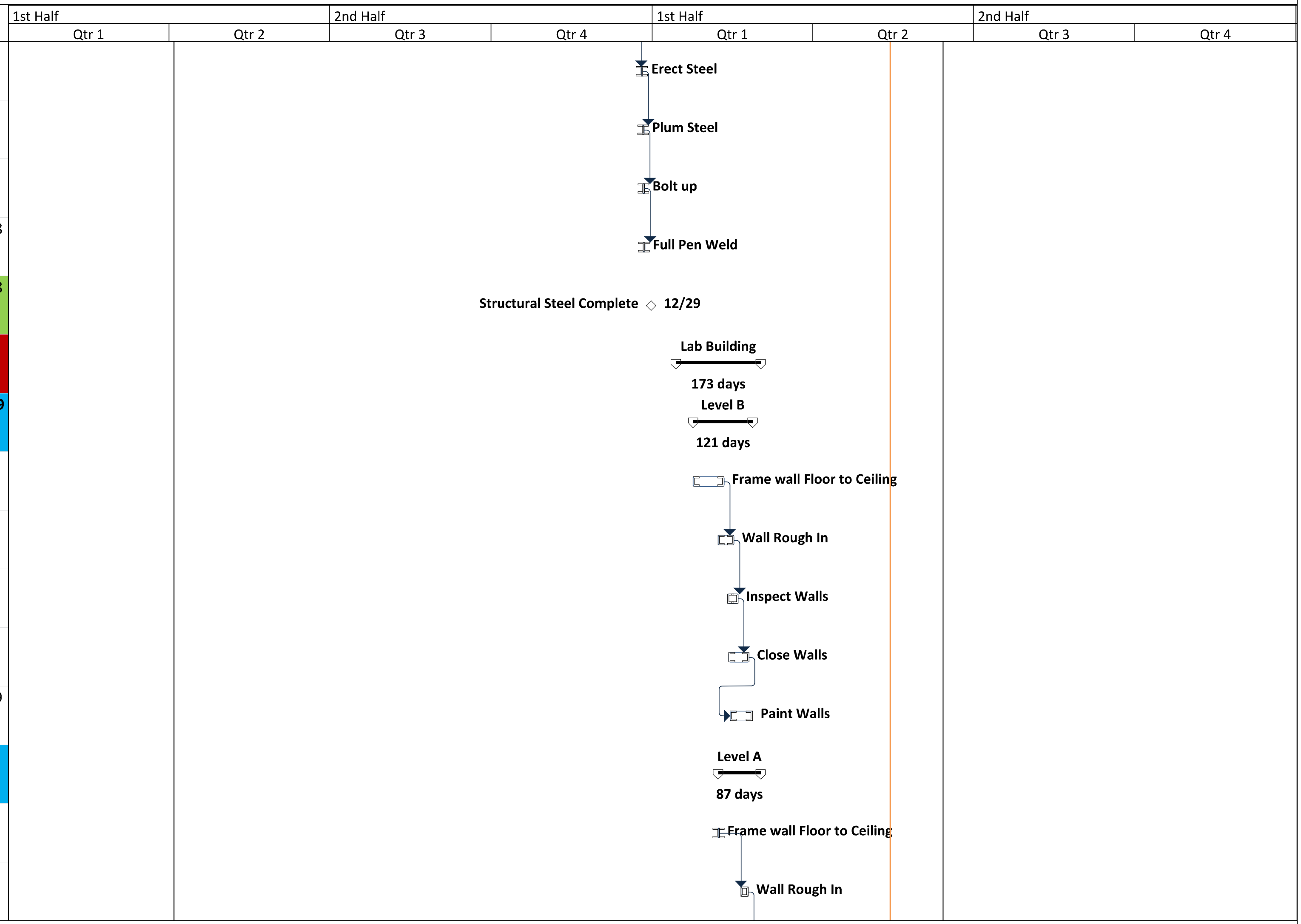
Scheduled Tasks | Milestones | Total Duration

Task Name	Duration	Start	Finish
Plum Steel	56 days	Thu 9/18/08	Thu 12/4/08
Bolt up	56 days	Fri 9/19/08	Fri 12/5/08
Full Pen Weld	57 days	Sat 9/20/08	Sat 12/6/08
Metal Deck	52 days	Fri 9/26/08	Sat 12/6/08
Pour Slab	37 days	Thu 10/23/08	Fri 12/12/08
Lab Building	**151 days**	**Mon 6/2/08**	**Mon 12/29/08**
Fab and Deliver	109 days	Mon 6/2/08	Thu 10/30/08
Erect Steel	44 days	Tue 9/23/08	Fri 11/21/08
Plum Steel	48 days	Thu 9/25/08	Mon 12/1/08
Bolt up	50 days	Thu 9/25/08	Wed 12/3/08
Full Pen Weld	54 days	Fri 9/26/08	Wed 12/10/08
Metal Deck	55 days	Mon 9/29/08	Fri 12/12/08
Pour Slab	48 days	Thu 10/23/08	Mon 12/29/08
Atrium	**111 days**	**Wed 7/9/08**	**Wed 12/10/08**
Fab and Deliver	77 days	Wed 7/9/08	Thu 10/23/08



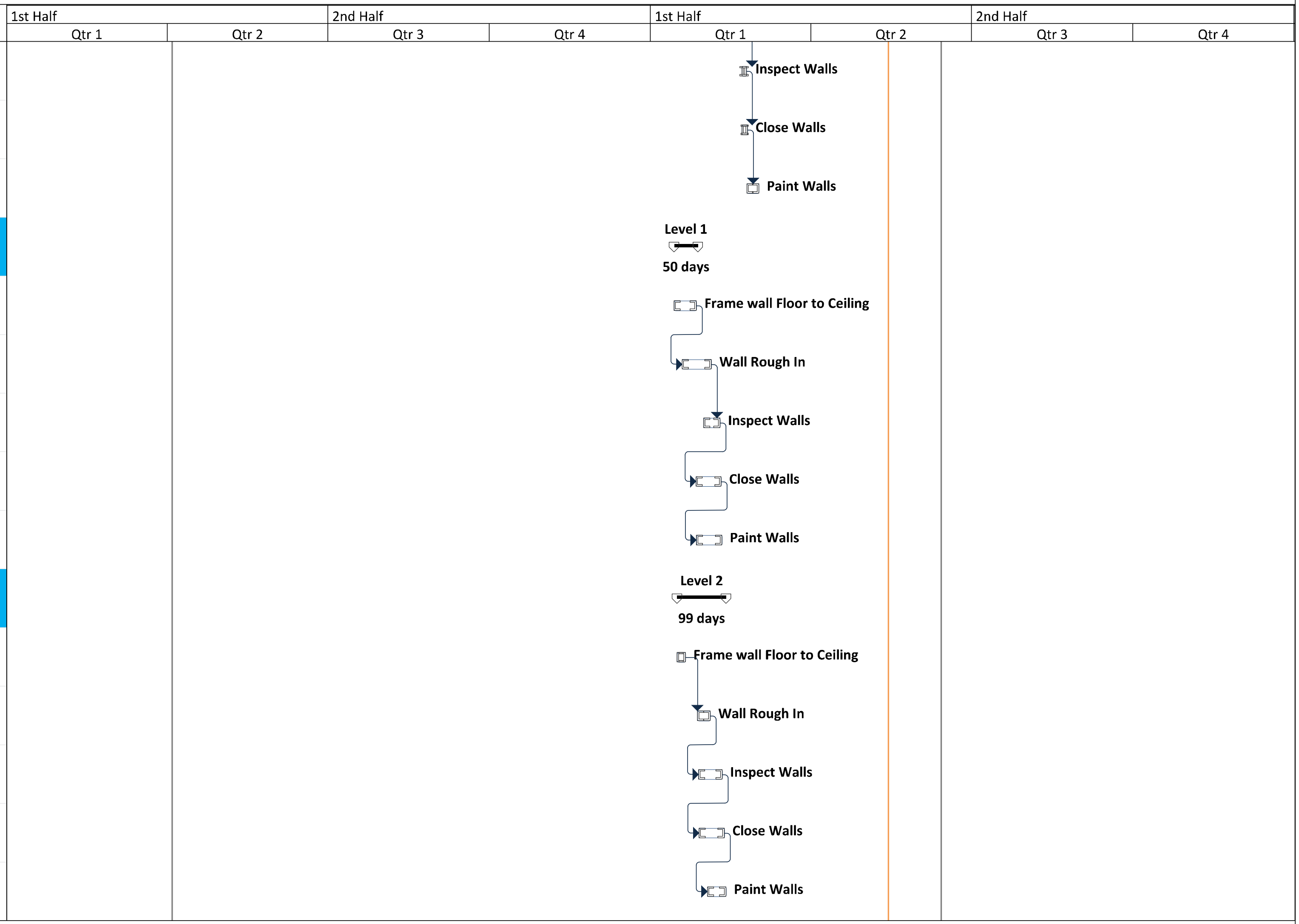
Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Erect Steel	4 days	Mon 12/1/08	Thu 12/4/08
Plum Steel	4 days	Wed 12/3/08	Mon 12/8/08
Bolt up	3 days	Fri 12/5/08	Tue 12/9/08
Full Pen Weld	4 days	Sat 12/6/08	Wed 12/10/08
Structural Steel Complet	0 days	Mon 12/29/08	Mon 12/29/08
Lab Building	**173 days**	**Mon 3/9/09**	**Wed 11/4/09**
Level B	**121 days**	**Mon 4/27/09**	**Mon 10/12/09**
Frame wall Floor to Ceiling	64 days	Mon 4/27/09	Thu 7/23/09
Wall Rough In	33 days	Tue 7/7/09	Thu 8/20/09
Inspect Walls	22 days	Mon 8/3/09	Tue 9/1/09
Close Walls	42 days	Thu 8/6/09	Fri 10/2/09
Paint Walls	46 days	Mon 8/10/09	Mon 10/12/09
Level A	**87 days**	**Tue 7/7/09**	**Wed 11/4/09**
Frame wall Floor to Ceiling	4 days	Tue 7/7/09	Fri 7/10/09
Wall Rough In	14 days	Thu 9/10/09	Tue 9/29/09



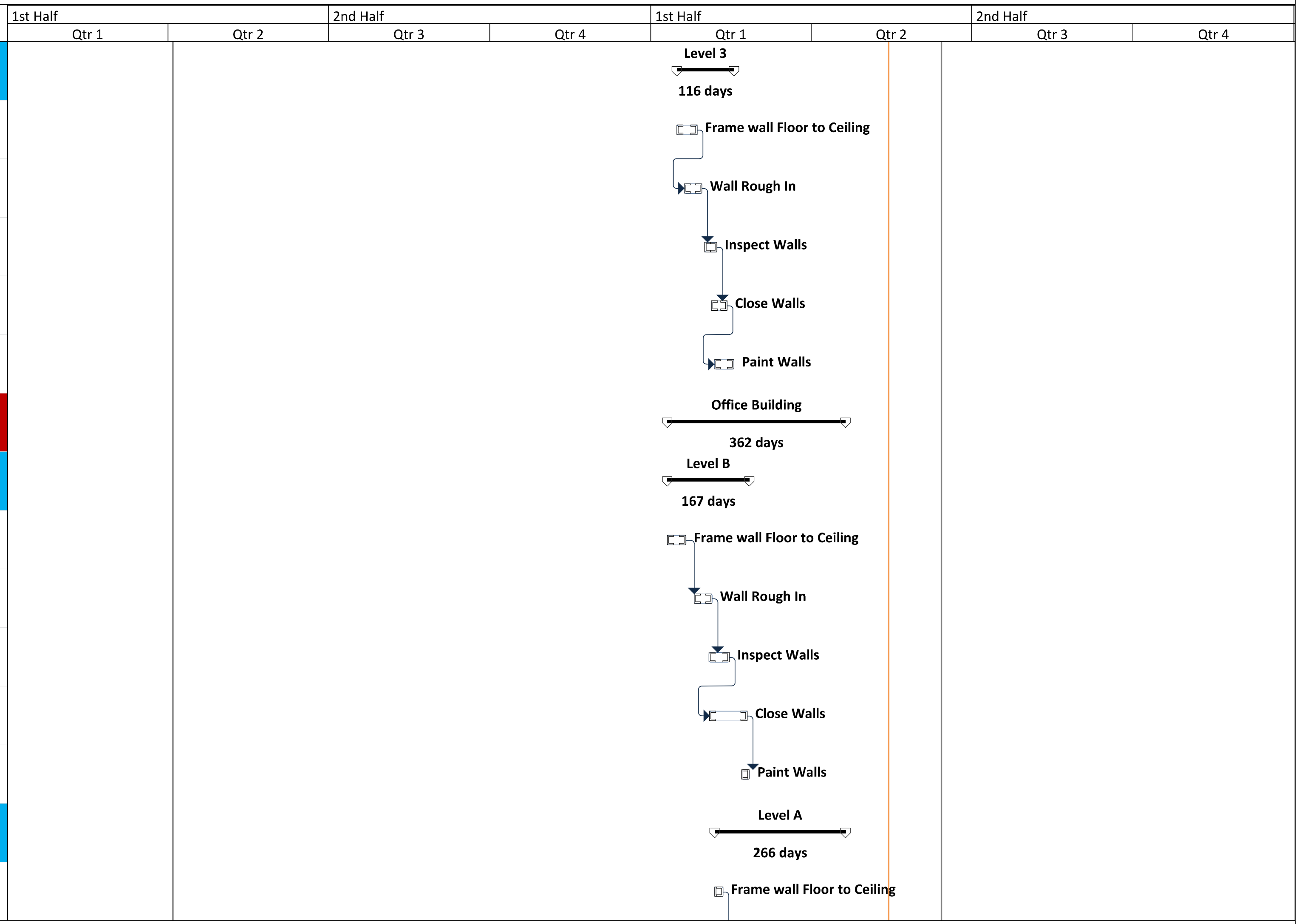
Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Inspect Walls	9 days	Fri 9/18/09	Wed 9/30/09
Close Walls	12 days	Fri 9/18/09	Sat 10/3/09
Paint Walls	24 days	Fri 10/2/09	Wed 11/4/09
Level 1	**50 days**	**Mon 3/9/09**	**Fri 5/15/09**
Frame wall Floor to Ceiling	46 days	Mon 3/9/09	Mon 5/11/09
Wall Rough In	59 days	Wed 4/1/09	Mon 6/22/09
Inspect Walls	35 days	Mon 6/1/09	Fri 7/17/09
Close Walls	51 days	Mon 5/11/09	Mon 7/20/09
Paint Walls	52 days	Tue 5/12/09	Wed 7/22/09
Level 2	**99 days**	**Wed 3/18/09**	**Mon 8/3/09**
Frame wall Floor to Ceiling	18 days	Wed 3/18/09	Fri 4/10/09
Wall Rough In	26 days	Fri 5/15/09	Fri 6/19/09
Inspect Walls	49 days	Mon 5/18/09	Thu 7/23/09
Close Walls	52 days	Tue 5/19/09	Wed 7/29/09
Paint Walls	37 days	Fri 6/12/09	Mon 8/3/09



Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Level 3	**116 days**	**Mon 3/16/09**	**Mon 8/24/09**
Frame wall Floor to Ceiling	42 days	Mon 3/16/09	Tue 5/12/09
Wall Rough In	36 days	Mon 4/6/09	Mon 5/25/09
Inspect Walls	25 days	Wed 6/3/09	Tue 7/7/09
Close Walls	33 days	Mon 6/22/09	Wed 8/5/09
Paint Walls	40 days	Tue 6/30/09	Mon 8/24/09
Office Building	**362 days**	**Tue 2/17/09**	**Wed 7/7/10**
Level B	**167 days**	**Tue 2/17/09**	**Wed 10/7/09**
Frame wall Floor to Ceiling	39 days	Tue 2/17/09	Fri 4/10/09
Wall Rough In	37 days	Mon 5/4/09	Tue 6/23/09
Inspect Walls	42 days	Mon 6/15/09	Tue 8/11/09
Close Walls	77 days	Wed 6/17/09	Thu 10/1/09
Paint Walls	16 days	Wed 9/16/09	Wed 10/7/09
Level A	**266 days**	**Wed 7/1/09**	**Wed 7/7/10**
Frame wall Floor to Ceiling	18 days	Wed 7/1/09	Fri 7/24/09



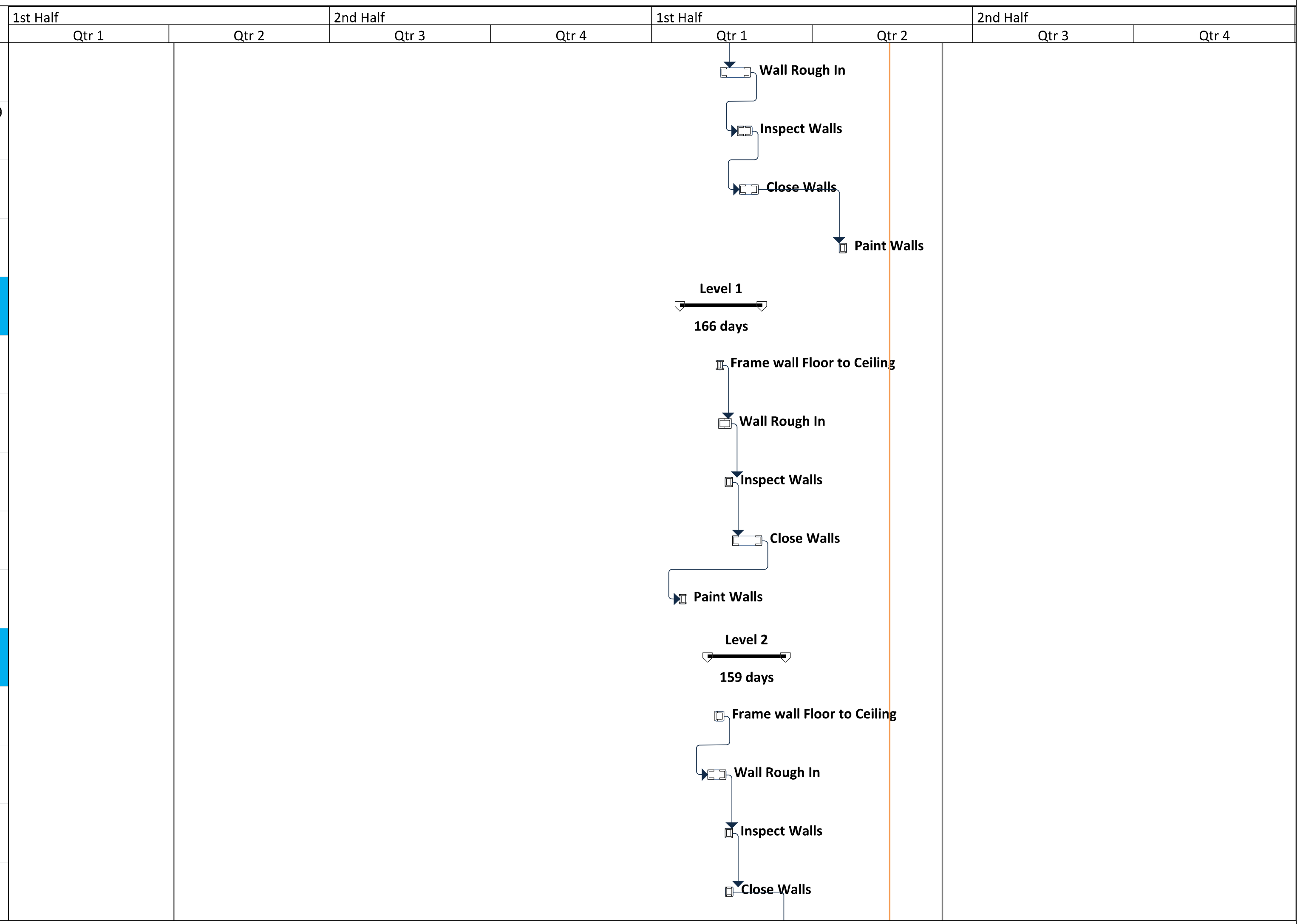
Scheduled Tasks | Milestones ◇ | Total Duration

Chemistry Building

Michael Gallagher
Construction Option

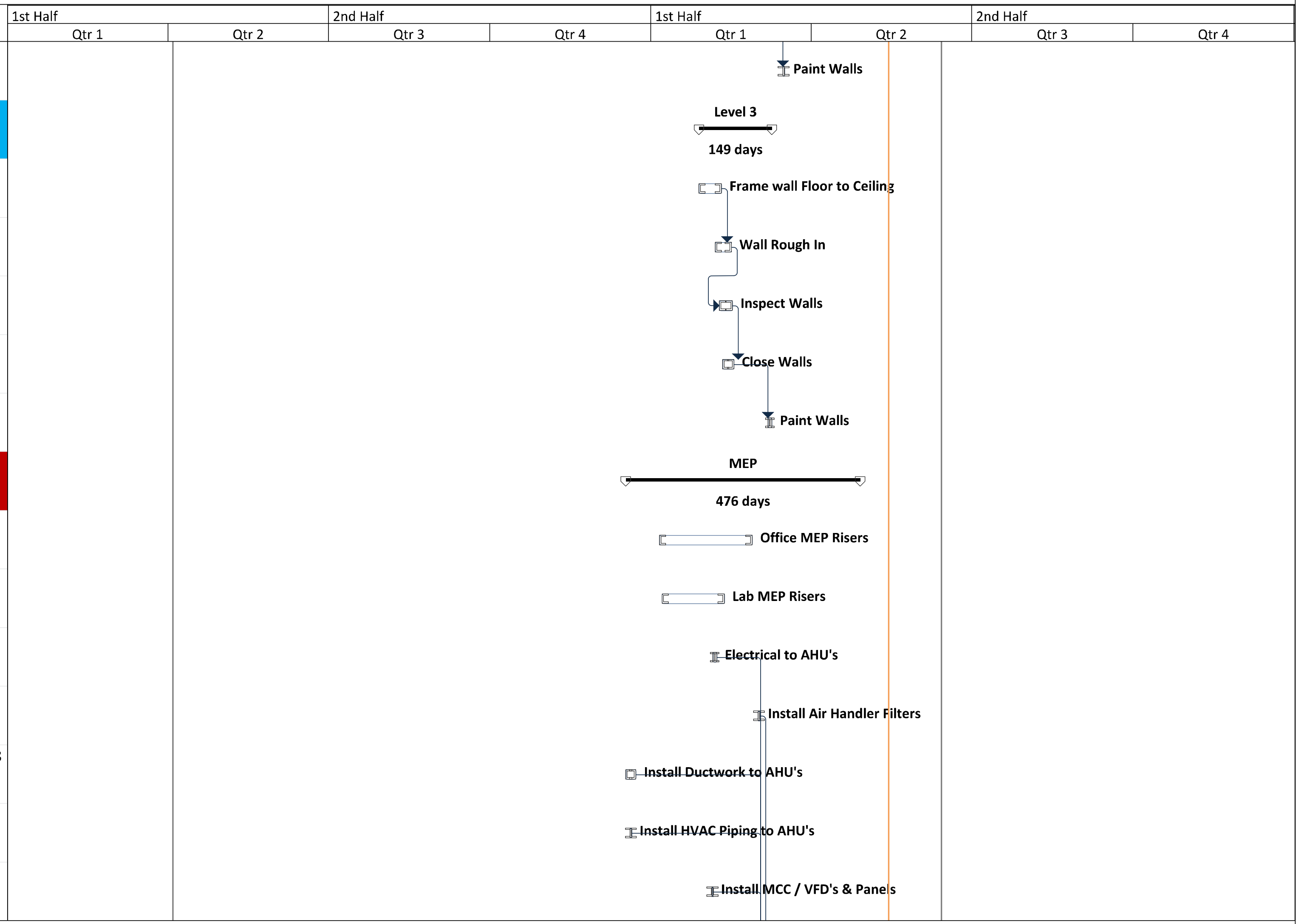
Tech Two - Detailed Schedule Summary
October 27, 2010

Task Name	Duration	Start	Finish
Wall Rough In	62 days	Wed 7/15/09	Thu 10/8/09
Inspect Walls	30 days	Tue 9/1/09	Mon 10/12/09
Close Walls	40 days	Mon 9/7/09	Fri 10/30/09
Paint Walls	15 days	Thu 6/17/10	Wed 7/7/10
Level 1	**166 days**	**Sun 3/22/09**	**Mon 11/9/09**
Frame wall Floor to Ceiling	10 days	Tue 7/7/09	Mon 7/20/09
Wall Rough In	26 days	Fri 7/10/09	Fri 8/14/09
Inspect Walls	15 days	Tue 7/28/09	Mon 8/17/09
Close Walls	60 days	Tue 8/18/09	Mon 11/9/09
Paint Walls	12 days	Sun 3/22/09	Mon 4/6/09
Level 2	**159 days**	**Tue 6/9/09**	**Fri 1/15/10**
Frame wall Floor to Ceiling	20 days	Mon 6/29/09	Fri 7/24/09
Wall Rough In	38 days	Tue 6/9/09	Thu 7/30/09
Inspect Walls	15 days	Tue 7/28/09	Mon 8/17/09
Close Walls	16 days	Wed 7/29/09	Wed 8/19/09



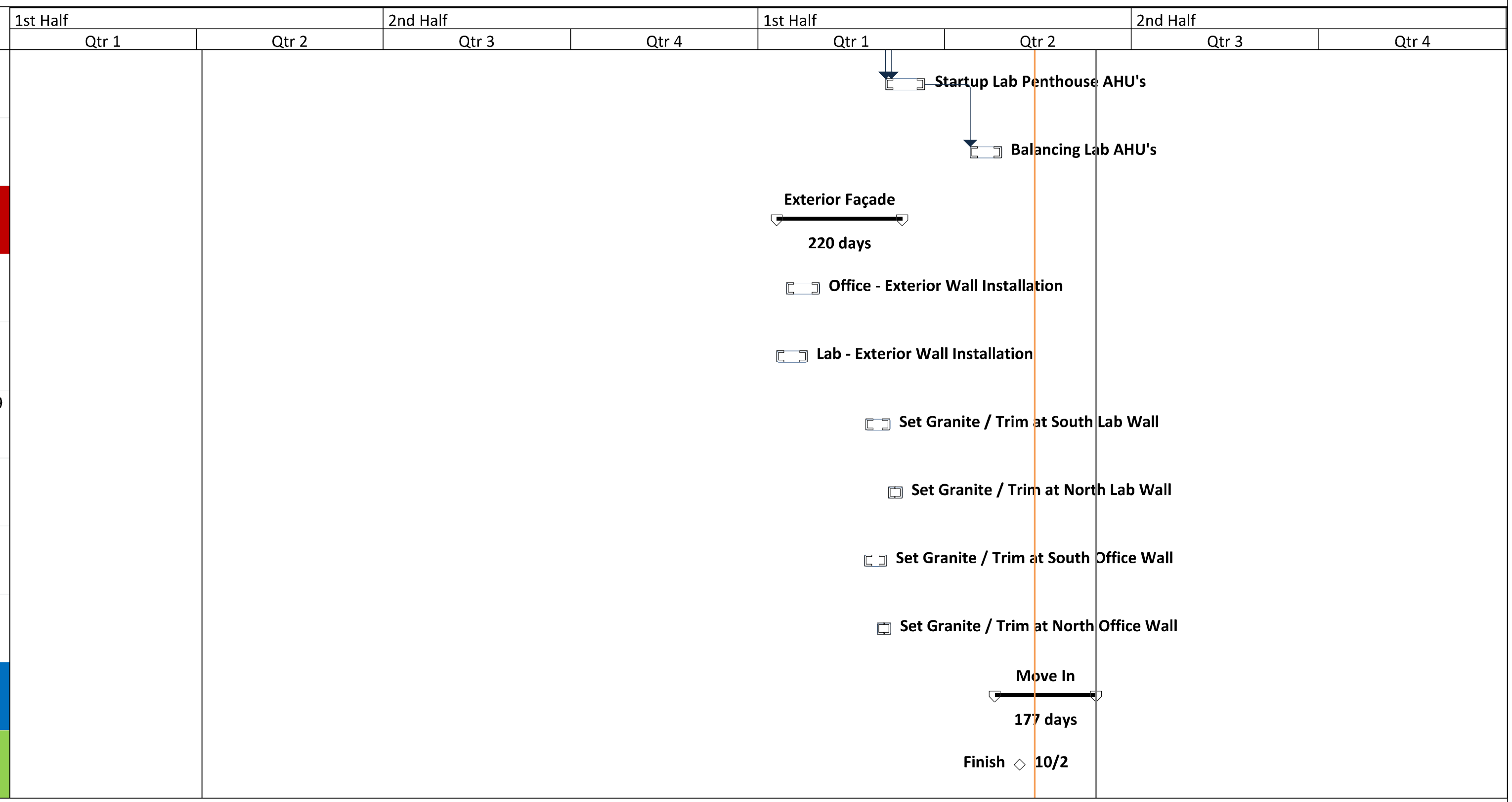
Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Paint Walls	5 days	Mon 1/11/10	Fri 1/15/10
Level 3	**149 days**	**Mon 5/18/09**	**Thu 12/10/09**
Frame wall Floor to Ceiling	46 days	Mon 5/18/09	Mon 7/20/09
Wall Rough In	32 days	Fri 7/3/09	Mon 8/17/09
Inspect Walls	27 days	Wed 7/15/09	Thu 8/20/09
Close Walls	22 days	Fri 7/24/09	Mon 8/24/09
Paint Walls	9 days	Mon 11/30/09	Thu 12/10/09
MEP	**476 days**	**Wed 10/22/0**	**Wed 8/18/10**
Office MEP Risers	189 days	Mon 1/26/09	Thu 10/15/09
Lab MEP Risers	127 days	Mon 2/2/09	Tue 7/28/09
Electrical to AHU's	8 days	Fri 6/26/09	Tue 7/7/09
Install Air Handler Filters	5 days	Mon 11/2/09	Fri 11/6/09
Install Ductwork to AHU's	21 days	Wed 10/22/08	Wed 11/19/08
Install HVAC Piping to AHU's	5 days	Mon 11/3/08	Fri 11/7/08
Install MCC / VFD's & Panels	3 days	Wed 6/24/09	Fri 6/26/09



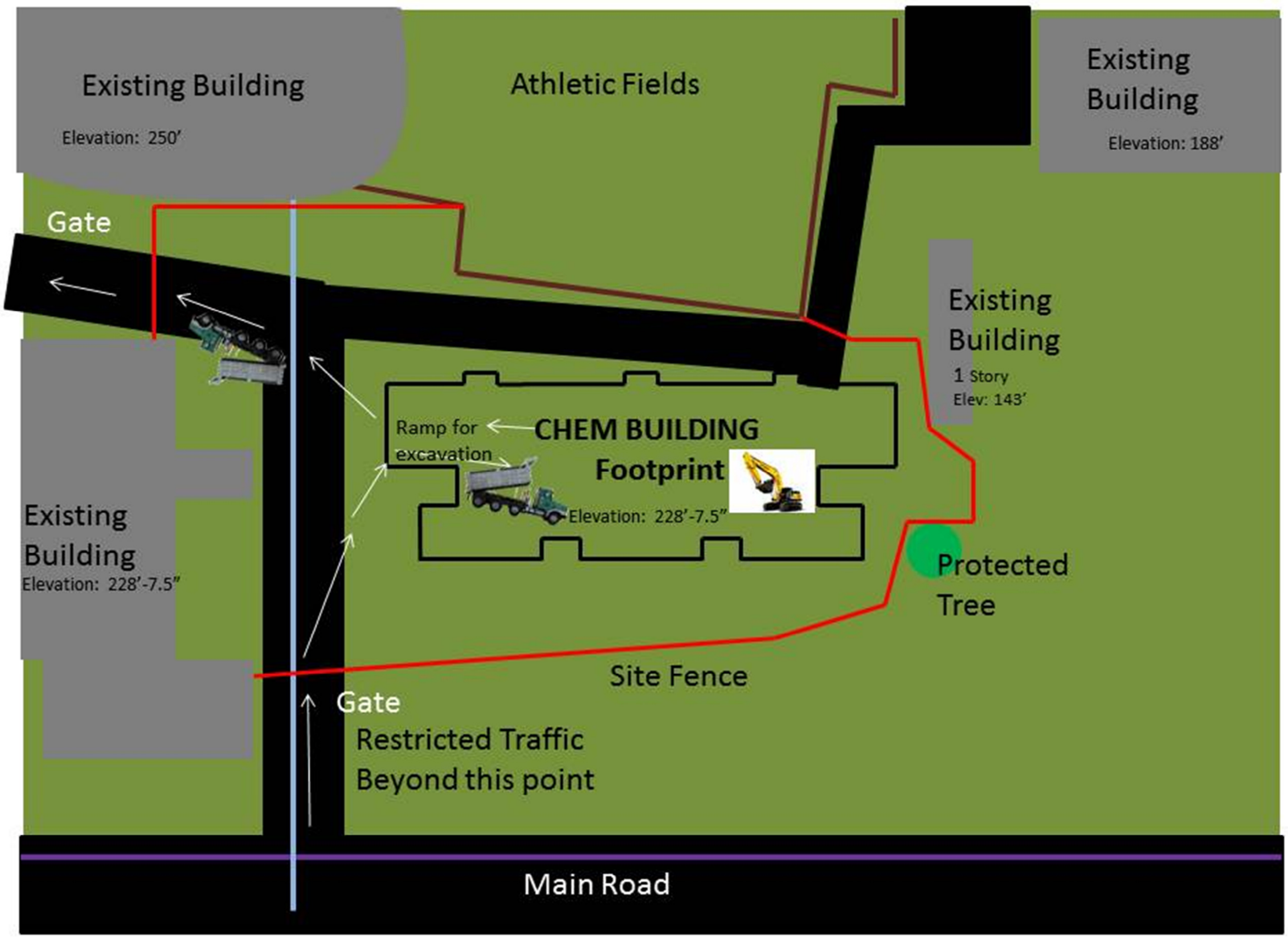
Scheduled Tasks | Milestones ◇ | Total Duration

Task Name	Duration	Start	Finish
Startup Lab Penthouse AHU's	69 days	Mon 11/9/09	Thu 2/11/10
Balancing Lab AHU's	55 days	Thu 6/3/10	Wed 8/18/10
Exterior Façade	**220 days**	**Mon 2/16/09**	**Fri 12/18/09**
Office - Exterior Wall Installation	58 days	Thu 3/12/09	Sat 5/30/09
Lab - Exterior Wall Installation	54 days	Mon 2/16/09	Thu 4/30/09
Set Granite / Trim at South Lab Wall	43 days	Mon 9/21/09	Wed 11/18/09
Set Granite / Trim at North Lab Wall	25 days	Mon 11/16/09	Fri 12/18/09
Set Granite / Trim at South Office Wall	38 days	Fri 9/18/09	Tue 11/10/09
Set Granite / Trim at North Office Wall	25 days	Mon 10/19/09	Fri 11/20/09
Move In	**177 days**	**Mon 8/2/10**	**Tue 4/5/11**
Finish	0 days	Sat 10/2/10	Sat 10/2/10



Scheduled Tasks | Milestones | Total Duration

APPENDIX B – SITE LAYOUT



MIKE GALLAGHER
Tech. 2

EXCAVATION
SITE LAYOUT PLAN

NORTH ARROW

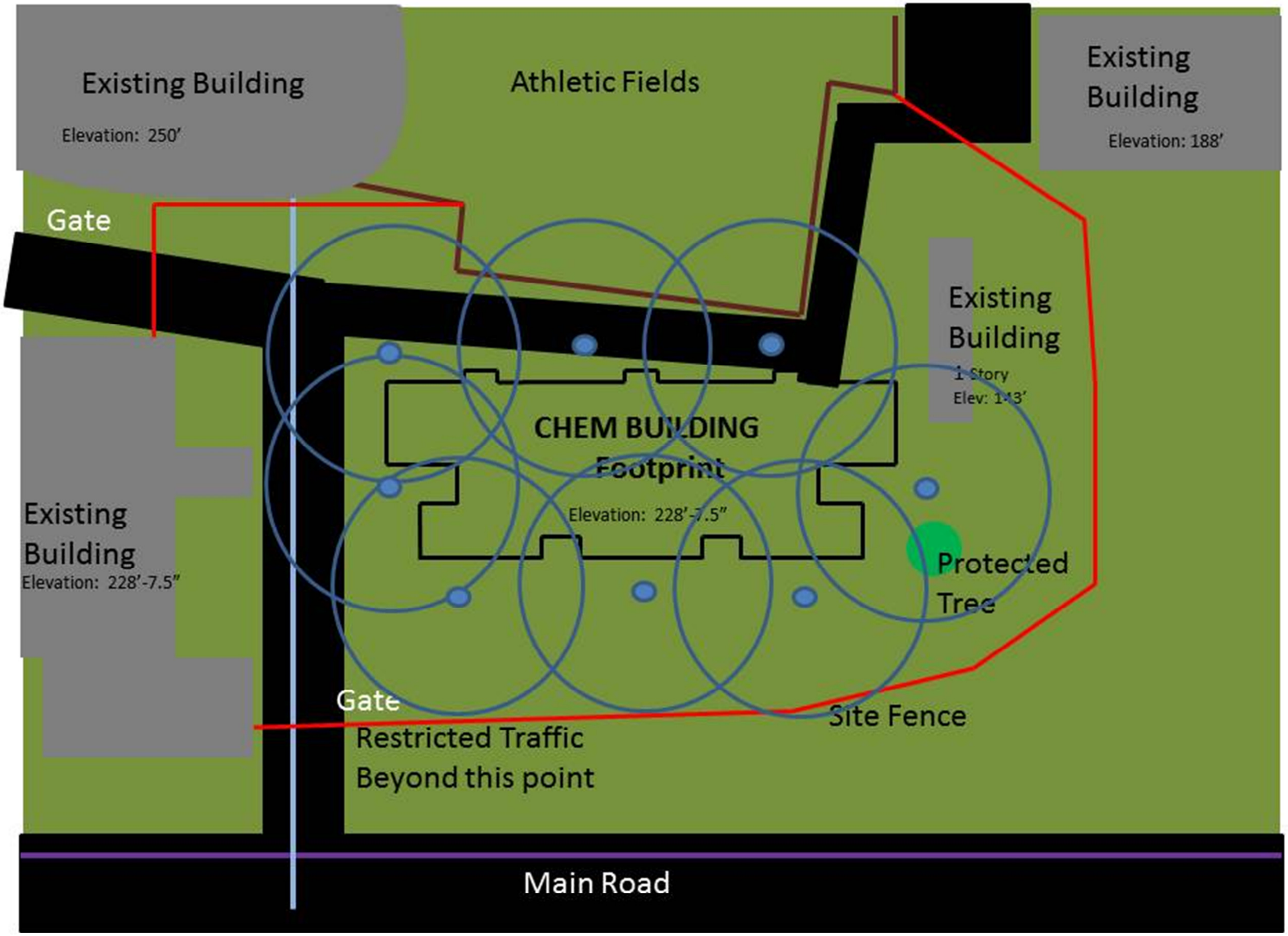
Steam Power Pipe
Electric Power
Water Pipe
Chilled Water Pipe
Gas Line
Sanitary Pipe

1 OF 3
10/27/10

MIKE GALLAGHER
Tech. 2

CRANE LOACTIONS
SITE LAYOUT PLAN

NORTH ARROW

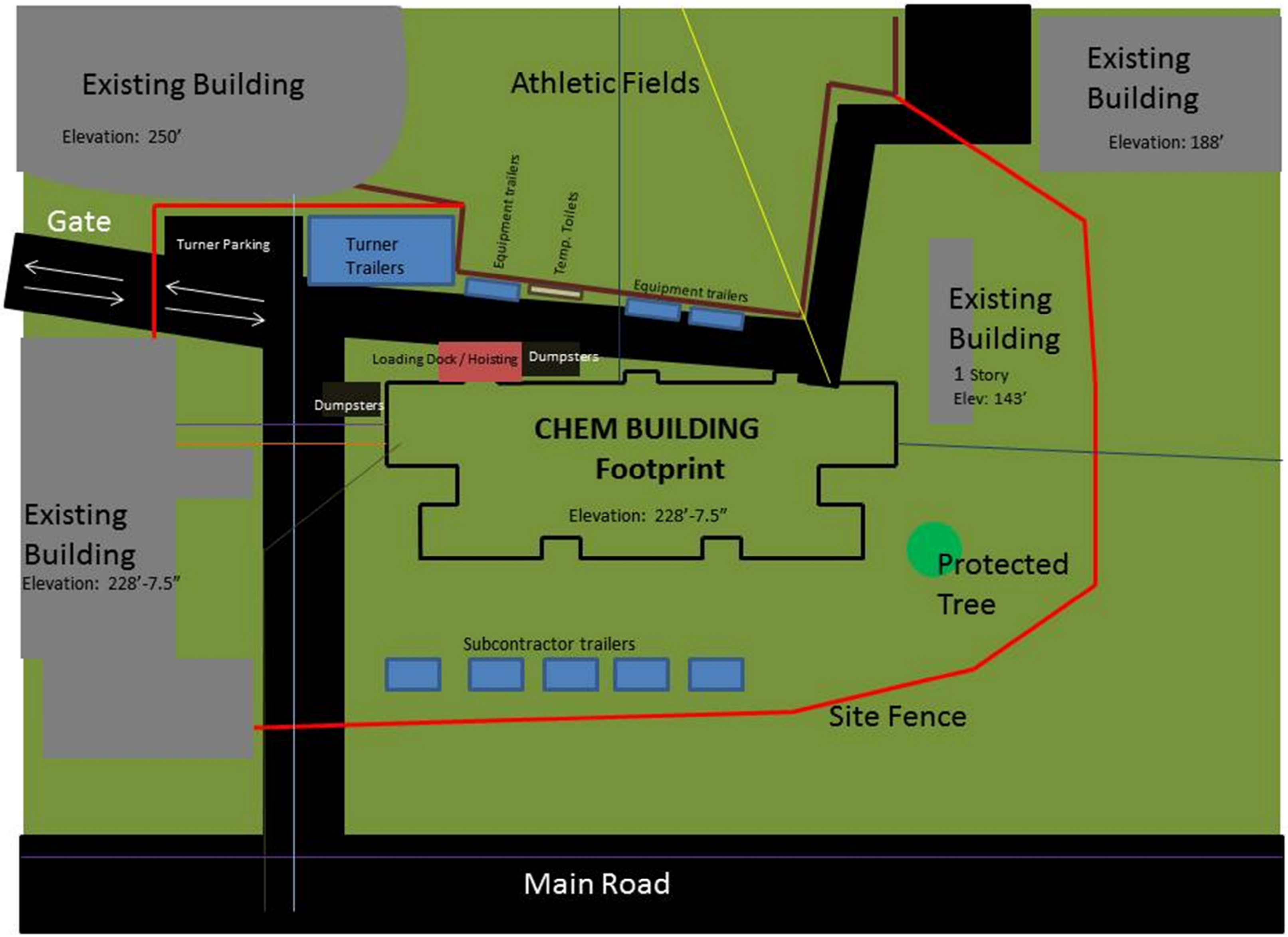


Steam Power Pipe
Electric Power
Water Pipe
Chilled Water Pipe
Gas Line
Sanitary Pipe

2 OF 3
10/27/10

MIKE GALLAGHER
Tech. 2

CONSTRUCTION
SITE LAYOUT PLAN



NORTH ARROW

Steam Power Pipe
Electric Power
Water Pipe
Chilled Water Pipe
Gas Line
Sanitary Pipe

3 OF 3
10/27/10

APPENDIX C – GENERAL CONDITONS ESTIMATE

GENERAL REQUIREMENTS				
Item	**Unit Rate**	**Unit**	**Total Units**	**Total Cost ($)**
Buses 4%	2,745.46	Weeks	165	453,000.00
Cleaning 48%	34,521.43	Weeks	140	4,833,000.00
Insurance 45%	27,830.00	Weeks	165	4,592,000.00
General Expenses 3%	1,540.00	Weeks	200	308,000.00
Total				**10,186,000.00**

GENERAL CONDITIONS				
Item	**Unit Rate**	**Unit**	**Total Units**	**Total Cost ($)**
Administrative	743.5	Weeks	165	200,000
Temp. Facilities	6,151.52	Weeks	165	1,015,000
Temp Toliets	545.46	Weeks	165	90,000
Dumpsters	3,878.79	Weeks	165	640,000
Protection and Safety	10.3	Weeks	165	1,700
Staff	588,454.55	Weeks	165	9,709,500
Total	**13,049,800**		**165**	**13,049,800**

PRECONSTRUCTION GENERAL CONDITIONS				
Item	**Unit Rate**	**Unit**	**Total Units**	**Total Cost ($)**
Administrative	743.5	Weeks	104	77,324
Precon Staff	13,400.00	Weeks	104	1,393,600
Total	**14,143.50**		**104**	**1,470,924.00**

PRECONSTRUCTION STAFF					
Position	**Unit Rate**	**Unit**	**Total Units**	**# of People**	**Total Cost ($)**
Project Exectutive	2,200.00	Weeks	104	2	457,600.00
Senior Estimator	1,950.00	Weeks	104	1	202,800.00
Estimator	1,700.00	Weeks	104	1	176,800.00
Scheduler	1,700.00	Weeks	104	1	176,800.00
Project Superintendent	1,950.00	Weeks	52	1	101,400.00
Project Engineer	1,950.00	Weeks	52	1	101,400.00
Cost Engineer	1,700.00	Weeks	104	1	176,800.00
Total					**1,393,600.00**

CONSTRUCTION STAFF					
Position	**Unit Rate**	**Unit**	**Total Units**	**# of People**	**Total Cost ($)**
Assistant Superintendent	1,500	Weeks	150	2	450,000.00
Superintendent	1,700	Weeks	165	9	2,524,500.00
Project Superintendent	1,950	Weeks	165	1	321,750.00
Laborers and Carpenters	1,200	Weeks	120	14	2,016,000.00
Assistant Engineer	1,500	Weeks	150	2	450,000.00
Field Engineer	1,700	Weeks	165	5	1,402,500.00
Project Engineer	1,950	Weeks	165	2	643,500.00
Safety Manager	1,700	Weeks	165	1	280,500.00
Change Order Manager	1,950	Weeks	150	1	292,500.00
Cost Engineer	1,700	Weeks	165	1	280,500.00
Project Executive	2,200	Weeks	165	2	726,000.00
Senior Estimator	1,950	Weeks	165	1	321,750.00
Total					**9,709,500.00**

APPENDIX D – MECHANICAL BREADTH CALCULATIONS

	Component	Length	Airflow	Width	Height	Hydraulic Diameter	Max Diameter	Area	Velocity	Absolute Roughness	Relative Roughness	Kinematic Viscosity	Density	Reynolds Number	Friction Factor	Pressure Drop Per 100ft	Velocity Pressure	Loss Coefficient	Pressure Drop
		(ft)	(cfm)	(in)	(in)	(in)	(in)	(in^2)	(fpm)	(ft)	(e/D)	(ft^2/s)	(lb/ft^3)	(Re)	(f)	(in wg per 100ft)	(in wg)	(Co)	(in wg)
		8.83	75000.00	66.00	84.00	73.92	73.92	4291.54	2516.6	0.0030	0.0004870	0.0001580	0.0750000	1635244.509	0.017000715	0.108932			0.0096
1.	Fan wall to duct								2516.6								0.394834968	0.064	0.0253
2.	Elbow from Fan wall to exit								2516.6								0.394834968	0.3	0.1185
3.	AHU exit								2516.6								0.394834968	0.18	0.0711
4.	Back Draft Damper								2516.6								0.394834968	0.19	0.0750
5.	Transition								2516.6								0.394834968	0.08	0.0316

Total Pressure Drop 0.3310

STEP #1

FAN WALL = 11,552 $in^2 = A_0$

$A_1 = 9108\ in^2$

$\frac{A_0}{A_1} = 1.268$

$C_0 = 0.0643$

STEP #2

$\frac{H}{W} = \frac{138}{66} = 2.091$

$C_0 = 0.30$

Based on ASHRAE Chart 3-6 Elbo, mitered, Rectangular

STEP #3

$a_0 = 9108$

$a_1 = 5544$

$\frac{a_0}{a_1} = 1.643$

$\tan^{-1} = \frac{54}{29.5} = 61.4°$

$C_0 = 0.18004$

Based on ASHRAE Chart 4-3 Transition, Rectangular Three sides straight

STEP #4

Assumed typical Loss of 0.19 for Damper

STEP #5

$a_0 = 5,544$

$a_1 = 3960$

$\frac{a_0}{a_1} = 1.40$

$\tan^{-1}\left(\frac{24}{57}\right) = 22.8°$

$C_0 = 0.08$

Based on ASHRAE Chart 4-3 Transition, Rectangular Three sides Straight

EQUATIONS

$$\Delta P = C_0 * \left(\frac{V}{4005}\right)^2$$

The Swamee - Jain equation is used to solve directly for the Darcy weisbach friction factor f

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

ε = Roughness height

D = Pipe Diameter

Hydrolic Diameter ≈ Pipe Diameter

$\frac{4A}{P}$ = Hydrolic Diameter

$$Re = \frac{\text{Velocity (fpm)}}{60} \times \left[\frac{\left(\frac{\text{Max Diameter}}{12}\right)}{\text{Kinematic viscosity}}\right]$$

APPENDIX E – SCHUCO E^2 FAÇADE PRODUCT DATA SHEET

Due to company policies this product data sheet will not be included. It can be found and viewed through the Schuco website if you register with a free account.

APPENDIX F – PV INVERTER DATA SHEET

Home > Products > Solar Inverters > SUNNY TOWER

SUNNY TOWER

Easy Installation – maximum yield

The Sunny Tower: As easy to install as a central inverter, as profitable as a Sunny Mini Central. Its exceptional efficiency of up to 98 % and easy installation ensure maximum power yield. The intelligent OptiCool temperature management system makes the Sunny Tower suitable for use at high ambient temperatures. In addition to this, the modular design makes it possible to combine Sunny Mini Central and Sunny Boy inverters, thus guaranteeing maximum flexibility in plant design and extension.

Overview | **Technical Data** | Downloads

	Sunny Tower with 6 Sunny Mini Central 8000TL	Sunny Tower with 6 Sunny Mini Central 11000TL
Input (DC)		
Max. DC power	49.6 kW	68.4 kW
PV voltage range	333 V – 500 V	333 V – 500 V
Max. DC voltage	700 V	700 V
Max. input current	6 x 25 A	6 x 34 A
DC voltage ripple	< 10 %	< 10 %
Max. number of strings (parallel)	6 x 4	6 x 5
Reverse polarity protection	short-circuit diode	short-circuit diode
Output (AC)		
Continuous AC power	48 kW at 40 °C	66 kW at 40 °C
Nominal AC power	48 kW	66 kW
Max. output current	3 x 70 A	3 x 96 A
THD of grid current	< 4 %	< 4 %
Nominal AC voltage	220 V – 240 V	220 V – 240 V
Nominal AC frequency	50 Hz / 60 Hz	50 Hz / 60 Hz
Power factor (cos φ)	1	1
Grid connection	bolt clamp, max. 5 x 95 mm²	bolt clamp, max. 5 x 95 mm²
Efficiency		
Max. efficiency / Euro-Eta	98.0 % / 97.7 %	98.0 % / 97.5 %
Protection devices		
Thermally monitored varistors	yes	yes
Ground fault monitoring	yes	yes
ESS DC load disconnection switch	yes	yes
Grid monitoring (SMA Grid Guard)	yes	yes
Short-circuit tolerance (current control)	yes	yes
Line circuit breaker	6 x B50	6 x B63
General data		
Inverter/Sunny Tower protection rating (acc. to IEC 60529)	IP65 / IP44	IP65 / IP44
Cooling concept	OptiCool	OptiCool

Solar Power Professional Search

Well informed and trained SMA contractors will be happy to help select the right product for you.

Postal Code

search

Operating temperature range	–25 °C ... +60 °C	–25 °C ... +60 °C
Topology	transformerless	Transformerless
Number phase conductors	3	3
Weight	320 kg	320 kg
Dimensions (W / H / D) in	1100 / 1810 / 990	1100 / 1810 / 990

Features

Warranty: 5 years/10 years	yes / opt.	yes / opt.
Plant monitoring (pre-wired): RS485 / Sunny WebBox / SMA Power Balancer	opt. / opt. / opt.	opt. / opt. / opt.

APPENDIX G – PAYBACK PERIOD FOR PV CALCULATION

FEASABILITY OF PV CURTAIN WALL SYSTEM CALCULATION

Year	Energy Cost per kwh	Energy Produced per Hour	Hours per Year	State Tax Credit Per Year	Total Savings Per Year	Total Savings To Date
1	0.1312	10.281	8,760.00	60,791.55	72,607.63	72,607.63
2	0.1325	10.281	8,760.00	60,791.55	72,725.79	145,333.42
3	0.1338	10.281	8,760.00	60,791.55	72,845.13	218,178.55
4	0.1352	10.281	8,760.00	60,791.55	72,965.67	291,144.22
5	0.1365	10.281	8,760.00	60,791.55	73,087.41	364,231.63
6	0.1379	10.281	8,760.00	60,791.55	73,210.37	437,442.00
7	0.1393	10.281	8,760.00	60,791.55	73,334.56	510,776.56
8	0.1407	10.281	8,760.00	60,791.55	73,459.99	584,236.54
9	0.1421	10.281	8,760.00	60,791.55	73,586.67	657,823.21
10	0.1435	10.281	8,760.00	60,791.55	73,714.62	731,537.84
11	0.1449	10.281	8,760.00	60,791.55	73,843.85	805,381.69
13	0.1464	10.281	8,760.00	60,791.55	73,974.38	879,356.06
13	0.1478	10.281	8,760.00	60,791.55	74,106.20	953,462.27
14	0.1493	10.281	8,760.00	60,791.55	74,239.35	1,027,701.62
15	0.1508	10.281	8,760.00	60,791.55	74,373.83	1,102,075.45
16	0.1523	10.281	8,760.00	60,791.55	74,509.65	1,176,585.10
17	0.1538	10.281	8,760.00	60,791.55	74,646.83	1,251,231.93
18	0.1554	10.281	8,760.00	60,791.55	74,785.38	1,326,017.32
19	0.1569	10.281	8,760.00	60,791.55	74,925.32	1,400,942.64
20	0.1585	10.281	8,760.00	60,791.55	75,066.66	1,476,009.30
21	0.1601	10.281	8,760.00	60,791.55	75,209.41	1,551,218.71
22	0.1617	10.281	8,760.00	60,791.55	75,353.59	1,626,572.30
23	0.1633	10.281	8,760.00	60,791.55	75,499.21	1,702,071.51
24	0.1649	10.281	8,760.00	60,791.55	75,646.29	1,777,717.80
25	0.1666	10.281	8,760.00	60,791.55	75,794.83	1,853,512.64