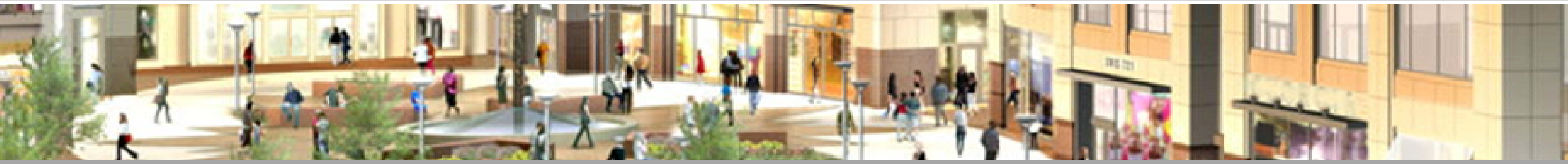
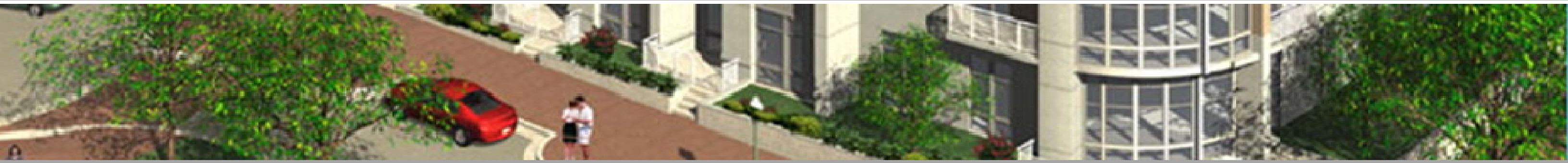


Wisconsin Place Residential

Chevy Chase, Maryland



Jenna Marcolina

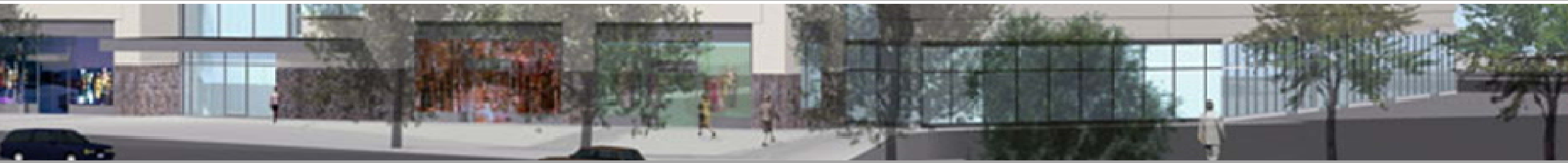
Final Senior Thesis Report

Construction Management

The Pennsylvania State University

Department of Architectural Engineering

Spring 2008



Wisconsin Place Residential

Chevy Chase, MD

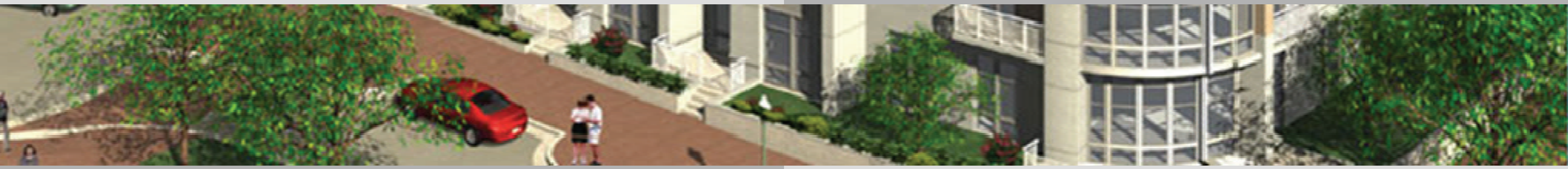
Shop Dine Live Work

Design & Construction Team

General Contractor: Turner Construction Company
Owner: Archstone-Smith Trust
Architect: SK&I Architectural Design Group, LLC
Structural Engineer: Smislova, Kehnemui & Associates, PA
Mechanical and Electrical Engineers: GHT Limited
Civil Engineer: Loeiderman Soltesz Associates

Construction & Structure

Size: 485,000 SF; 15 stories
Cost: $90 million
Schedule: June 2007 - February 2009
Delivery: GMP
Post-tensioned concrete building constructed atop existing parking garage w/ spread footing foundation



MEP Systems

Constant air volume system w/ open & closed loop filtration
Rooftop AHU's operate on 3 phase 480 Volt power
Hydronic Fire Protection System
3 phase 2,000 Amp main electrical service feed
120/208 Volt apartment panels w/ individual metering units
350 kW emergency generator located on roof

Architecture & Unique Facts

WPR is part of a 1.1 million SF mixed use development containing high end retail, restaurant & office space
Façade consists of brick, glass, stone & aluminum
Tower features fitness room and pool on 13th floor
4 CM's and 3 developers working on one podium
3 cranes on site requires meticulous coordination

http://www.engr.psu.edu/ae/thesis/portfolios/2008/jem412/

Jenna Marcolina

Construction Management
Sponsored by Turner Construction Company

Contents

Acknowledgements

Executing this senior thesis has been both a challenging and rewarding experience for me. I have certainly learned a lot through my research and analysis and feel a great sense of pride and accomplishment as I compile my booklet in 308 Sackett. This was a massive undertaking for my fifth and final year at Penn State, and I could not have done it without the help from the following people:

- Turner Construction Company
    - Barbara Choate
    - Thomas Bizzarri
    - Rich Murphy
- Penn State Faculty
    - Dr. Michael Horman
    - Dr. John Messner
    - Dr. David Riley
    - Dr. Albert Lose
- Smith-Midland Corporation
- Industry members from PACE who inspired my research topic
- My family and friends for their love and encouragement
- My fellow AE’s for the best 5 years of my life

My sincerest thanks for all of your assistance!

Executive Summary

Prefabrication Depth

The major theme of my thesis will be prefabrication and the building façade. I intend to perform detailed research to investigate its current state in the modern day industry. Prefabricated systems have been around for a while, but I feel that many groups are unsure of how to utilize them to their utmost advantage. By looking at case studies, peer reviewed articles, and industry opinions I will determine some of the best applications of prefabricated brick systems as well as shed light on some cutting edge technologies that have not yet reached the masses.

Analysis 1: Precast Slenderwall Panel Implementation

As part of my prefabrication research I will redesign the façade of Wisconsin Place Residential to be a prefabricated brick enclosure. The reasons for doing this include the site congestion, coordination issues, and schedule constraints. After performing extensive research and speaking with manufacturers and engineers, I selected the Slenderwall® precast panel system due to its ease of construction and high level of façade unitization. My structural breadth is embedded in this area. I calculated and compared the weight of the new system to that of the old to ensure the superstructure is able to support the panel load. The connection details for the precast panels to the post-tensioned slab were designed and methods to improve the moisture resistive and thermal characteristics of the envelope were investigated, as these are areas of concern with prefabricated materials. A schedule review showed a 22 week reduction by switching to the Slenderwall® system. A budget review was performed and the overall cost savings due to implementing the Slenderwall® façade is $1,409,630. All of these results were processed to make a final recommendation of changing to Slenderwall®, the optimal system.

Analysis 2: Photovoltaic Glass Replacement

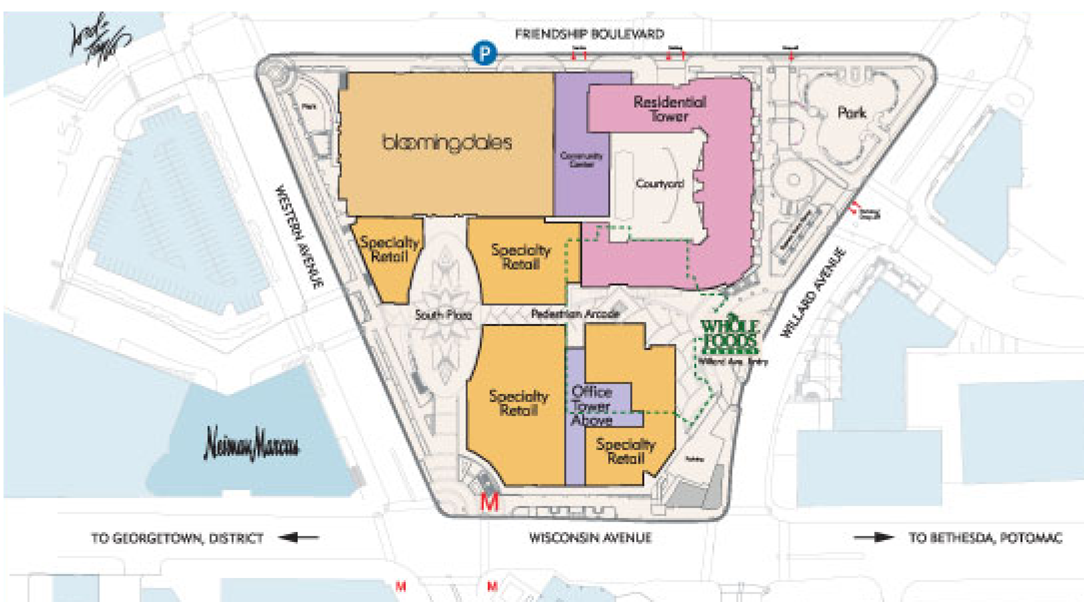
A class about building envelopes brought me to the idea of using photovoltaic glass as a way to convert solar energy from the sun into electrical energy for the building. Yes, this solar cell glass is more costly than regular, but its benefits can greatly pay off over time. This analysis will look at the energy benefits to utilizing PV cell panels in a functional manner as windows. The idea is to replace all of the foot-level glass panels with PV glass since they will not obstruct the view from the apartments. As my mechanical breadth, I used the software program Energy10 to determine the energy savings per year from adding these PV panels to the façade. The cost of implementing the PV panels was considered, and proved to be a bad business move due to the 108 year return on investment. The reason for this is that the 50 Watt panels selected are not powerful enough o make any significant reductions in building mechanical loads and therefore will not affect the utility bills for tenants.

PROJECT OVERVIEW

Archstone-Smith, a prominent developer in the Washington, DC area, hired Turner as the general contractor for the 15 story, 485,000 square foot GMP project that began construction in June 2007. WPR is only part of a 1.1 million square foot mixed use development known as Wisconsin Place that includes high end retail, restaurant, and office space. A basic site plan below depicts the proposed layout. Wisconsin Place presents a very unique situation. Due to the magnitude of the project, it has been divided into four main parts and the work was awarded to four separate general contractors. They are assigned as follows:

1. Turner- parking garage
2. Turner- residential tower
3. Centex- office tower
4. TBD- retail

Three developers are also involved in the massive project: New England Development, Archstone-Smith Trust, and Boston Properties, Inc. Each firm has a specialized interest in Wisconsin Place, and three grand visions will be realized in its construction. It will be interesting to see how all of these players interact and cooperate on a congested site in the middle of the city.



Project Schedule Summary

*A detailed existing project summary can be found in Appendix A.

Foundation

Wisconsin Place Residential sits directly on top of a four level below grade parking garage. Therefore, no foundation system is required for the residential tower. Turner is the General Contractor on the parking garage project, but that is an entirely separate job with separate team members. Construction of the parking garage is still in progress, which poses daily challenges to both Turner teams working in such close quarters. Weekly coordination meetings alleviate site congestion problems.

The parking garage is supported by spread footings and foundation walls and was designed to carry the full load of the residential tower above. The parking garage sits on a very sturdy foundation of solid rock which was hit almost immediately after excavation began. Spread footings and slab on grade were then a suitable foundation system since they sat upon such stable sub grade. The column and wall footings are designed for a bearing pressure of 40,000 psf. Turner entered the WPR site in June 2007 to pour the 1st floor slab, and construction has progressed from there.

Structural

The building structure consists of concrete columns and post-tensioned concrete slabs. The 7-wire stress-relieved strands are unbonded and spaced at no more than 5 feet apart. A minimum of 2 tendons in each direction is required directly over columns.

The post-tensioned concrete structure is built floor by floor. The specifications mandate that at least one floor be fully formed or shored with a minimum of 3 floors reshored at any time. This ensures the concrete has fully cured and reached its maximum compressive strength before the forms are released, keeping the building and the workers safe. Concrete reaches its minimum stressing strength within 72 hours of pouring, and the tendons should be stressed within 96 hours of pouring.

The slabs are typically broken into 3 to 5 sections for pumped concrete pours. To track progress more closely, Turner has created a concrete pour schedule that is updated daily. The schedule projects that they will pour 15,893 SF of concrete per week in 32 weeks. The average area of a pour is 6,228 SF.

Two types of formwork are used for the structure of the building: plywood and preassembled. Currently, the concrete subcontractor is using the preassembled to expedite the process. The preassembled formwork is one unit connected by joints that easily snap together with anchors and fasteners. It is reusable and conducive for such a large project. Snap-off form ties hold the formwork together and a colorless, non-staining form release agent is used to lubricate the forms.

Finishes

The finishes of the building are installed from the first floor up, and trades are staggered as necessary to avoid field collisions and counter productivity. Finishes will be installed in the following order:

- Light Fixtures
- Drywall
- Ceilings
- Ceramic Tile
- Cabinets and Counters
- Finish Paint
- Flooring
- MEP Trim-Out

Mechanical System

All of the major mechanical equipment is located on the penthouse level. Each apartment unit contains a small AHU to regulate temperature and air flow. This makes each apartment independent of the next and optimizes comfort control for residents. Placing the large cooling towers and air handling units on the roof also minimizes noise throughout WPR. No one ever wants to rent the apartment adjacent to a mechanical room because it generates so much noise, heat, and vibration. The mechanical system features automatic temperature controls and a submetering system.

The constant air volume system includes open and closed loop filtration to service WPR. The penthouse contains 5 rooftop units made up of a compressor, supply air, heating and cooling coil that operate on 480 Volt 3 phase power. Two cooling towers with a 48 gpm pump also inhabit the penthouse. They operate at a 1450 gpm flow rate between temperatures of 85 to 95 degrees Fahrenheit. A sand filtration and UV disinfection system help purify the water that passes through the cooling towers, and nitrites are added to further cleanse the system.

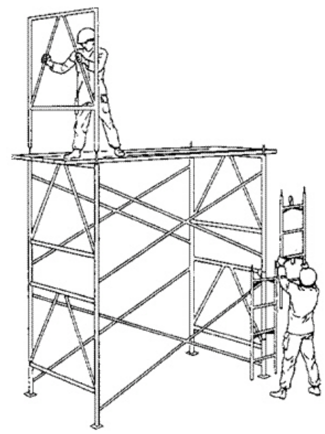
A hydronic fire protection system, consisting of wet and dry standpipes, is to be installed throughout the building. Sprinkler heads are located below the ductwork and above light fixtures in finished spaces. A supervised shut-off valve, flow detector, drain line, and inspector's test connection are to be provided at each connection between standpipes and sprinkler systems. Where water pressure exceeds 100 psig, automatic pressure restricting fire hose valves are to be provided.

Electrical System

Wisconsin Place receives a main feed of 3 phase 2,000 Amp service from the existing switchboard in the parking garage electrical room. Each apartment has its own 120/208 Volt panel along with an individual metering unit. This makes it possible to bill each apartment separately for electricity and saves the owner a lot of footwork. A 350 kW standby emergency generator is located on the roof. Small electric rooms are located on each floor of the apartment building, while a larger main electric room is located on the penthouse level.

Masonry

Many non-load-bearing materials constitute the façade of Wisconsin Place, including glass, glazing, aluminum-faced composite wall panels, brick, precast and cast stone, aluminum window system, aluminum metal panel system, and pre-finished steel channels.



The brick exterior wall system is comprised of ½ inch gypsum board followed by a 6 mil polyethylene vapor barrier. R13 batt insulation lines the space between the gypsum and 4 inch light gauge steel studs topped with ½ inch sheathing and asphalt felt. Galvanized brick ties fasten the brick to the façade, and continuous flashing extends 1/8 inch beyond the face of the brick for proper drainage. Cell vents are placed at 24 inches on center horizontal above finish grade where flashing does not cover the brick.

The cast stone exterior wall system is very similar to the brick wall system. Galvanized brick ties hold cast stone in place while ½ inch mortar joints are left between each row of stone. Weep holes are located at 24 inches on center to allow water to escape.

There are two types of scaffolding being used on the project. The 1st through 3rd floor masonry will be applied using a typical two frame built up scaffolding system shown to the right. This basic form of scaffolding is constructed from the ground up but becomes dangerous at high levels. It must be fastened to the building in some way to prevent collapse or tipping. To prevent this hazard, swinging scaffolding is used for the 4th through 15th floors. Swinging scaffolding is suspended by ropes or cables from a block and tackle attached by roof hooks and can be raised or lowered to any height. This is convenient for tall buildings like WPR because it is so versatile.

Project Cost Information

The total square footage of Wisconsin Place is 484,960 gross SF, 395,503 net SF, with an average efficiency of 81.55%.

Construction Cost: $85,115,971

CC/SF: $175.51/SF

Total Project Costs: $93,394,462

TC/SF: $192.58/SF

Building Systems Costs:

Mechanical Total: $20,653,363

Mechanical Total/SF: $42.59/SF

HVAC/Plumbing: $19,428,363

Fire Protection: $1,225,000

Electrical Total: $11,565,198

Electrical Total/SF: $23.85/SF

Structural Total: $18,433,019

Structural Total/SF: $38.01/SF

Concrete: $12,435,819

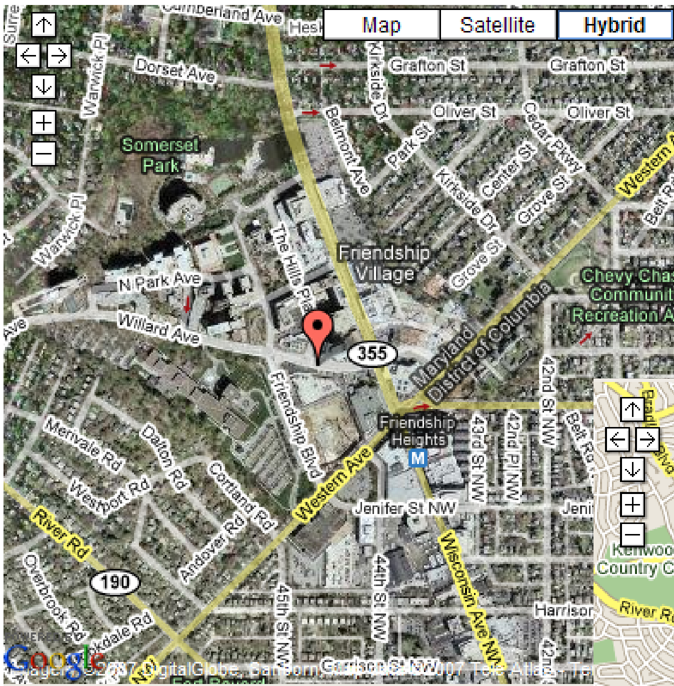
Structural Steel & Misc Metals: $1,187,200

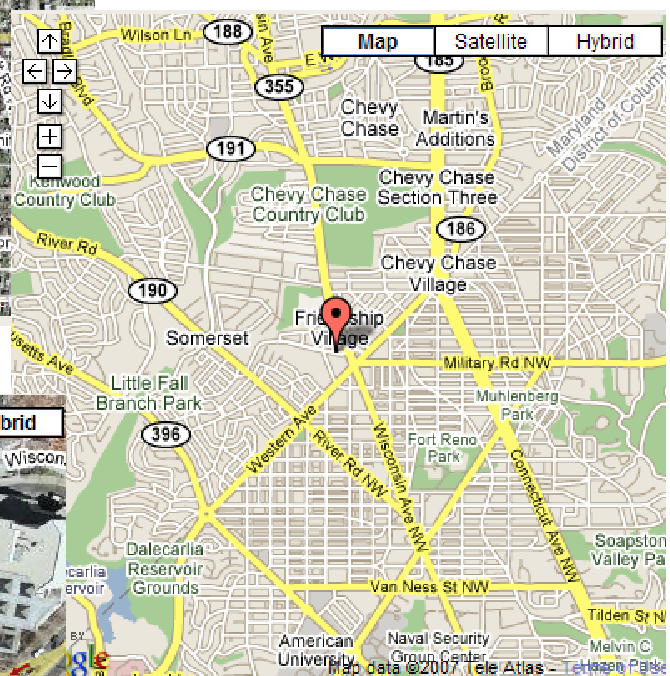
Masonry: $4,810,000

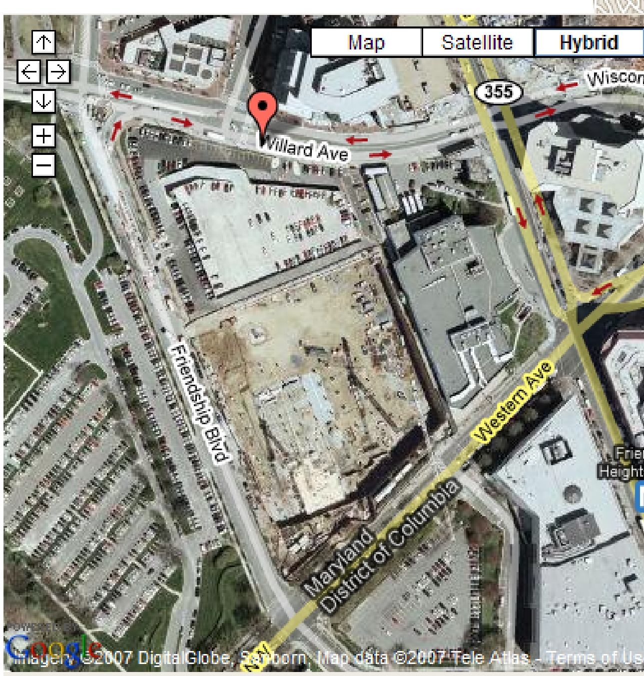
Local Conditions

Concrete structures, especially pre-stressed systems, are common to the Maryland/Washington, DC area due to labor availability. The cost of labor can be reduced through competitive bidding. Concrete seems to be the optimal solution to the extreme site congestion of Wisconsin Place. Steel requires laydown and staging areas and is a permanent fixture on site until erection is complete. Concrete, on the other hand, arrives in a truck each day and leaves the site when it is finished. Steel erection is also a crane intensive activity, while concrete only utilizes a pump truck that arrives just before the concrete truck. Post-tensioned concrete is a much faster process than cast-in-place concrete because the slabs can be stressed, stripped, and reshored when the concrete reaches 75% of its ultimate 28 day strength.

VICINITY MAPS: CHEVY CHASE AND SURROUNDING AREA







EXISTING SITE LAYOUT PLAN

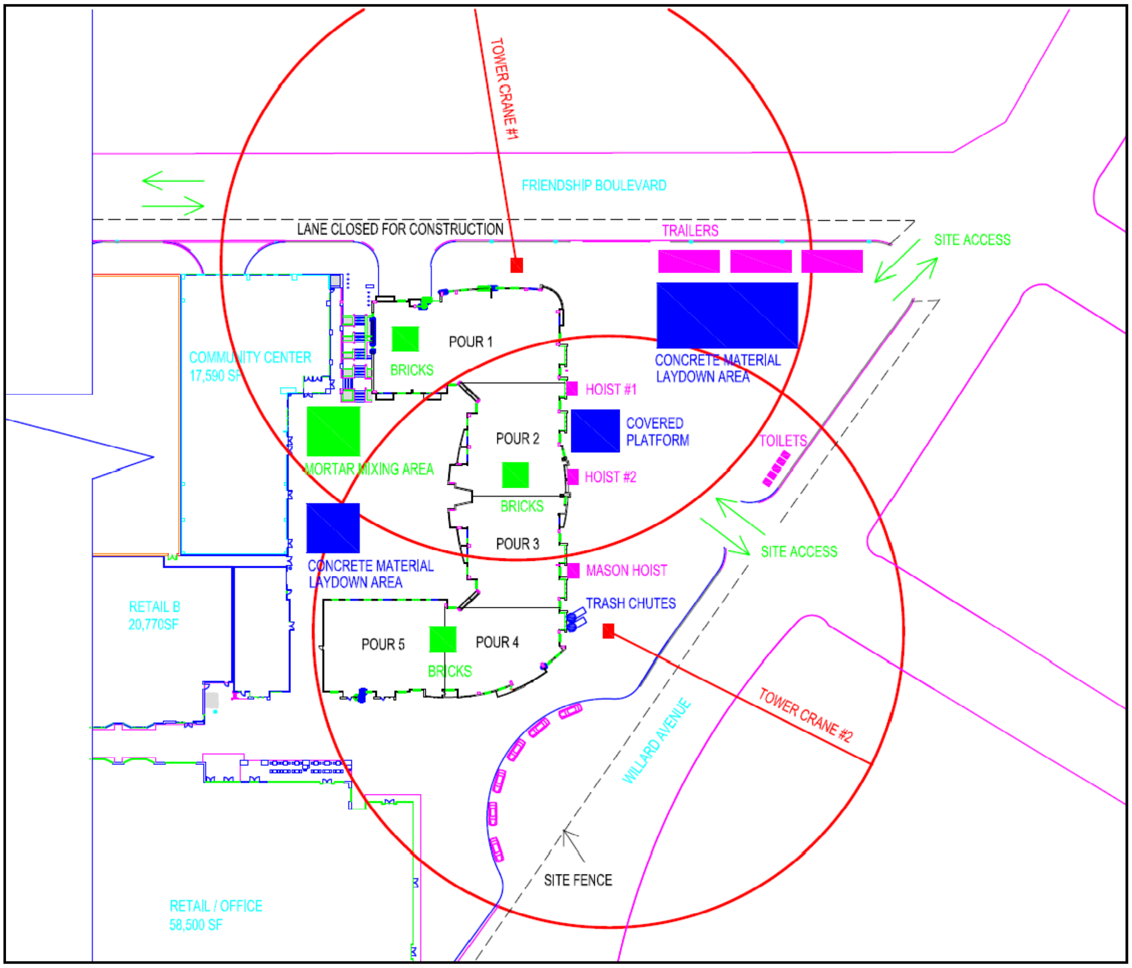
The site plan below shows the superstructure phase of the Wisconsin Place project. At first glance, it is evident that the site is very congested. Three other projects including an office tower, parking garage, and retail stores are happening concurrently on the same plot of land. Turner has experienced many space and coordination issues thus far.

One potential way to divide the floor slabs into sections is shown on the existing site layout plan. Most of the deliveries and staging happens in the northwest corner of the site, as there is limited space elsewhere. Two main entrances to the site are depicted on the plan as well.

The far right lane of Friendship Boulevard has been closed for construction and helps with the space constraint. Delivery trucks, however, are not allowed to unload from this section of road. It becomes dangerous when a thin metal fence is the only thing that separates passing vehicles from heavy machinery and materials. So, it is best to keep the hazardous material as far away from the public as possible.

Trash chutes are a great way to manage waste on a job site. They keep debris contained until trucks haul it all away. These chutes are conveniently located along the driving path so that dump trucks can pick and go.

It would be interesting to see the tower cranes repositioned within the building footprint to increase space in the public areas. For example, the tower crane could be placed in the elevator shaft until the building tops out. Then, it can be removed and the elevators installed. As evidenced by the site photo on the previous page, the WPR construction site is extremely tight. Employees are no longer allowed to park on site due to congestion issues. To add to this, Tower Crane #1 seems to be placed in an inopportune spot, with nearly half of its boom swing wasted over Friendship Boulevard. Perhaps it could be positioned in a way that would make it more accessible to resources on site.



Existing Site Layout Plan

Client Information

Archstone-Smith, the owner of Wisconsin Place, is recognized in the Washington, DC area as a leader in apartment investments and operations. A partnership of two major developers, Archstone and Charles E. Smith, they pride themselves on a strong 56-year legacy in the greater Washington D.C. market. Consequently, Archstone-Smith ranks as one of the largest apartment owners and operators, with more than 21,000 apartments in greater Washington, D.C. Their market also focuses on the most desirable neighborhoods in Southern California, the San Francisco Bay Area, the New York metropolitan area, Seattle, and Boston. The company's mission is "to leverage the talents and resources of our organization to reinvent our industry and create value for our shareholders, customers and associates."

Archstone-Smith sees Chevy Chase as a very up-and-coming location in Maryland. It is quickly developing into a posh upscale region inhabited by young professionals and families. Their

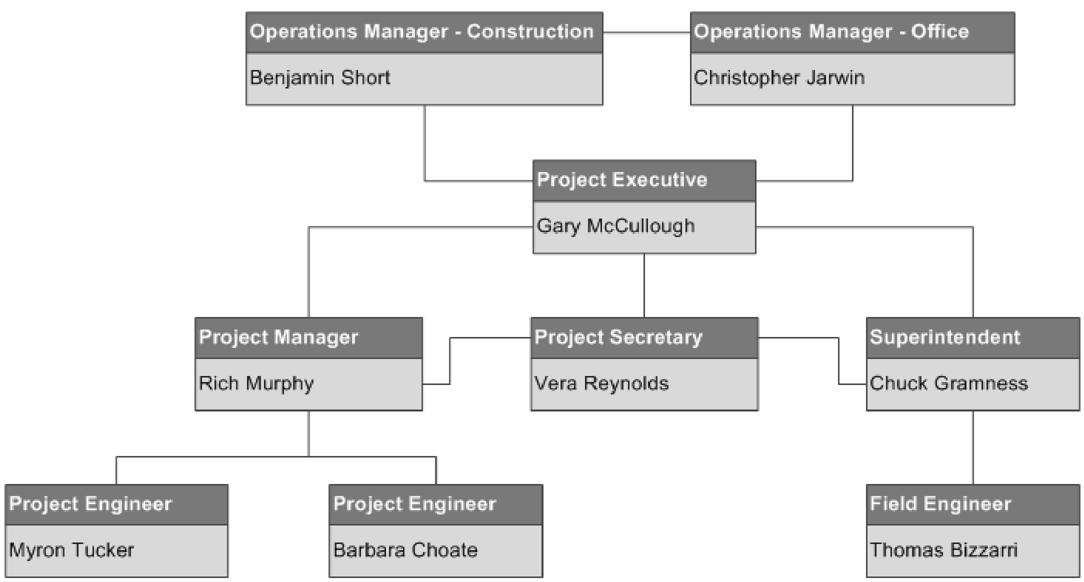
primary interest in this project is the monetary aspect. Downtown apartments are a highly lucrative market that Archstone-Smith has been capitalizing upon for decades.

Archstone-Smith is dedicated to ensuring cost, quality, and schedule performance and it shows in their involvement in the project. They have one representative who is permanently positioned on site. He is the liaison to the owner and keeps Archstone-Smith closely connected to Turner. Another representative visits the site about once a week to attend coordination and progress meetings.

There are two sequencing issues of principal concern to the owner. Those are access to the site and concrete pours. With four separate projects happening concurrently, logistics are of utmost importance. Painstaking planning is required to ensure each GC can get their labor and materials to the site every day. Working in such close quarters makes it difficult to allocate storage and laydown areas as well. There are currently 2 cranes on site that belong to Turner. A third crane is being utilized by the general contractor on the office building and is in close proximity to the other 2 cranes. Turner has closed down a lane of traffic on Friendship Boulevard and Willard Avenue to alleviate some site traffic flow problems.

Turner Project Team

The project team works very closely together on WPR. Dealing with a project of this magnitude, there is really no other way. On a typical day they will encounter numerous pressing issues that need to be resolved in a short time frame to keep the project moving. In a single day, one project engineer was juggling tracking the status of cast stone for the façade, working with the architect to change the anchors for the window washing system, and getting the sprinkler system approved by the county, all critical tasks.

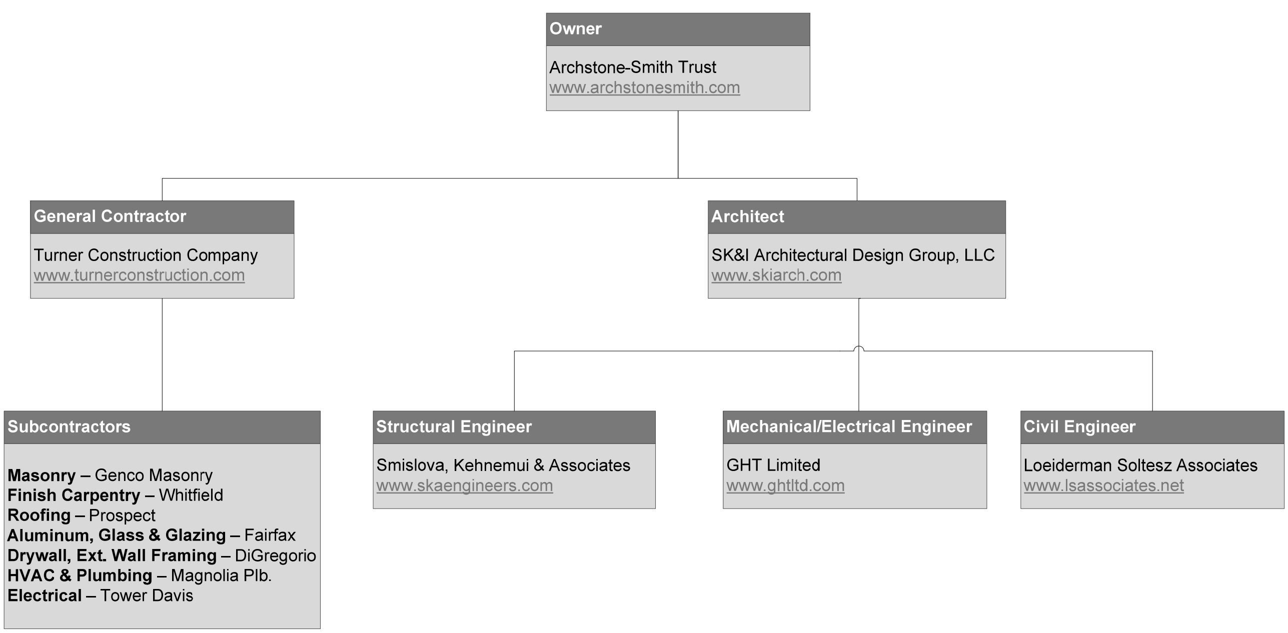


Two operations managers monitor all Turner projects in the Maryland territory, an enormous job considering there are currently about 64 projects underway in the region. One operations manager takes care of the construction side, and the other takes care of the office side. An assistant visits the site every six weeks to address scheduling, budget, or staffing issues. He then reports back to the operations managers who will repair any imbalances.

Both the project executive and project manager are on site 100% of the time. The project executive communicates more with the owner while the project manager is more closely associated with project-specific operations. The project manager is described as the "problem solver" by team members. He uses his work experience to come up with solutions before an RFI has to be sent out to the architect. The project engineers essentially build the project on paper in the form of submittals and drawing control before it is physically built in the field. They are responsible for ensuring materials arrive to site in time. From here, the superintendents take over and oversee the installation of these materials on site. A field engineer is an entry level superintendent. He performs the same tasks and responsibilities as the main superintendent but under supervision. The on-site project team meets once a week with the owner to discuss current issues and look ahead schedules.

Project Delivery System

Turner acts as the General Contractor on Wisconsin Place and provided comprehensive pre-construction services to the development team over a 28 month period. Archstone-Smith chose a GMP because the design was incomplete when the project went out to bid. The GMP provides built in flexibility in the form of allowances for the uncertain portions of work. For instance, the GMP budget for WPR has allocated funds such as "Plumbing Allowance" or "Electric Allowance" to accommodate changes or refinements to design.



Turner holds a CCIP with most of their subcontractors, which includes worker's compensation and general liability insurance. This CCIP also covers payment and performance bonds. Some subcontractors are classified as "high risk" and are required to provide individual bonds to Turner to ensure they are covered. For example, Otis Elevator was not part of the CCIP, so they will provide their own bond for the duration of the project.

All of the contracts held between Turner and subcontractors are lump sum. This is a typical contract arrangement and allows for change orders to easily reimburse costs that exceed the project budget.

The owner would not disclose the types of contracts held between Archstone-Smith and their hired consultants. However, Turner explained that they are most likely service agreements, which means that each firm establishes a fixed price for defined services and the owner pays for additional services beyond the defined scope. For example, a service agreement between the owner and the structural engineer may include drawings and test reports. If the owner decides at a later date that he would like this engineer to attend weekly meetings on site that would be an additional charge beyond what is outlined in the contract.

Prefabrication Depth

Problem Statement

Prefabrication is an incredibly useful tool available to the construction industry today. Unfortunately, it has a stigma attached to it that makes some owners cringe when they hear the word. While prefabrication has been around for hundreds of years, it is still very misunderstood. Owners and designers need a better basis for making the decision to go prefab.

Goal

Through this prefabrication research I wish to determine the origins of prefabrication and what has kept the concept going for so many years. This depth study will identify the advantages and disadvantages to prefabrication and describe a model to help owners make the decision of using prefabricated materials. Finally, since the theme of this thesis project is the building façade, I will research and compare various types of precast brick panels systems. This will ultimately assist in selecting a specific product to be used on the Wisconsin Place project.

Research Steps

1. Gather research on the history of prefabrication.
2. Research methods for deciding to choose prefabrication.
3. Identify the advantages and disadvantages of prefabrication.
4. Research prefabricated facades and compare products.
5. Research new technology for prefabricated brick facades.

Tools

1. Journal of Construction Engineering and Management
2. Journal of Aerospace Engineering
3. PACE conference
4. KPFF Consulting Engineers
5. ASCE Journal of Architectural Engineering
6. Penn State Libraries

Expected Outcome

The results of this prefabrication research should be further enlightenment as to why the decision to implement prefabricated items is such a complex one and to establish a fixed method to make the decision. After comparing different precast brick panel systems I would like to select one to use in my Analysis 1 precast façade implementation.

History

Prefabrication has been around for many years, but the concept and practices are still evolving. Andreas Palladio standardized architectural forms like column proportions and stair arrangements in the 16^{th} century as a response to the high demand for palaces and villas of similar size and structure. Following World War I in Europe, prefabricated houses replaced the ones that were destroyed in the fighting. The Baby Boomers of World War II once again sparked the need for cheap and fast housing in the US when they returned home to start families. It is evident that there has been a continual need for prefabrication around the world for centuries, but the need is ever changing with the times and new technology.

The concept behind prefabrication in construction is that large units of a building can be pre-assembled in factories or warehouses and delivered to site ready-to-install. A key factor in optimizing prefabrication lies in the ability to break a task down into smaller components, like an assembly line. By combining smaller parts into a whole, larger elements can be incorporated into the building system, reducing schedule time and site congestion.

This depth focuses specifically on prefabricated building facades and compares different systems and methodologies. It addresses why, after thousands of years, people are still hesitant to use prefabricated materials. My research will also include some tips, even a decision guide, to determining whether or not a project should utilize prefabrication. I will compare different precast systems and look into some new technologies that have not yet broken out onto the market.

Advantages and Disadvantages

On any given project, an owner is seeking high levels of value, safety, quality, productivity, and performance. Prefabricated items can satisfy all of these requirements as long as the project team is willing to invest the extra time and money into planning for it. On a project with adverse site conditions prefabrication would be beneficial. For example, if a building is being constructed in an area with very cold climate, it would be extremely difficult to maintain a steady concrete pour schedule for the structural system. Concrete requires a certain window of temperatures to cure, so the project would be delayed on the days when it is too cold to pour slabs.

Prefabrication is an effective solution for a demanding schedule, as it is faster to attach larger pieces to a building. Projects looking to reduce costs can realize savings in a shorter schedule. Complex designs sometimes dictate prefabrication. Intricate elements are better assembled off-site, where quality control can be more closely monitored.

In many cases, owners and designers alike rule out the idea of prefabrication on a project because it requires much more careful planning and execution. Prefabrication is also a decision that needs to be made upfront so that proper design and coordination can be ensured by the architect and general contractor. Owners are hesitant to commit to prefabrication so early in the design stage.

Some other drawbacks to prefabrication are a potentially higher upfront cost as well as transportation cost. If a factory is 50 miles away the contractor/owner needs to consider how the materials will arrive to the site. Besides the cost of gas, physical limitations like low underpasses or truck weight limits could prevent materials from travelling to their desired location. Lack of flexibility in design also detracts buyers from prefabricated products. This is not so true today,

but in the past, prefabrication was strongly associated with a standard vanilla box. Maintaining a sound building envelope is another major concern of the owner, architect, and general contractor. Since assembling a precast façade is like putting a puzzle together, there will be many tiny cracks between the connections. This affects the acoustical, thermal, and water-resistant properties of the exterior skin. Consideration must be given to sealants, insulation, and vapor barriers to make a precast building just as good as a stick-built one.

Prefabrication requires more engineering, more materials, and additional work to assemble materials. The cost is usually higher than ground-up construction, and lead times are a concern for all those involved with the design process. But if these constraints are addressed early enough in the design process prefabrication can be a feasible option.

Computer Software & PPMOF

In a paper published in the Journal of Construction Engineering and Management, a team of one graduate student, one project engineer, and three professors discuss the factors influencing the decision of prefabrication use. The term PPMOF is coined as 'Prefabrication, Preassembly, Modularization, Off-site fabrication.' It was noted that the use of prefabrication has nearly doubled over the past 15 years, but the industry has not fully recognized the potential improvements that PPMOF has to offer. The paper stresses that prefabrication is something that should be directly applied to certain areas of a project, like the façade or furniture. It is not something that can be applied across the board as a percentage. In this way, prefabrication is still misunderstood.

The researchers explain about MODEX, a DOS-based software system used to determine the feasibility of implementing modular technology. The program prompts the user for project information, existing conditions, etc., and provides a cost analysis as well as projected schedule. Form this output, the user can determine the feasibility of utilizing prefabrication on their project. Results of testing concluded that the program's recommendation matched that of industry professionals 91% of the time.

Neuromodex is a more advanced software tool that is able to handle inexact and incomplete inputs. Typically, at the beginning of a construction project, there are many holes in design that the architect fills in later. This program is a step up from the original MODEX that required more exact data. It also uses expertise input by humans to rationalize the use of PPMOF. Neuromodex extends beyond basic known facts and exercises higher level reasoning. However, the program is still not aware of the rules that motivate its decision-making.

In 2000, a prefabrication study was conducted to see how many industry members used either MODEX or Neuromodex as a decision tool for modularization. The results of surveying 29 construction professionals showed that the use of these two computer programs has increased from 14% to 27% over the past 15 years. The areas of significant growth included equipment, instrumentation, ironwork, mechanical piping, and structural assembly. The survey determined that the top driving factors for PPMOF were cost, schedule, and workforce issues like lack of labor. Some of the barriers to prefabrication were additional planning, increased transportation difficulties, greater inflexibility, and more advanced procurement requirements.

CII Decision Guide

In order to successfully implement prefabrication on a project, managers need a clear and decisive method for analysis, and a team of two researchers, Cigolini and Casteliano (CII), have been collaborating since 2002 to develop the following evaluation model. It looks at the cost variance between stick-built and modular construction and tries to bridge the gap between the economic analysis of MODEX and the actual estimation process.

To come to a conclusion, CII visited nine industrial sites and were able to identify several commonalities between all nine projects. One was that prefabrication complexity determines decision timing. If the entire project is being modularized, precise decisions had to be made during pre-project planning. If less critical prefabricated elements were to be used, decisions could wait until the detailed design phase. Most of the companies took advantage of weekly meetings between disciplines to ensure proper communication.

Analysis of labor differentials associated with moving the activity from field to factory were also considered. Managers examined differences in wage rates, productivity, project risk, equipment, and overhead costs related to labor.

Finally, transportation was another major issue that was investigated for prefabrication. One company maintained a specific department that dealt with transportation planning. Another company required that prefabricated products be tested before they are shipped to ensure they can withstand the stresses of travelling.

I was interested to learn that these nine companies considered prefabrication a form of outsourcing, or sending work to a separate location where it can be accomplished best and cheapest due to economies of scale. I usually identify outsourcing as sending work overseas to be completed. But outsourcing exists within the United States as well. I think there are many advantages to this, some being promoting homeland economic growth and lowering shipping costs.

The figure below shows a decision framework chart to help industry members think completely through the prefabrication design process. Levels I and II are meant to walk managers through primary drivers and roadblocks to prefabrication. Strategic I is a business planning screening tool that evaluates the feasibility of PPMOF. Level II is to be used during pre-project planning and assumes more project knowledge like site location, labor, permitting, and infrastructure can be provided. The Tactical Level Analysis is the final level that focuses on the bottom line: cost. It is recommended that this step be performed during the conceptual design phase when quantities are known.

Activity	Project Life Cycle Through Construction				
	Business planning	Conceptual planning	Conceptual design[a]	Detailed design[b]	Construction
1. Complete Strategic Level I analysis	◆				
2. Accumulate preliminary information including plot plan, flow sheets, and equipment lists	▬	▬			
3. Complete Strategic Level II analysis		◆			
4. Develop alternatives for PPMOF use		▬	▬		
5. Complete Tactical Level analysis (I)[c]			◆		
6. Refine estimate and quantities			▬	▬	
7. Complete Tactical Level analysis (II)[d]				◆	

[a] At start of conceptual design: estimate approximately ±30%, project team has plot plan, flow sheets, and equipment lists
[b] At start of detailed design: estimate approximately ±10%, quantities determined
[c] For decisions on level of modularization and complex preassembly
[d] For decisions on level of simple preassembly and prefabrication

Decision timing map for prefabrication, preassembly, modularization, and off-site fabrication

The extent to which the decision framework must be used depends a lot on the company and how much they want to justify PPMOF use. The nice thing about this guide is that it can be utilized to the extreme or as a precursory analysis of prefabrication.

The evaluation tools designed by the CII team allow managers to rank the relative importance of various factors such as cost, schedule, safety, design, and transportation. An example of Levels I and II are shown below.

Decision Support for
Prefabrication, Preassembly, Modularization, and Off-site Fabrication

Strategic Level I Evaluation Evaluation Date:

Project Name: Evaluator:

Answer questions based on knowledge of the project under consideration. Follow the interpretation and save the results for later use, as they can be combined with the results of later evaluations for the final decisions regarding PPMOF.

Section	Question	Impact on PPMOF
Schedule	Are their significant constraints or requirements for the project schedule? PPMOF may help to meet schedule constraints such as outage duration and time to market or decision needs.	Yes Maybe No
Labor	Is there a lack of good local labor available in the project area? PPMOF may help by moving work to areas with adequate labor.	Yes Maybe No
Safety	Is there an opportunity to decrease safety risks by using PPMOF? PPMOF may be able to relocate work to less hazardous environments such as ground level or controlled climates.	Yes Maybe No
Environmental, Legal and Regulatory	Are there significant environmental, legal and/or regulatory considerations that may constrain the project? PPMOF may help to alleviate constraints by allowing parallel work while such issues are handled.	Yes Maybe No
Site Attributes	Are there significant site attributes such as extreme weather or lack of infrastructure that may impact project performance? PPMOF can potentially relocate work to more favorable conditions.	Yes Maybe No
Site Access	Do available routes and lifting paths allow using modules with the dimensions set by truck, rail, or barge shipment? Using the largest possible modules increases the benefits of PPMOF.	Yes Maybe No

Strategic Level I Evaluation

CII Strategic Decision Tool for PPMOF
(Prefabrication, Preassembly, Modularization, and Off-site Fabrication)

Reports of Extremes for Strategic Level II Evaluation

Project Name:	Fill out on Welcome page	**Data Date:**	Fill out on Welcome page
Evaluator:	Fill out on Welcome page	**Evaluation Date:**	June 19, 2002

Factors Most Strongly Supporting PPMOF

Rank	Raw Score	Weighted Score	Factor	Category	Question No.
1	5	1.00	Shortened schedules	Schedule	1
1	5	1.00	Timing of environmental or other project permitting	Schedule	5
2	5	0.60	Local, regional, or national labor availability	Labor	3
3	5	0.40	Reductions in insurance costs	Safety	6
3	5	0.40	Requirement for early "freezing" of design	Design	2
3	2	0.40	Late business decisions	Schedule	3
3	2	0.40	Early startup benefits	Schedule	4
3	2	0.40	Rewards for early project completion	Schedule	9
4	2	0.32	Requirements to meet new regulatory or other imposed requirements	Cost	3
4	2	0.32	Future reuse value	Cost	4

To save and print your evaluation results, please go to the Final Score (Summary) sheet and press the "Save" and "Print" buttons. | **Final Score** | **Final Score Interpretation**

Strategic Level II Evaluation

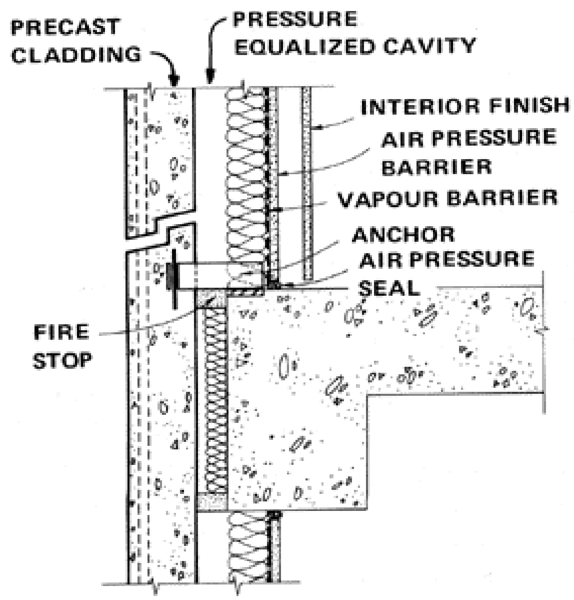
The CII tool seems to be a very practical and useful aid for managers because it facilitates a design process dialogue between all disciplines, forces people to prioritize their decisions, is easily maintained, and clearly identifies the supporting and deterring factors to introducing PPMOF on a given project.

PRECAST BRICK PANELS

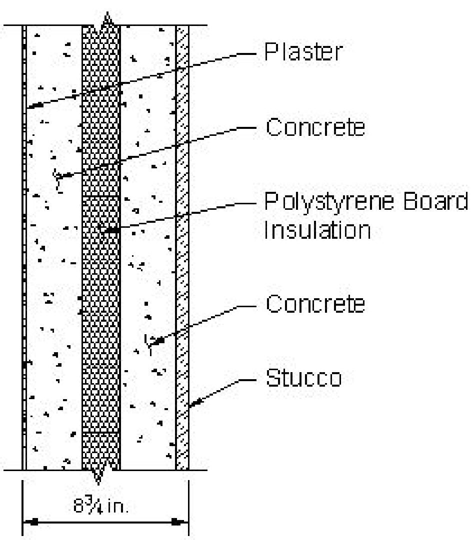
Rising material, fuel, and labor costs drive the market toward prefabrication. Precast façade panels allow for faster, more economical construction and can be constructed year round, as opposed to the temperature-sensitive concrete that is delayed in extreme weather conditions. Precast panels sometimes allow for a reduction in the structural system—smaller beams and columns— because panels are lightweight. The precast panel industry has come a long way from 'standard vanilla.' Panels can be highly customized with a multitude of exterior finishes, pre-installed windows, and pre-finished interiors.

Precast concrete brick panels are a new technology that the construction industry is embracing today. Some of their benefits include superior strength and durability, design flexibility, aesthetic diversity, minimal site impact, faster construction time, and reduced life cycle costs. There are four main types of precast panels: curtain walls, load-bearing wall units, shear walls, and formwork.

Many precast concrete panels consist of a reinforced concrete panel with brick facing. They are connected to the structure via clips or angles embedded in the concrete slab or welded to steel beams. The downside to this type of precast is that insulation and moisture protection is still required behind the panels. Installation of these elements can be difficult when trades are faced with hard-to-reach spaces.

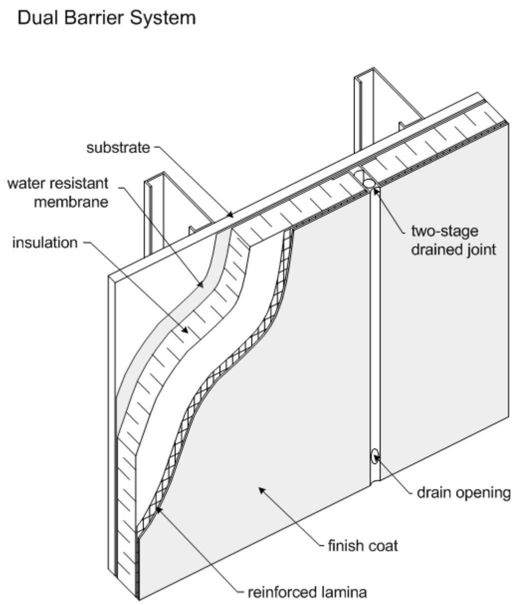


Precast Concrete Panel



Sandwich Panel

Sandwich panels are another option. This precast system consists of closed cell insulation between two concrete panels. They do not have much better thermal properties than traditional precast panels because the layer of insulation is so thin. Thermal performance of a wall system depends primarily on the thickness and density of insulation placed in the wall cavity. The thicker the insulation, the better the thermal properties. These panels are popular in construction because they come with pre-finished interiors. The downside to this is that the contractor must take extra care not to damage the drywall while placing the panel.



EIFS Dual System Barrier

Similar to sandwich panels is EIFS (Exterior Insulating Finishing System), a synthetic stucco panel system that relies primarily on its outermost layer to protect against moisture penetration. A typical panel is composed of polymer based synthetic stucco on top of expanded polystyrene insulation board on top of plywood sheathing. This very thin and lightweight panel attracts buyers to the product. For EIFS to be effective, all of the water must be stopped at the exterior surface, and this is hardly ever the case. The diagram shows a more sophisticated EIFS system that provides more safeguards against thermal and moisture penetration.

Prefabricated Whole Brick Panels

As has been discussed at the PACE conference, in classes, and in research, there is a lack of skilled labor in the construction industry today. Whether through subliminal messaging from the media or the influence of teachers and parents, young people no longer view construction work as a "good job." Physical labor is viewed as grunt work. People who are uninterested in attending college are turning to technical institutes to acquire the certification to manage construction work in a shorter time frame than a typical 4 year university. The industry is getting to a point where there are too many people managing work but not enough people actually performing the work. These two sides of construction are equally important, but there is certainly more emphasis on the management side. Industry is suffering greatly from the lack of skilled labor.

Prefabricated whole brick panels are one innovation present in very few places in the United States. Basically, these brick panels are hand laid at off-site location using clay bricks and mortar. They have every resemblance to stick built brick façade, except they require structural support to hang them on the building.

It was interesting to learn the logistics of how these panels operate. The panel is hung from a connector near the top. Since the lower portion is in tension, the panel behaves as a beam and supports its own weight. The panels are designed as reinforced masonry. Reinforcement is installed in both directions, and a typical panel is about 7 feet high by 3- feet long.

Similar to laid-in-place brick, brick panel walls are not insulated. Manufacturers recommend a full back-up system including a vapor seal. Completed brick panels are washed and damp proofed with a clear water-repellant coating.

I see great potential in this construction technique and so do some industry professionals. I spoke with an engineer at KPFF in Seattle, Washington, who has been designing these systems for several years. He says that he sees a future for prefabricated brick, but unfortunately, manufacturers are not catching on. Vet-O-Vitz is a company based in Ohio that fabricated these panels for a while, but, due to a lack of sufficient demand, they have gone out of business. So, there must be a joint effort between designers and suppliers to implement these panels. Construction managers need to suggest these products to inexperienced owners and get the word out about whole brick panels.

Whole brick panels have some benefits over precast concrete thin brick panels. Since these panels are built by hand in controlled environments, the quality of construction is much higher. Custom formwork does not drive up the cost of production, and the mason has much more freedom of design. Also, these whole brick panels look and feel like 'real' hand laid brick. It is the next best thing to site-constructed brick facades, and to some owners, authenticity is of utmost importance. Thermal and acoustical properties are not compromised; the whole brick panels are even more massive than hand-laid due to their structural reinforcing. Another major advantage to using any kind of prefabricated building skin is the elimination of scaffolding to construct the façade. This saves the owner a great deal of money and eliminates the insurance risks associated with masons working hundreds of feet in the air.

In a paper published in 1999, Fred Galassi of Barkshire Panels Systems states that their competition is not laid in place brick, but other skin systems like metal or precast. He explains that whole brick panels are usually less expensive than precast systems, but more expensive than hand-laid brick. I think prefabricated whole brick panels could be a viable construction option if there were an increase in manufacturers across the US and an influx of skilled factory workers to erect the panels.

The Future of Prefabrication

In a highly automated time, construction is one industry that makes little use of technological advances when it comes to the equipment used onsite. The methods used to construct a brick wall are essentially the same as they were 6,000 years ago. The managerial side sees improvements like savvy computer programs to assist with scheduling and coordinating tasks, but the field staff lives in a different world. Some subcontractors are living in a time where hand-drawn plans are the norm while general contracting firms are working form cutting edge building information models. So when will we see some advancement in the labor force?

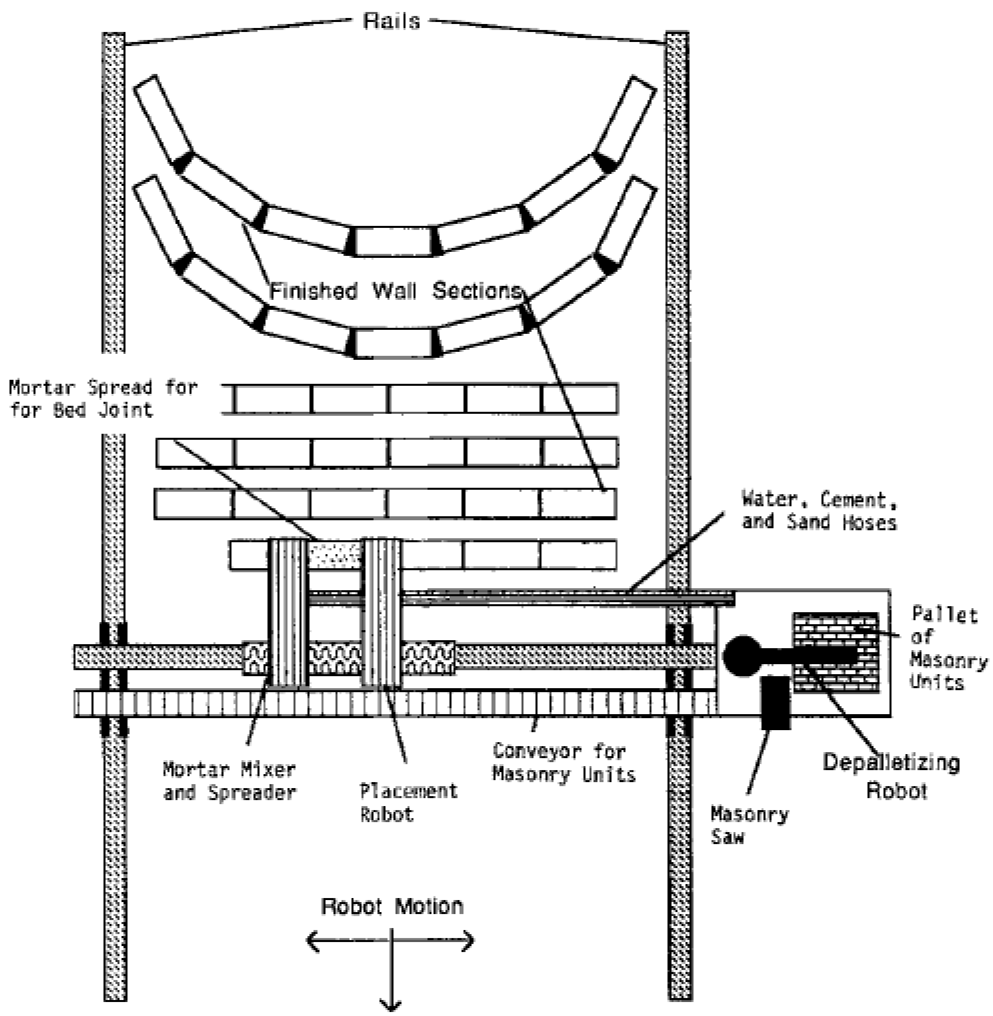
Another problem with field labor is the lack of skilled workers. I remember my summer internship from two years ago. We had a lot of people onsite, but only a select few actually knew what they were doing. It slowed down production so much and posed a dangerous situation because many of the workers were unaware of safe work practices. They operated on a 'do as you're told' basis. Otherwise they stood around waiting for orders. If everyone on a jobsite were a skilled worker, tasks would get done a lot quicker, safer, and with higher quality.

One area that is currently under investigation for the future of prefabricated brick technology is the use of robots to construct brick panels in a controlled environment. In a case study titled "Prototype Robotic Masonry System," the authors consider masonry to be a good candidate for robotization because it is tedious, unpleasant, physically demanding and critical to finishing projects on time. One automated system was explored by Anliker in 1988. He detailed a semi-automatic machine that can construct walls up to 8 feet long. The $80,000 system required the help of two men and could produce 30-35 square meters of wall sections per day. Later in 1989, scientist Lehtinen et al. determined that a masonry robot could be built for approximately $330,000 with an estimated payback period of 6 years. To date, no fully automated masonry system has been built and tested in the United States.

A research team at the University of Maryland is attempting to produce a prototype bricklayer that could be integrated into a flexible manufacturing system (FMS). An FMS is defined as an automated production system that is capable of producing a range of products with minimal manual intervention. The team has broken masonry construction into six main processes:

1. Preparation of mortar
2. Preparation of units
3. Delivery of mortar
4. Delivery of units
5. Spreading of mortar
6. Laying of unit

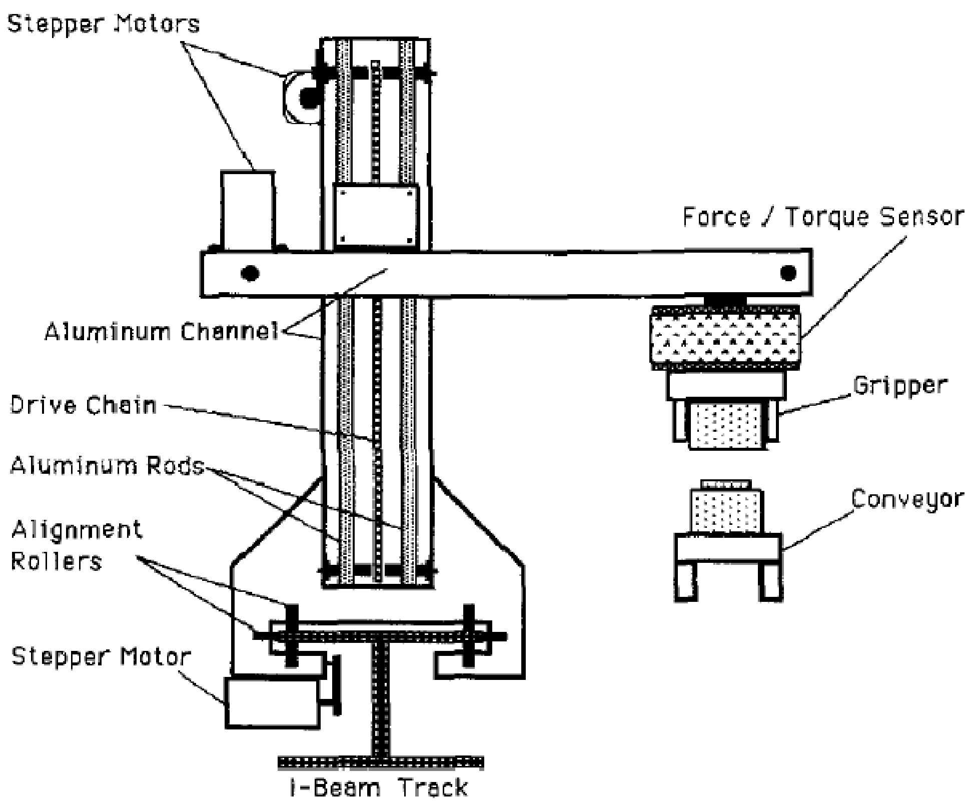
The figure below demonstrates a proposed system of a semi-fixed production unit. The basic framework is a gantry arrangement that moves back and forth on rails. The work center at the end of the frame cuts and places masonry units on a conveyor belt that transports them to the placement center in the middle of the figure. The placement cells contain the mortar mixer, spreader, and laying robot. The gantry can move in both horizontal and vertical planes so that it can reach all points of the wall for placement. It also has some rotational movement to account for inaccuracies. Water, sand, and cement are delivered to the mixer beside the robot through hoses. The mortar is mixed and spread on demand, eliminating problems with expired mortar mixes or clogged hoses.



General concept for robotic masonry system

Extensive testing revealed that the robot's placement was fairly accurate with a standard deviation of 0.055 inches. The Initial Rate of Absorption tests showed that the bricks had fewer pores which means less surface area for mechanical bonding of bricks. To remedy this, greater force must be applied when placing bricks. The mortar spreader produced uniform beds of mortar, although some clumping problems persisted in the spreader head. The bond strength results further proved that the bricks were not placed with enough force to properly adhere to the mortar. The placement method needs to be revised.

One aspect of the brick robot system that was not researched by the Maryland team but is critical to the success of the prototype is the interface between computer systems. The programmability of the machine will determine its effectiveness and conformance to standards.



Brick-Laying Workstation

The brick robot is an emerging technology that could revolutionize brick-laying and certainly address the issue of a dwindling work force. Although not such a popular research topic today, I can see how this unconventional technology could take flight in the future, especially if used to produce the whole brick panels mentioned in the previous section.

Conclusion

This depth study has identified some driving factors for prefabrication to be cost, schedule, and workforce issues. Some of the barriers to prefabrication were additional planning, transportation difficulties, design inflexibility, and more advanced procurement requirements. I think it is important to note that while software programs can crunch numbers faster than people, the decision to use prefabrication on a project is usually best made by a human. A computer cannot be taught common sense and basic instincts. I do think that the CII structure simplifies the thinking process and prioritizes the owner's requests.

In my quest for a panelized brick system I found the whole brick panels to be a unique product. I heard of one project that utilized a system similar to this, but it is obviously not a widespread industry practice. I see this as such an innovation for the construction world. Quality and authenticity can coexist with low cost and schedule time. I almost selected these panels for my Analysis 1, but decided against the idea when I discovered the closest manufacturer of these panels is in Ohio.

The brick robot may seem a bit far-fetched, but I completely agree with the researchers that in a highly automated time, construction lags behind the technology curve. The brick-laying process is a tedious and physically taxing activity that often results in worker injury. If robots can accomplish the same task and eliminate that risk, I am all for it. Skilled masons would still be hired for complex masonry work, but the monotonous and repetitive sections could be handled by machines.

Analysis 1: Slenderwall Panel Implementation

Problem Statement

Wisconsin Place is a project faced with many constraints including time, money, resources, and space. The site is extremely crowded already, and some of the concurrent projects have yet to begin. Conditions will only worsen as time wears on. Turner and all subcontractors onsite could benefit greatly by simplifying the building process in as many ways as possible.

Goals

It is my goal through this analysis to simplify the construction of the façade by limiting the number of trades that need access to it. The intent is to reduce the amount of trades working in one space and to accelerate the schedule. Potential cost savings exist in the shortened project timeline as well as the removal of the masonry hoist and scaffolding from the project scope. This analysis will also address structural design considerations, specifically reducing the exterior loads and connection to the post-tensioned slabs. Finally, thermal performance is a predominant concern whenever precast is introduced to the façade. A governing factor in the selection of a panelized system will be its resistance to the elements. Overall, superior quality, productivity and performance can result from the implementation of precast panels. It is just a matter of selecting the appropriate system for the project.

Research Steps

1. Research precast systems and determine the most relevant one for this project.
2. Calculate the load associated with prefabricated panels.
3. Design the panel to slab connection detail.
4. Create a site layout plan to allocate a holding space for the panels.
5. Modify the schedule to show time savings.
6. Modify the budget to show the cost differential.
7. Determine constructability issues associated w/ prefabrication.
8. Determine thermal load differential between the existing and proposed systems.
9. Calculate the costs associated with crane, scaffolding, and hoist usage.
10. Make recommendation of proceeding with precast system.

Tools

1. RS Means 2008 Edition
2. Smith-Midland Corporation – Slenderwall Manufacturer
3. PCI Code

4. Turner GMP Budget
5. AISC Steel Construction manual
6. Whole Building Design Guide

Expected Outcome

I think that the schedule can be greatly reduced by using precast brick panels for the exterior cladding. This could eliminate the need for a material hoist and scaffolding. In turn, it will increase the demand on the crane. I expect to see a cost increase in selecting a precast system over a stick-built one, but hope to find savings in other areas like hoist and scaffolding removal. Coordination will become a more critical issue. The panels will need to be delivered to site in the order they are to be erected, and they may need a staging area. I plan to address this by developing a site layout plan that will allocate material storage areas and delivery routes.

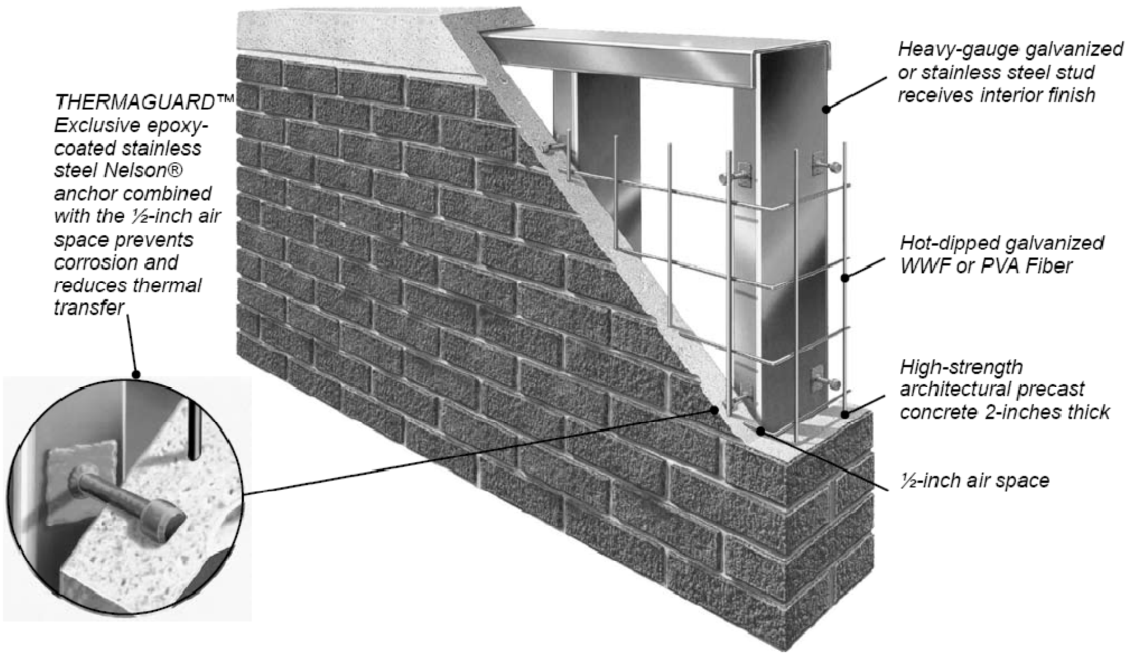
Product Information

After researching many different precast systems I have selected Smith-Midland's Slenderwall® panel system. I found this system to be very unique and even cutting edge. Their website contained extensive literature on the product, leading me to believe that it has been thoroughly tested and proven to be an effective façade system.

Slenderwall® is comprised of a 16 gauge 6 inch galvanized steel studs on 2 foot centers. The outer layers of the panel include a 2 inch concrete facing. A ½ inch air space separates the concrete and studs, reducing thermal transfer from the exterior to interior by up to 25%. These panels are self-supporting, and eliminate the need for exterior framing. In addition, they also eliminate the need for a material hoist and scaffolding, since they can be easily placed using the crane. Refer to the picture below for some of the key features.

SLENDERWALL®

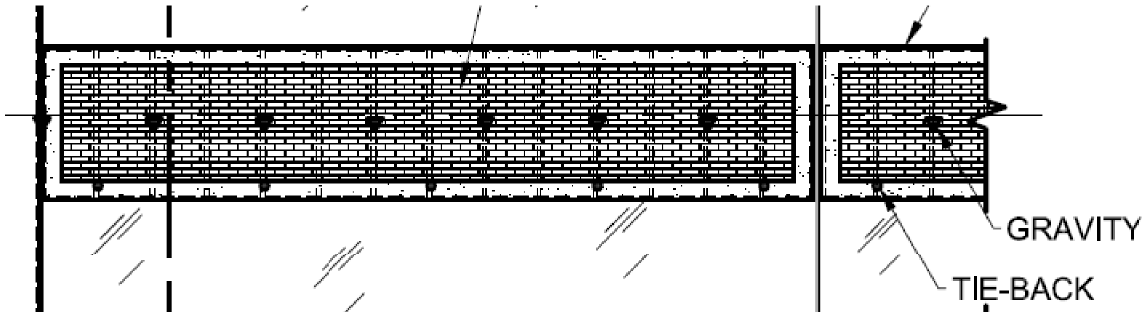
Architectural Precast Concrete/Steel Stud Building Panels



Slenderwall ® uses 5,000 psi concrete with galvanized wire mesh for reinforcing. An integral concrete admixture is incorporated to reduce water penetration. Smith-Midland has successfully completed more than 50 projects in 11 different states. The average panel size is 8 feet by 30 feet. A typical size is 10 feet by 30 feet. A Slenderwall® panel weighs around 30 pounds per square foot, significantly less than a conventional precast panel weighing 85 pounds per square foot. Both Slenderwall® and conventional precast panels must rely on a backup system of insulation and waterproofing, but Slenderwall ® incorporates the exterior studs into one panel. I was drawn to this system because it achieves my goal of consolidating the building envelope trades. EASI-SET Industries provides certified drawings that are reviewed and stamped by registered professional engineers.

Smith-Midland recommends consulting with the Hilti Company or STI, Inc. to achieve a typical 2 hour fire rating between floors. A piece of light gauge break metal provided and installed by the drywall contractor bridges the gap between the floor slab and the panel since it is mounted on the exterior of the slab, adding several inches to the perimeter of the slab. Smith-Midland also recommends that a mineral-wool fireproof material be installed in the gap between the slab and the precast.

The average lead time for these Slenderwall® panels is around 12 weeks from the start of shop drawings. Slenderwall® is installed by PCI-qualified erectors or professionals who have at least 5 years of experience installing Slenderwall®. The panels are attached to the perimeter of the building by gravity and lateral connections at the floor slab. Gravity connections are suggested to be spaced at 4 feet on center with lateral tie-backs at 6 feet on center. Slenderwall® attaches easily to other wall systems using expansion joints. The caulking contractor is responsible for sealing between the panels.



Vapor barriers can be applied by the HVAC contractor. They are applied to the heated side of the panels on the northeast side of the building between the frame and concrete. The R-value of Slenderwall® when assembled with 6 inches of batt insulation and drywall is R-21. The life of Slenderwall® panels is from 50-100 years. They are warranted for one year.

A foamed-in-place insulation is available with panel installation and acts as a thermal, moisture, and air barrier. It is pressure-sprayed into the wall cavity on top of the metal studs. Because it is sprayed in a semi-liquid state, it is able to fill even the smallest cracks of the panels, making the building envelope airtight. The liquid insulation expands and hardens to seal the building skin.

Slenderwall® won the National Precast Association's Creative Use of Precast Award for above ground precast in January 2008. Below are two featured projects that implemented the Slenderwall® product.

New Jersey Institute, Newark, NJ

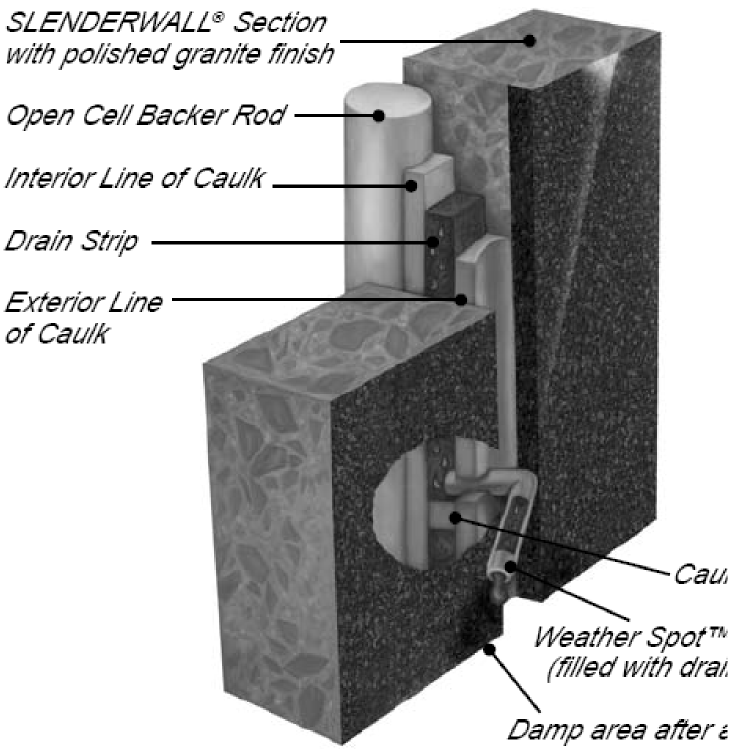
*Second Nature™ (Architectural Precast Concrete Brick)

Courthouse Metro Plaza, Arlington, VA

Design Considerations

Smith-Midland carefully addresses many design issues on their website. They use a DURAFLEX 360 precast to stud frame connection that allows 360°of movement to isolate the precast skin from structural stresses like wind loads, frame movement, expansion, contraction, and seismic shock. H_2OUT™ is a secondary drainage caulk joint leak detection system. If a caulk joint fails, the water exits the building and can be located within 20 feet of the leak.

THERMAGUARD™ is Smith-Midland's patented air barrier that consists of a ½ inch air space between the concrete and stud and the use of epoxy coated stainless steel Nelson anchors. The connection prevents corrosion and reduces thermal transfer by as much as 25%.

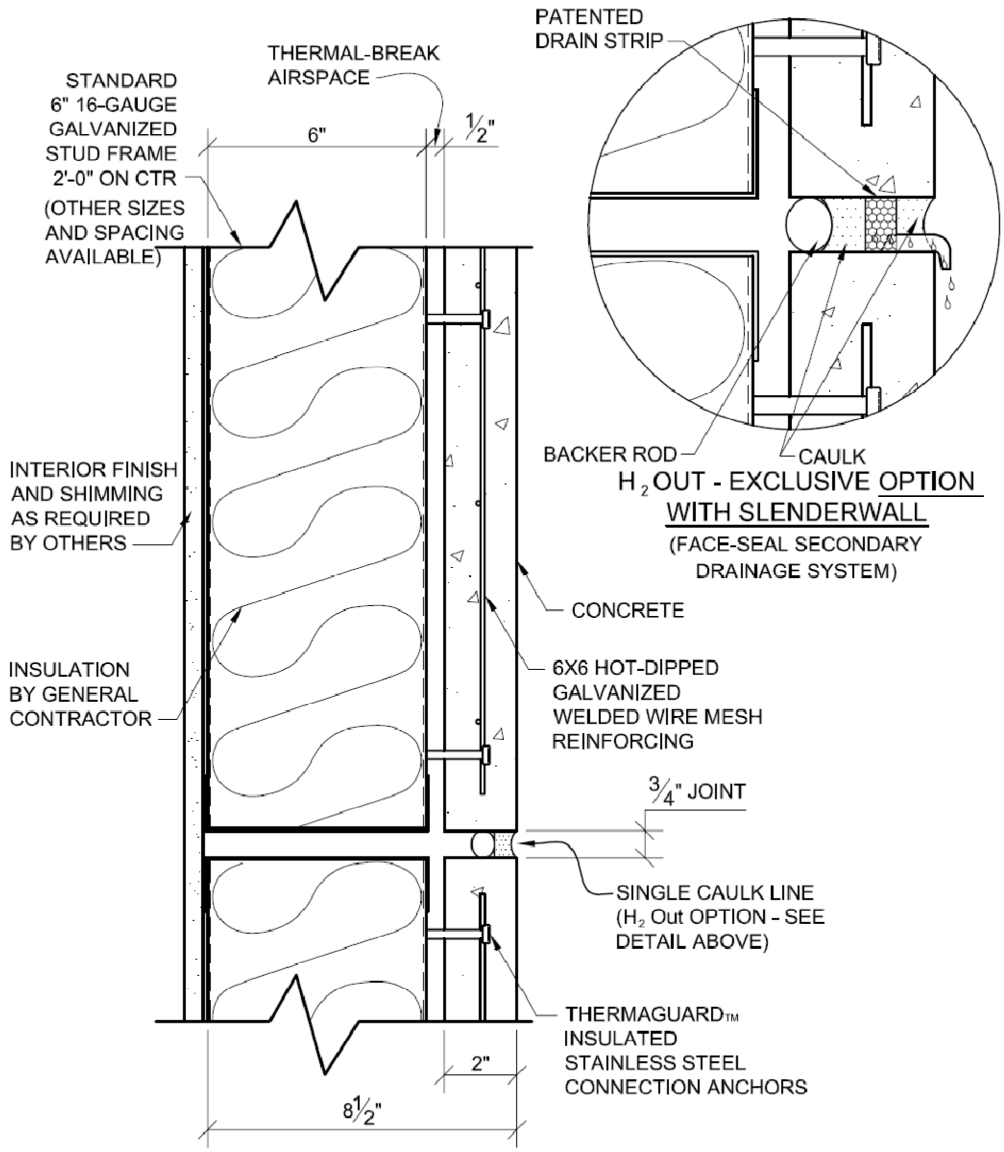


H_2Out™

DURAFLEX 360°™

Slenderwall® offers a foamed-in-place urethane continuous-insulation method that acts as an insulation, water, and air barrier. In hot and humid seasons, vapor tends to migrate from the exterior to the interior skin of a building. A closed-cell polyurethane insulation can be applied to the interior side of the concrete to remedy this issue. In cold seasons, vapor migrates in the opposite direction. To avoid this moisture problem, a layer of plastic can be installed over the light gauge steel studs on the interior before the drywall is installed.

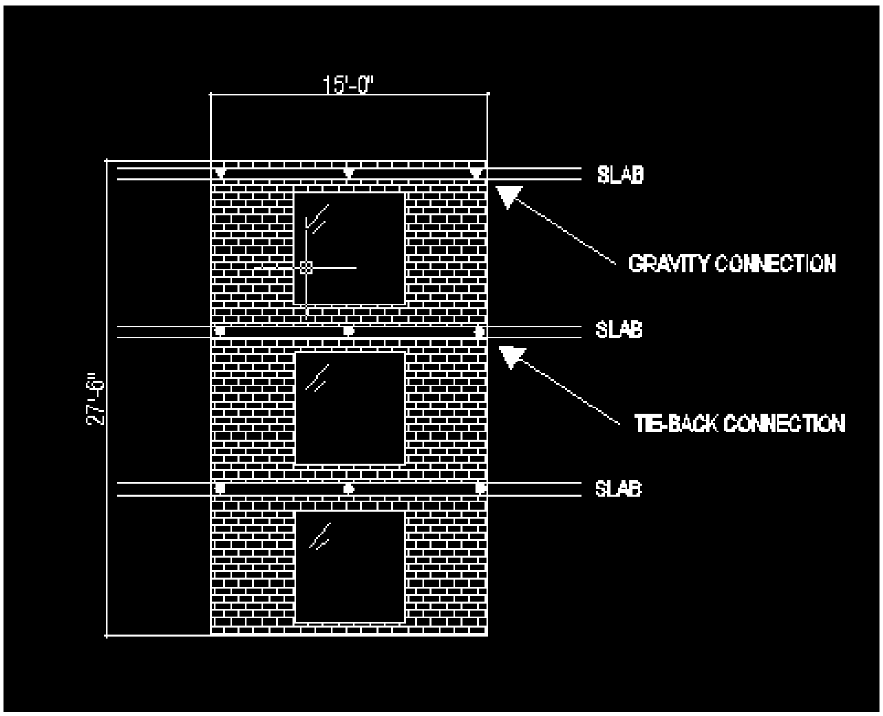
Slenderwall® panels can gain building owners LEED points due to energy savings and material selection. I was so impressed by this product because its manufacturers addressed all of the common concerns and have a solution for each. I think this stud and precast panel system will integrate well into the Wisconsin Place project, but I will save my recommendation for the end of the analysis.



TYPICAL SLENDERWALL SECTION

Structural Attachment Design

The figure below depicts the largest panel that will be used on the façade of Wisconsin Place. Note that gravity connections are only located at the topmost slab. The others are just tie-back connections to resist lateral loads like wind. The window openings will be cut out in the factory so that this is a solid piece.



Typical Panel Connection Design

15' x 27.5' vertical panel containing (3) 6' x 6' windows

Tributary Area = 10' x 27.5' = 275 SF

Gravity connections spaced at 5'

Point Load = 275 SF x 87.75 PSF = 24,131 lbs = 24.13 kips

1. Angle Design

Steel manual → Try L2.5" x 2.5" x 3/16"

Shear Yield = 29.2 k

Shear Rupture = 29.4 k

$A_n = 0.572\ in^2 > A_{e,min} = 0.552\ in^2$

$A_g = 0.9\ in^2 > A_{g,min} = 0.74\ in^2$

Shear Yield:

$A_g = 0.9 \text{ in}^2$

$\Phi P_n = 0.9F_yA_g = 0.9(36)(0.9) = 29.16 \text{ k}$

Shear Rupture:

$A_n = 0.572 \text{ in}^2$

Shear Lag Factor, u

X =0.687"

$U = 1 – x/L = 1 – (0.687/3) = 0.771$

$A_e = 0.771(0.572) =).441 \text{ in}^2$

$\Phi P_n = 0.75F_uA_e = 0.75(58)(0.441) = 19.18 \text{ k}$

Block Shear:

Tension: $A_{nt} = 0.762 \text{ in}^2$

$P_n = F_uA_{nt} = 58(0.762) = 44.18 \text{ k}$

Shear Yield: $A_{gv} = 1.5(3/16) = 0.281 \text{ in}^2$

$P_n = 0.6(36)(36)(0.281) = 6.07 \text{ k}$

Shear Rupture: $A_{nv} = [1.5 – 0.75(3/4 + 1/8)](3/16) = 0.158 \text{ in}^2$

$P_n = 0.6(58)(0.158) = 5.5 \text{ k}$

$\Phi R_n = 0.75(44.18 + 5.5) = 37.3 \text{ k}$ Block Shear

<u>2. Bolt Design</u>

Steel manual → 15.9 k/bolt for ¾" threaded

Shear: 24k/(15.9 k/bolt) → 2 bolts

Shear: 31.8 k

Bearing:

$L_c = 1.5 – 0.5(3/4 + 1/16) = 1.09" < 2d = 1.5"$

Tearout controls @ top bolt

$R_n = 1.2FuLct = 1.2(58)(1.09)(3/16) = 14.2 \text{ k/bolt}$

$L_c = 3 – (3/4 + 1/16) = 2.19" > 2d = 1.5"$

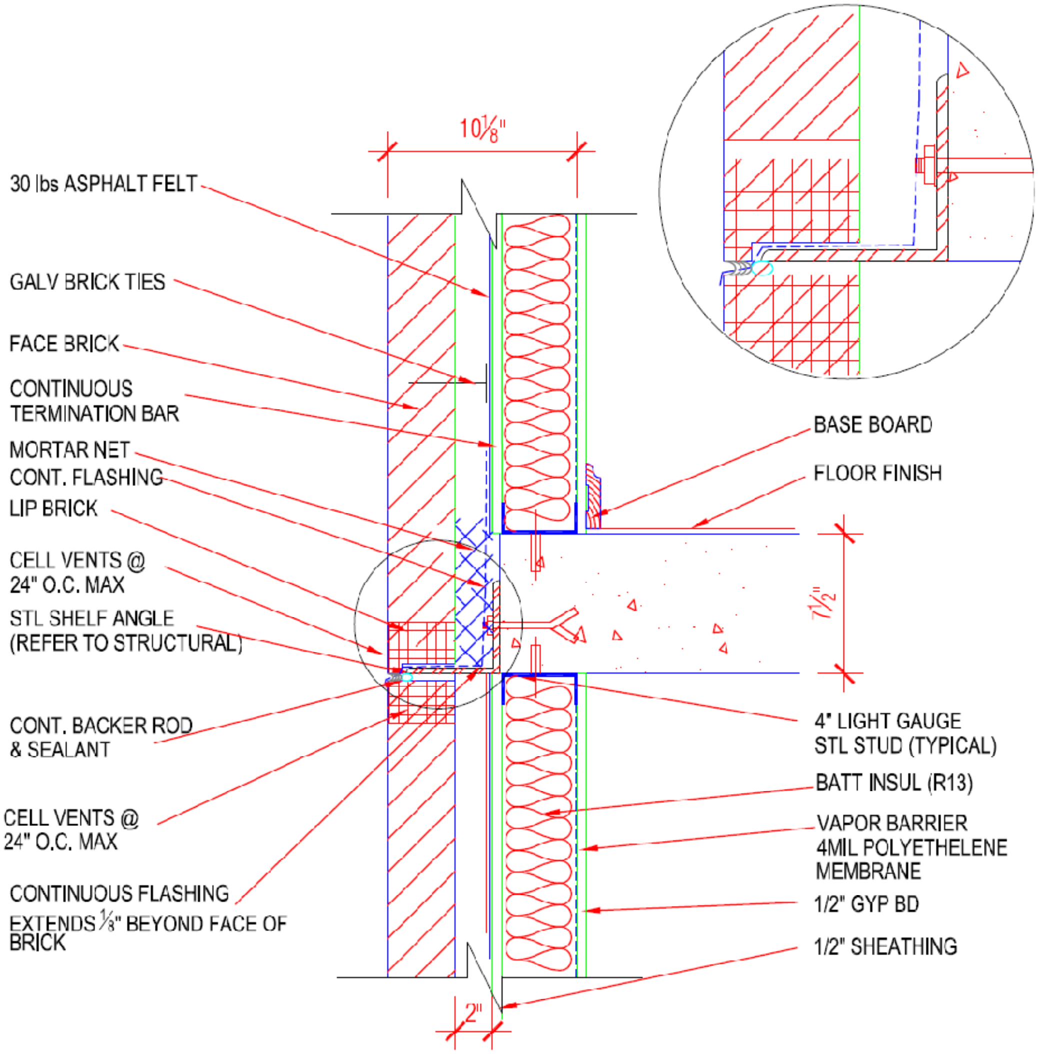
Tearout does not control at bottom bolt

$R_n = 2.4dtF_u = 2.4(3/4)(3/16)(58) = 19.6$ k/bolt

$\Phi R_n = 0.75(14.2 + 19.58) = 25.3 \text{ k} < 31.8 \text{ k}$ OK

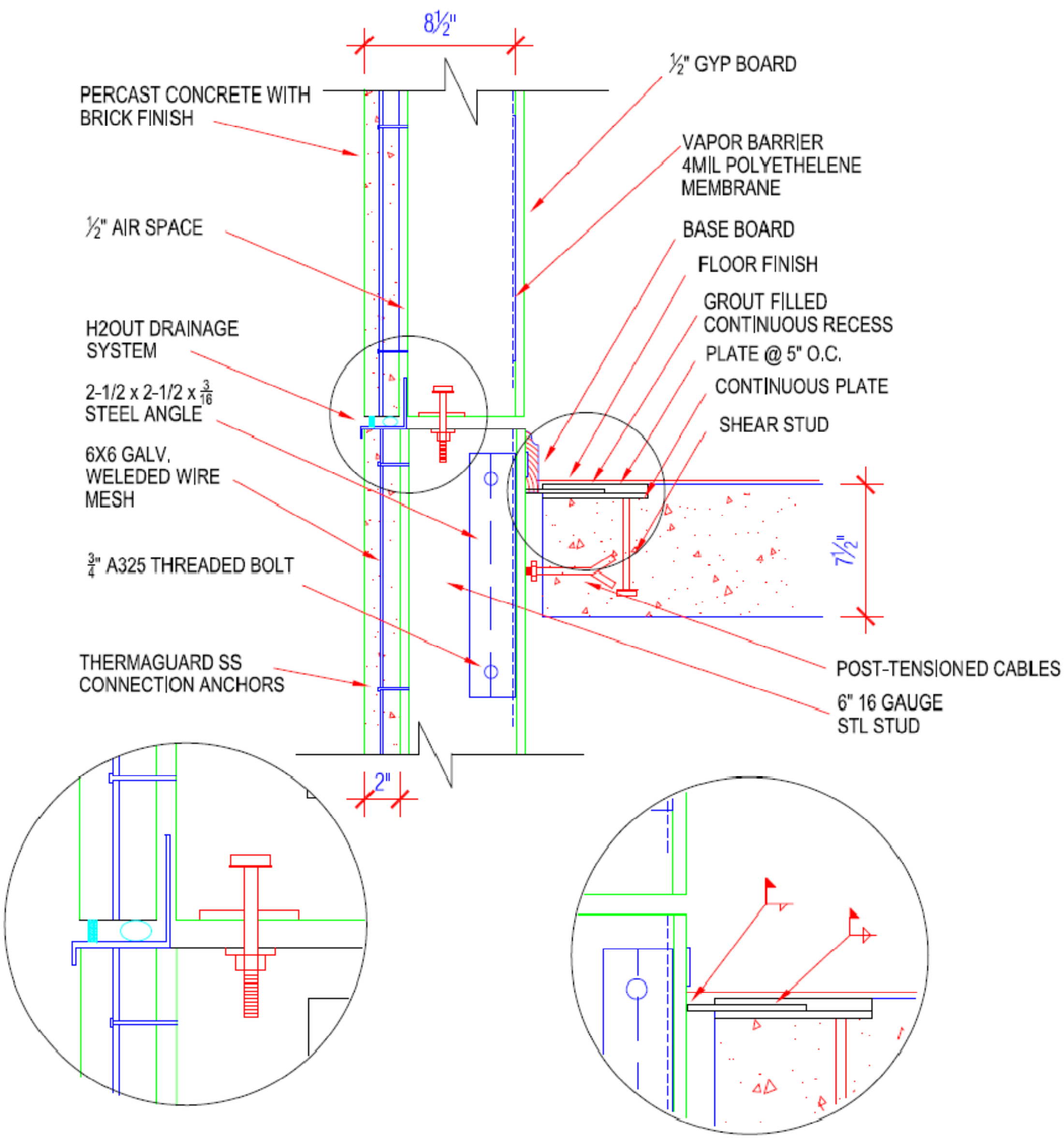
Connection Details

The following figures depict connection details as suggested by the manufacturer. The overall thickness of the typical brick and metal stud veneer is 10-1/8" while the Slenderwall® panel is only 8-1/2". Additional connection details can be found in Appendix B. One benefit to the Slenderwall® panels is that they are attached on the outside face of the slab, as opposed to the existing metal studs that are constructed on top of the slab. Hence, the Slenderwall® panels add approximately 6-8 inches to every apartment unit. All of the connection details can be found in Appendix B.



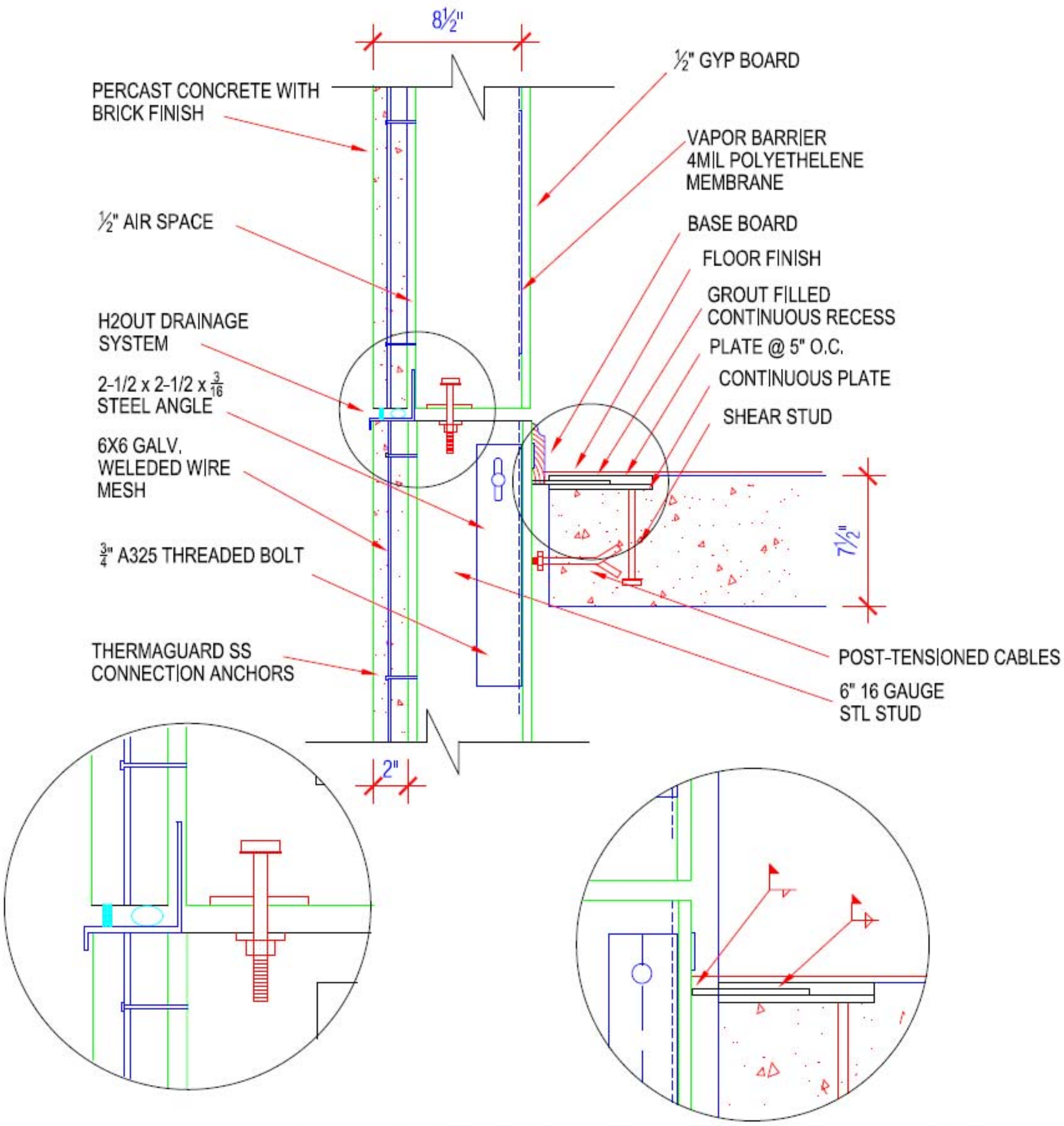
1 TYPICAL BRICK VENEER CONSTRUCTION

SCALE: 1 1/2"=1'-0"



2 TYPICAL PRECAST GRAVITY CONNECTION

SCALE: 1 1/2"=1'-0"



3 TYPICAL PRECAST TIE-BACK CONNECTION

SCALE: 1 1/2"=1'-0"

Building Load Analysis

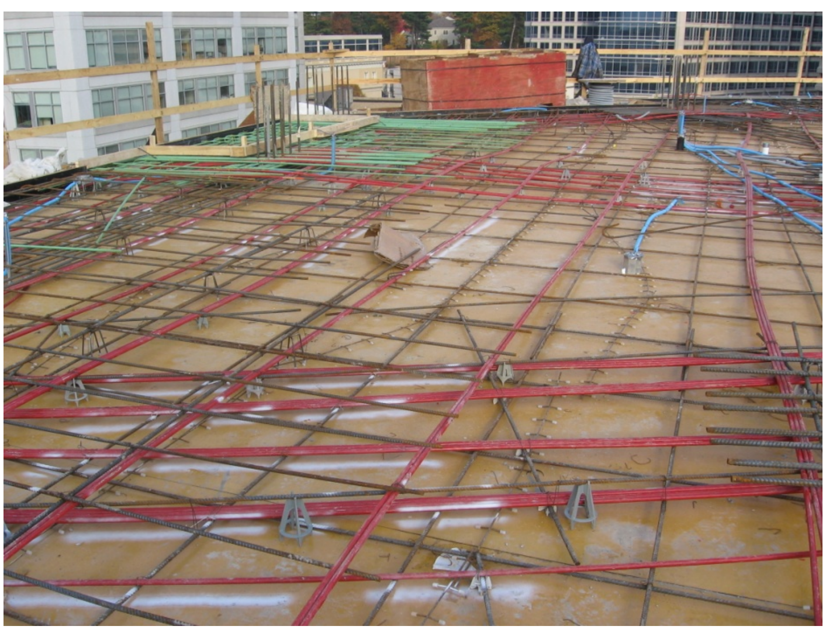
Existing System

Component	Weight (psf)
Gypsum Board	2
Steel Studs	18
Sheathing	50
Mortar	39
Brick	35
Total Weight	**144**

Proposed System

Component	Weight (psf)
Slenderwall Panel	30
Gypsum Board	2
Sheathing	50
Total Weight	**82**

Since the Slenderwall® system weighs about half of the existing brick veneer system, there will be no structural implications associated with changing to the alternate. Perhaps some structural modifications could be made. This would be an extremely difficult undertaking because the post-tensioned slab is already a slim 7-1/2" thick. If it were reduced to a smaller thickness I cannot guarantee that all of the tendons and conduits could be cast into it. Please refer to the picture below showing how many elements are embedded into the floor slab.



SCHEDULE REVIEW

Durations

System	Quantity	Unit	Daily Output	Days
Brick w/ Metal Studs	79208	SF	565	140.2
Slenderwall	79208	SF	2500	31.7
		Difference:		**108.5**

Day Reduction

The Slenderwall® brochure claims that each panel can be set by the crane in 20 minutes, but this does not account for adjustments and field welding. So to be conservative I said that a typical panel takes about 2 hours to fully erect. There are roughly 250 panels to be placed on the exterior. This brought me to a duration of 31.7 days. Remember that the Slenderwall® system is replacing both the brick veneer and metal studs, so I combined the schedule time of the two to attain a duration of about 7 months, or 140 days. The overall time savings from switching to the Slenderwall® system is 22 weeks.

CONSTRUCTABILITY REVIEW

According to the brochure, one Slenderwall® panel can be installed in 20 minutes thanks to the Lift-and-Release system. This means that the panel can be plumbed and aligned after the crane has unhooked using a turn-of-nut connection. Welds are completed after the panel is aligned. I have made the inference that the installation of one panel takes approximately 2 hours. The crane will be needed only for those first 20 minutes, however. Basing my calculations off of this piece of information and the estimated 250 panels that must be attached to the exterior, the added crane usage time due to the Slenderwall® system is:

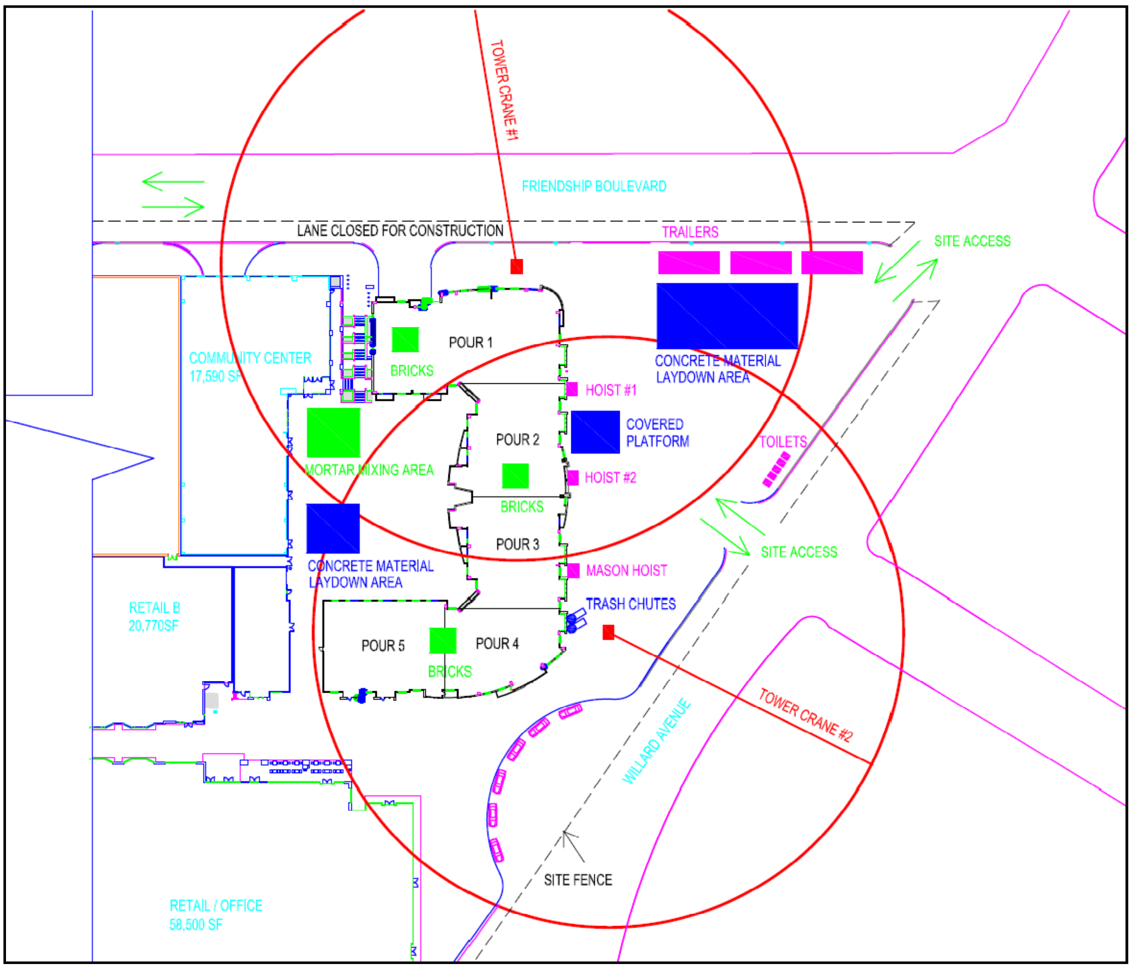
250 panels x .333 hours/panel = **83.33 hours of crane operation**

The schedule above shows that it will take roughly 32 days to place the Slenderwall® panels, not including the waterproofing, insulation, and interior drywall. The crane usage per day during this period is:

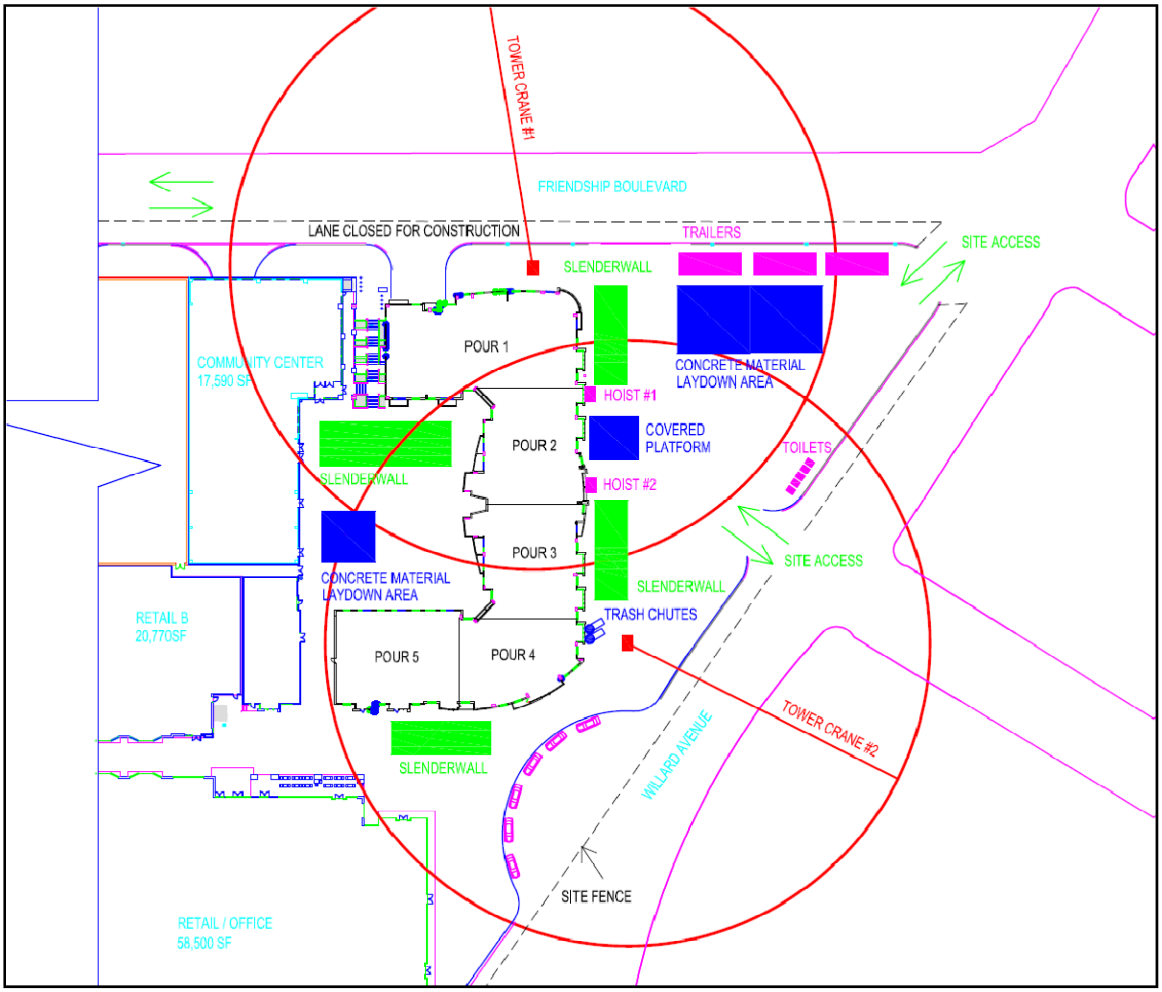
83.33 hours/32 day duration = **2.6 hours/day of crane operation**

This will be a coordination issue to discuss with the other subcontractors on site, especially since the concrete structure will be going up as the panels begin to be attached. If a crane usage schedule can be developed by Turner and the subcontractors this situation could have a favorable result. Maybe the concrete crew will spend the morning forming columns and slab and pour in the afternoon. This way the crane will be free to place panels as the pump truck places concrete.

The two figures below show a comparison between the existing superstructure layout plan and the proposed superstructure layout plan. It is worth noting that standard bricks must be either pre-loaded onto the building floors or kept on a covered elevated platform outdoors to shield them from moisture. If wet bricks are placed in mortar the excess water prevents it from curing properly, a detrimental effect on the assembly's overall strength. The Slenderwall® panels can be stored outside as long as they are protected from physical injury. They connect via plates and angles that are bolted and welded. The Slenderwall® panels will require more laydown area, but they are a pick and place material that will go quickly. Also note that there is no longer a need for the masonry hoist.



Existing Superstructure Layout Plan



Proposed Superstructure Layout Plan

Thermal Analysis

Another deciding factor in the recommendation of a cladding system is the thermal performance of the Slenderwall® panels compared to the existing stick-built brick veneer. I initially thought the hand-laid brick system would be more sound because there are not joints in the façade. After reviewing Slenderwall® literature and all of the additional insulating products they offer, my thinking changed. The following charts calculate the R-values for the existing and proposed systems. Remember that a higher R-value means greater resistance to heat transfer, whether from the inside to outside in winter or the outside to inside in summer.

Existing System

Component	Thickness (inches)	Unit R-Value	Unit	Total R-Value
Inside air layer	N/A	0.68	ea	0.68
Gypsum board	0.5	0.45	ea	0.45
R-13 insulation	4	13	ea	13
Sheathing	0.5	1.09	ea	1.09
Asphalt felt	N/A	0.12	ea	0.12
Air gap	2	1.68	inch	3.36
Standard 4" brick	4	0.44	ea	0.44
Outside air layer	N/A	0.17	ea	0.17
Total Thickness	**11**	**R-Value**	hr-sf-F/BTU	**19.31**
		U-Value	BTU/hr-sf-F	**0.0518**

Proposed System

Component	Thickness (inches)	Unit R-Value	Unit	Total R-Value
Inside air layer	N/A	0.68	ea	0.68
Gypsum board	0.5	0.45	ea	0.45
Vapor barrier	N/A	0.12	ea	0.12
R-13 insulation	6	13	ea	13
Air gap	0.5	1.68	inch	0.84
Foamed-in-place insulation	0.5	6.25	inch	3.125
Concrete w/ admixtures	2	2.615	ea	2.615
Outside air layer	N/A	0.17	ea	0.17
Total Thickness	**9.5**	**R-Value**	hr-sf-F/BTU	**21**
		U-Value	BTU/hr-sf-F	**0.0476**

Using the U-values calculated above, the overall heat gain and loss can be computed for Wisconsin Place.

Summer Heating Loads: To = 90F, Ti = 75F

ΔT = 15F

Summer Heat Gain

System	Area (SF)	U-Value	ΔT (°F)	Heat Gain (BTU/hr)
Standard Brick	79208	0.0518	15	61544.616
Slenderwall Panels	79208	0.0476	15	56554.512
			Difference	**4990.104**
				8.11%

Reduction of Heat Gain

Winter Cooling Loads: To = 15F, Ti = 70F

ΔT = 55F

Winter Heat Loss

System	Area (SF)	U-Value	ΔT (°F)	Heat Loss (BTU/hr)	
Standard Brick	79208	0.0518	55	225663.592	
Slenderwall Panels	79208	0.0476	55	207366.544	
			Difference	18297.048	
				8.11%	Reduction of Heat Loss

In the category of thermal resistance, Slenderwall® appears to be a winning choice. Even a small difference in heat transfer can mean big savings in electric bills and possible reduction of the size of mechanical equipment.

Budget Review

Wall System Cost Comparison

System	Quantity	Unit	Cost/SF	Total Cost	
Brick w/ Metal Studs	79208	SF	$35	$2,772,280	
Slenderwall	79208	SF	$50	$3,960,400	
		Difference		$1,188,120	
				42.86%	Increase in Cost

At first glance, the Slenderwall® panels cost about $1 million more than the standard brick, but they have many benefits. Since the exterior studs are incorporated into the panels, that eliminates the need for an exterior framing subcontractor altogether, further simplifying the building enclosure. So, when figuring out the schedule savings, I also accounted for the exterior framing timeline as well, bringing the existing system of brick with metal studs to 7 month duration. The crane will need to be rented for two months to place these panels because they charge on a monthly basis and it takes a little over 1 month to erect all of the panels.

Scaffolding Cost

Cost	Unit	Surface Area	Total Cost
$252	SFCA	2700	$680,400

Tower Crane Cost

Cost	Unit	Rental Period	Total Cost
$35,200	month	10	$352,000
			x 2 cranes
		Total Rental Cost:	$704,000

Masonry Hoist Cost

Cost	Unit	Rental Period	Total Cost
$4,775	month	10	$47,750

Taking all of these factors into consideration, I developed the following chart that details all of the costs and savings that go along with the Slenderwall® panel implementation. The Slenderwall® cost differential is the added cost of changing to a new system. The 2 month crane rental is another cost that is incurred from the change. Some savings include the elimination of scaffolding, the masonry hoist, and the exterior framing contract. In total, this replacement looks like it will turn out to be an economical choice after all.

Costs	
Slenderwall Cost Differential	$1,188,120
Crane Usage (2 months)	$70,400
Total Cost	**$1,258,520**
Savings	
Scaffolding Removal	$680,400
Hoist Removal	$47,750
Cancel Ext. Framing Contract	$1,940,000
Total Savings	**$2,668,150**

The **net amount of money saved** by implementing the Slenderwall® system is:

$2,668,150 - $1,258,520 = **$1,409,630**

Conclusion & Recommendation

I would strongly recommend switching from a hand-laid brick façade to a precast Slenderwall® panel enclosure based upon the fact that it saves $1,409,630 (all things considered), significantly accelerates the schedule by 22 weeks, is lightweight and easy to handle, and reduces the heating and cooling loads on the building. Wisconsin Place could greatly benefit by switching to this precast cladding system.

Analysis 2: Photovoltaic Glass Replacement

Problem Statement

Building operating costs can be astronomical in this technologically savvy world. Many of these advanced devices require electrical power to function. Photovoltaic glass panels can supplement the electrical power that is streamed to Wisconsin Place from nearby transformers. Even though PV glass is more expensive, I would argue that the windows will pay for themselves eventually and may save the owner/residents a great deal in electric bills.

Goals

I will determine the advantages and disadvantages of using PV glass in a high rise apartment building in Chevy Chase, Maryland. I aim to quantify the amount of electrical energy that can be generated from one panel of PV glass and how that translates to the entire building. This analysis will quantify the amount of energy savings and utility costs that result from the PV glass replacement and determine if the glass replacement is feasible from a financial and energy standpoint.

Research Steps

1. Research photovoltaic glass, advantages and disadvantages.
2. Estimate the amount of glass in the curtain wall and windows.
3. Compare prices of regular glass to PV panels.
4. Attend Energy10 tutorial session and learn program.
5. Calculate the energy savings associated with switching to PV glass.
6. Calculate life cycle cost.
7. Show schedule impact of replacing glass.
8. Determine whether to stick build or prefab PV glass.
9. Make recommendation on PV glass replacement feasibility.

Tools

1. RS Means 2008 Edition
2. Whole Building Design Guide
3. Energy10
4. National Renewable Energy Laboratory
5. BP Solar

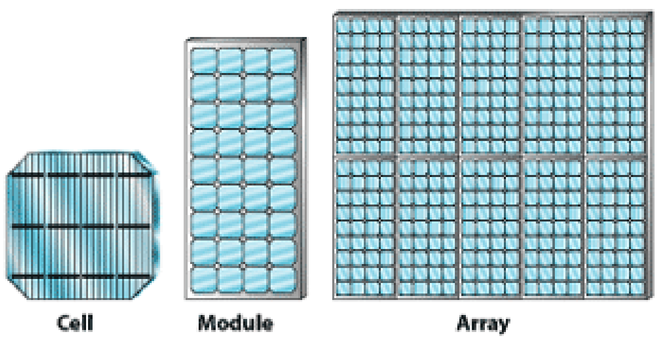
6. US Green Building Council
7. Xantrex
8. US Department of Energy

Expected Outcome

My hope is that this photovoltaic glass will be an upfront investment that saves on operating costs in the long term. Since Wisconsin Place is a rental apartment building, I am assuming the owner will hold onto it for a few years as opposed to selling it immediately following construction. This fact leads me to believe that the owner will buy into the idea of a value-enhancing alternative even if means reaching deeper into their pockets initially.

Photovoltaic Glass

Photovoltaic cells are made of multicrystalline silicon and are used to collect solar radiation from the sun. This solar energy can then be converted into electrical energy to power building systems. These cells can be either transparent or opaque, and light transmission through the cells can be set from 4% to 30% depending upon the spacing. There are two main types of PV modules: thick crystal and thin-film. The thick crystal cells are more efficient than the thin film, but they do not permit as much sunlight to pass through. They produce 10-12 Watts per square foot of PV array. The thin film panels are cheaper but less efficient, producing 4-5 Watts per square foot of PV array.



Photovoltaics are an important energy technology because they are reliable and require little maintenance. PV panels are produced domestically and support energy security in the US. These panels are modular and can be used in various applications due to their flexible design. As an added bonus, PV panels serve the purpose of form and function, as they are being used more and more as architectural features of a building, as opposed to being hidden on a roof or assembled in the middle of a field.

A Building Integrated Photovoltaic (BIPV) system incorporates photovoltaic modules into the building enclosure. This innovative technology serves two functions: the building skin and a source of electricity. I feel that BIPV is a much more economic use of PV panels because they are one product serving two purposes. They are a substitute for a façade element, not an additional component added to the building.

The PV array can either be grid-tied or a stand alone off-grid system. The benefits to a grid-tied system are savings to the utility losses associated with transmission and distribution during peak hours of operation. The utility grid acts as storage and backup for the PV array. Any excess electricity produced by the PV array is fed back into the grid. A stand alone PV system makes more economic sense for smaller applications where it would be too expensive to run power lines to the electrical grid. This cost can range from $15,000 to $50,000 per mile. Typically, buildings in secluded location will opt out of becoming grid-tied for this financial reason.

Grid-tied systems are 100% efficient and can benefit both the building owner and the utility system. This is because the on-site production of solar electricity is usually greatest at the time of the building's peak utility loads. The contribution from the solar panels reduces the energy costs for the building owner and supports the utility grid during the time of its greatest demand. So BIPV is a joint effort between owners and utility services because both benefit simultaneously from the PV module implementation.

Photovoltaic Skylight Array

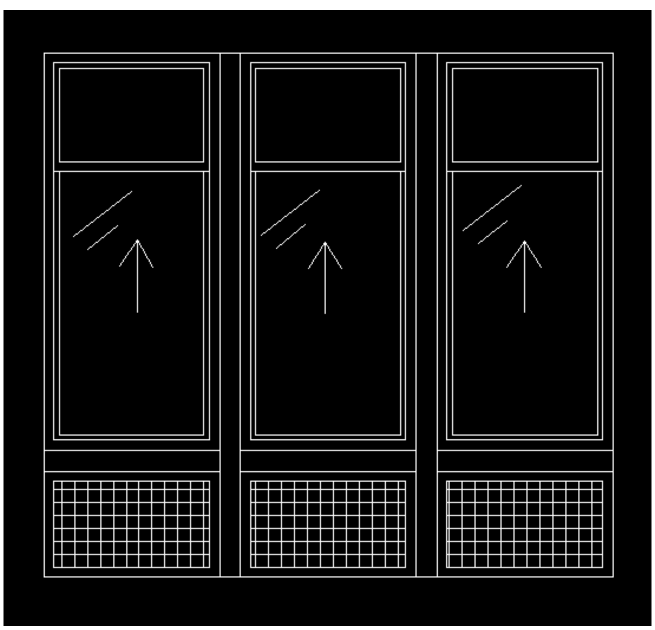
The Public Utility Regulatory Policy Act of 1978 requires power providers to purchase excess power from grid-connected renewable energy systems at a rate equal to what it costs the power provider to produce the power itself. Power providers in most states including Maryland now allow net metering, an arrangement where the excess electricity generated by grid-connected renewable energy systems "turns back" the electricity meter as it is fed back into the grid. A bi-directional meter allows users to record both electricity they draw from the grid and the excess electricity their system feeds back into the grid. The meter spins forward as they draw electricity, and it spins backward as the excess is fed into the grid. At the end of the month, if they use more electricity than the system produced, they pay retail price for that extra electricity. If they produce more than they used, the power provider generally pays you for the extra electricity at its avoided cost. The real benefit of net metering is that the power provider essentially pays the user retail price for the electricity they feed back into the grid.

Some power providers will now let users carry over the balance of any net extra electricity their system generates from month to month, which can be an advantage if the resource they are using to generate their electricity is seasonal. If, at the end of the year, they produce more than they use they forfeit the excess generation to the power provider.

The local, state, and federal governments often provide valuable incentives and rebates to owners looking to incorporate renewable energy systems into their building. Federal incentives include a 30% investment tax credit for owners who purchase solar electric systems and an accelerated depreciation of the solar panels. On the website Database of Incentives for Renewables and Efficiency, the state of Maryland offers a vast amount of financial incentives including corporate and personal tax credit, rebates, tax exemption, and loan programs.

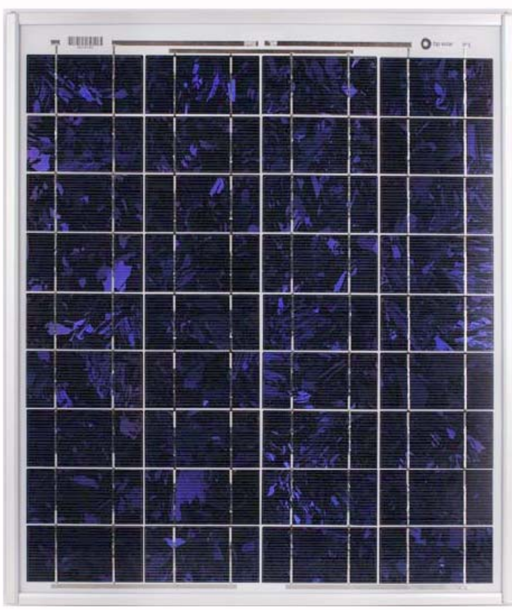
Product Information

In an attempt to lower utility costs of Wisconsin Place Residential, I have decided to implement photovoltaic panels into the façade of the building. This was achieved by replacing all of the foot level tempered glass panels with PV glass panels as shown below. This should be a relatively simple adjustment to the project. It only requires that the PV panels be provided to the aluminum window manufacturer so that they can install them in the factory. This way, the windows are still produced as one unit, and no additional installation time is associated with the change. In total, 2,342 PV panels (about 33% of the total façade glass) will replace the tempered glass foot panels for this analysis.



The crystalline cells are opaque and let significantly less light pass through than regular glass, so these panels cannot be placed at eye-level. The view from the apartments will not be obstructed and the addition of PV glass will add texture and dimension the façade. I have elected to use 50 Watt solar panels from BP Solar. One panel contains 72 cells in a 4 x 18 matrix connected in 2 parallel strings of 36 in series. The cells are enclosed in an aluminum frame that will easily connect with the masonry façade. The panel face is made of 1/8 inch tempered glass, so this will still hold up to resident traffic. Each panel weighs around 13 pounds, and has dimensions of 2.75' x 1.75' x 2". The panel and technical information can be found below.

bp solar



Electrical Characteristics		
Typical Data At STC		
Rated Power	Pr	30W
Peak Power	Pmpp	30W
Peak Power Voltage	Vmpp	18.0V
Peak Power Current	Impp	1.67A
Open Circuit Voltage	Voc	22.1V
Short Circuit Current	Isc	1.80A

The performance of the solar cells is measured at Standard Test Conditions (STC): 1000 W/m^2 irridiance, AM 1.5 spectrum and 25° C cell temperature.

Physical Characteristics		
Length	Inches (mm)	26.2 (666)
Width	Inches (mm)	16.2 (412)
Thickness	Inches (mm)	1.31 (33)

Cable Type	18/2	
Cable Length	feet (cm)	15.0 (457.2)

BP Solar 50 Watt Photovoltaic Module

Design Considerations

The PV panels will be delivered to the glass manufacturer to install in the aluminum casement. This way, the window is delivered in one solid piece and there are not field complications with installing the panels. The schedule time to install the PV glass panels is unaffected since the panels are factory installed into the aluminum window frames as shown in the diagram above. There is, however, a lead time associated with ordering the PV panels, which must be coordinated with the glazing contractor in advance.

Upon obtaining panel weight information from manufacturers, it was concluded that the PV panels will not introduce a significantly higher load to the window array. Refer to the tables below.

Existing

Component	Weight per Panel (lbs)
Reinforced Glass Foot Panels	10.8

Proposed

Component	Weight per Panel (lbs)
Reinforced PV Glass Foot Panels	13.2

The addition of PV panels to the façade will add a new dimension to the overall look of the building. Below is a part of an elevation depicting the contrast in color of the window panels. Overall, I do not feel that the panels alter the architecture of the building.

The National Renewable Energy Laboratory created a program called PV Watts that calculates the amount of energy produced by a PV system in any location in the US. The PV Watts Calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual energy production in kilowatts and energy value. There is some power loss associated with changing DC power into AC power, which is why a derate factor must be used in the conversion from DC to AC. The AC energy for each hour is calculated by multiplying the DC energy by the DC to AC derate factor. In this case, the derate factor for Baltimore, MD was determined to be 0.77. These hourly values are summed to calculate monthly and annual AC energy production, shown in the figures below.

Station Identification	
City:	Baltimore
State:	MD
Latitude:	39.18° N
Longitude:	76.67° W
Elevation:	47 m
PV System Specifications	
DC Rating:	4.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.08 kW
Array Type:	Fixed Tilt
Array Tilt:	39.2°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	7.8 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.47	339	26.44
2	4.40	386	30.11
3	4.79	447	34.87
4	5.12	452	35.26
5	5.28	463	36.11
6	5.70	465	36.27
7	5.61	471	36.74
8	5.28	444	34.63
9	4.95	410	31.98
10	4.90	440	34.32
11	3.58	324	25.27
12	2.85	270	21.06
Year	4.66	4911	383.06

Inverter Sizing

To convert from DC to AC power, inverters are needed for the system of modules. I selected a GT5.0 Grid-Tied Inverter from Xantrex to convert the DC energy from the panels into AC power that can be utilized by the apartment building.

50 V / 21.8 Voc = 2.29 → 3 panels in series

(2,342 panels x 50 W/panel) / (4500 W/inverter) = 26.02 → **26 inverters**

Xantrex GT5.0 Inverter

Model	Features	xantrex
GT2.8 Inverter	208VAC Max. Output: 2700W 240VAC Max. Output: 2800W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	 *Xantrex GT Series Inverter*
GT3.3N Inverter	208VAC Max. Output: 3100W 240VAC Max. Output: 3300W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	
GT4.0N Inverter	208VAC Max. Output: 3800W 240VAC Max. Output: 4000W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	
GT5.0 Inverter	208VAC Max. Output: 4500W 240VAC Max. Output: 5000W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	

Budget Review

Existing

Component	Quantity	Cost per Unit	Total Cost
Reinforced Glass Foot Panels	2342	$175	$409,850

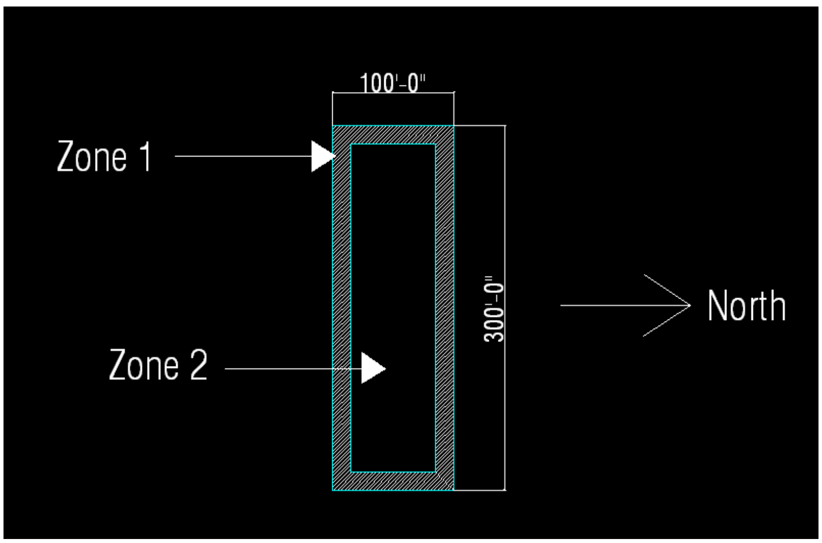
Proposed

Component	Quantity	Cost per Unit	Total Cost
Reinforced PV Glass Foot Panels	2342	$305	$714,310
Inverters	26	$3,059	$79,534
		Total	**$793,844**

The added cost to implement this photovoltaic glass system is $383,994. This initial cost was used in Energy10 to calculate the payback period of the proposed system and determine the life cycle cost.

Mechanical Energy Analysis

Wisconsin Place was modeled in Energy10 to obtain energy and cost savings data. Energy10 is a software tool developed by the National Renewable Energy Laboratory's (NREL) Center for Building and Thermal Systems. The program calculates energy performance of buildings based upon information like the building mechanical and electrical systems and the skin materials. To model Wisconsin Place in Energy10, I created a simple model of a 100' x 300' building with two separate zones, and interior and exterior, as depicted below. The perimeter is Zone 1, which is the outer 15 feet of the apartment building. This is where all of the building skin and window information is input into Energy10. Zone 2 is the interior space that is treated as a windowless space.

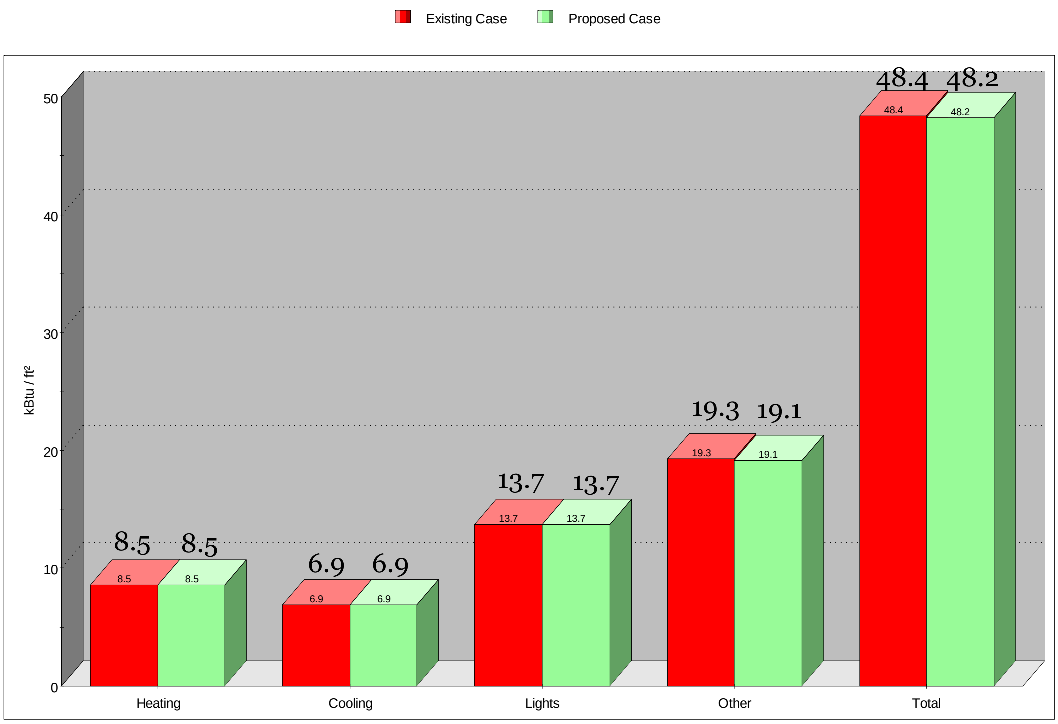


After all of the existing building information was added to the program, I created a second building model that was similar to the first in every way, except that I added in the PV panels. I ran a simulation was that calculated energy usage over a one year period for both buildings. The results indicate slight changes in energy use from installing the PV modules in the exterior. However, the cost savings is a mere $1,800 per year, which I do not feel is a substantial reduction considering the initial investment of $383,994. Below are some output graphs showing annual energy use breakdowns and life cycle costs of the existing and proposed glass systems. Additional graphs showing peak energy usage, emissions comparisons, and life cycle costs can be found in Appendix C.

Energy Use Comparison Report - 50 Watt Panels

Results	Existing Case	Proposed Case	% Change
Energy cost			
$/Therm	0.4	0.4	
$/kWh	0.078	0.078	
$/kW	2.47	2.47	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kBtu	21765730	21693586	-0.33
Energy cost, $	546526	544872	-0.3
Saved by daylighting, kWh	-	-	
Total Electric, kWh	6378610	6357468	-0.33
Internal Lights, kWh	1768050	1768050	0
External Lights, kWh	38556	38556	0
Heating, kWh	1126022	1126022	0
Cooling, kWh	904783	904783	0
Fan, kWh	179306	179306	0
Hot water, kWh	1290020	1290020	0
Unregulated/process loads	1071873	1071873	0
Peak Electric, kW	2973.2	2973.2	0
Annual Emissions			
CO_2, lbs	8572851	8544436	-0.33
SO_2, lbs	50391	50224	-0.33
NO_x, lbs	26152	26066	-0.33
Construction Costs	**$82,087,992**	**$82,267,384**	**0.22**
Life-Cycle Cost	**$100,265,040**	**$100,374,976**	**0.11**

Note that both the construction cost and life cycle cost are higher for the proposed PV system. Energy costs are reduced by $1,654 over the course of a year, and emissions are also slightly lessened. Still, these are miniscule improvements in the grand scheme of things. The chart below shows this data in graphical form.

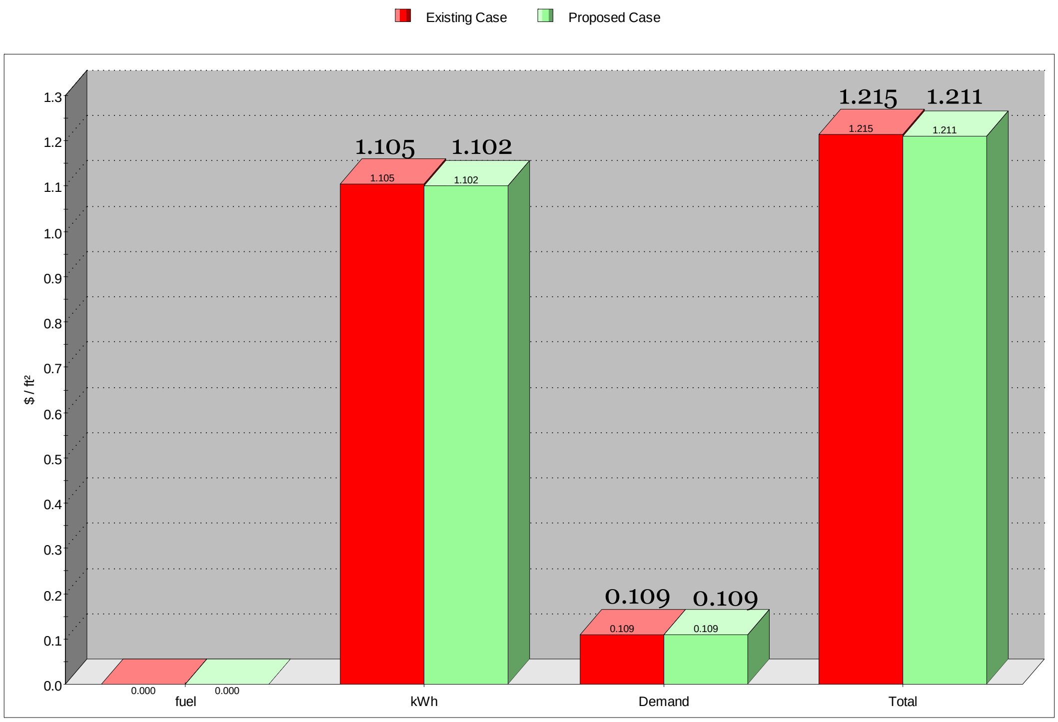


Annual Energy Use – 50 Watt Panels

Cost Summary Report - 50 Watt Panels

Scheme Name	Existing Case	Proposed Case	Difference
Construction	$82,087,989	$82,267,383	-$179,394
Fixed	$78,750,000	$78,750,000	$0
EE strategies	$0	$179,394	-$179,394
HVAC installation	$3,337,989	$3,337,989	$0
Mortgage payment	$7,530,966	$7,547,424	-$16,458
HVAC replacement	$2,503,491	$2,503,491	$0
Annual fuel	$0	$0	$0
Annual electric	$546,526	$544,872	$1,654
Annual maintenance	$225,000	$225,000	$0

Life Cycle Cost Results	Existing Case	Proposed Case	NetPresentValue
Capital	$16,027,146	$16,062,172	-$35,026
Property taxes	$5,926,513	$5,939,464	-$12,951
Mortgage	$77,531,169	$77,700,605	-$169,436
Utilities	$25,128,064	$25,052,017	$76,047
Maintenance	$8,122,171	$8,122,171	$0
HVAC replacement	$4,357,429	$4,357,429	$0
Tax deductions	-$36,827,452	-$36,858,882	$31,430
Life-Cycle Cost	**$100,265,040**	**$100,374,976**	**-$109,936**
Internal Rate of Return, IRR,	**1.70%**		



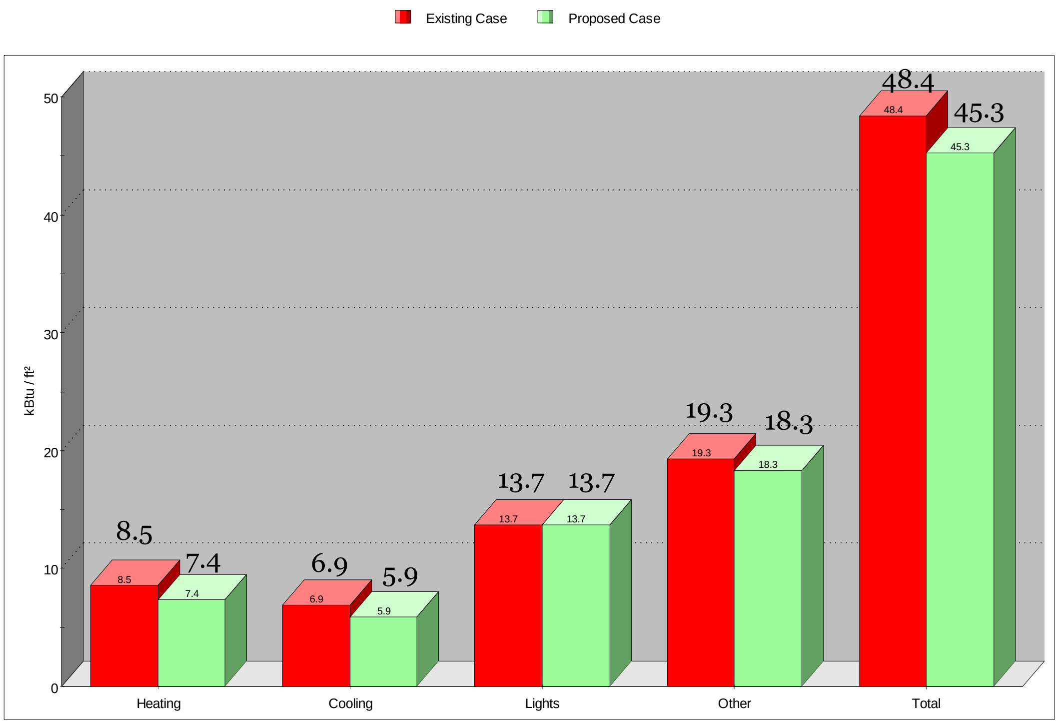
Annual Energy Cost – 50 Watt Panels

Energy10 determined the payback period for this PV system replacement to be 108 years, which is absolutely ridiculous, considering the maintenance life cycle for a building is typically 15 years. I have reached the conclusion that these 50 Watt PV panels do not produce enough energy to make their implementation efficient. To prove this point, I created a new project in Energy10 with the same parameters as the first simulation, except I used 200 Watt PV panels. Those results can be found on the following page.

Energy Use Comparison Report - 200 Watt Panels

Results	Existing Case	Proposed Case	% Change
Energy cost			
$/Therm	0.4	0.4	
$/kWh	0.078	0.078	
$/kW	2.47	2.47	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kBtu	21765730	20370890	-6.41
Energy cost, $	546526	512000	-6.32
Saved by daylighting, kWh	-	-	
Total Electric, kWh	6378610	5969841	-6.41
Internal Lights, kWh	1768050	1768050	0
External Lights, kWh	38556	38556	0
Heating, kWh	1126022	972772	-13.61
Cooling, kWh	904783	780654	-13.72
Fan, kWh	179306	147465	-17.76
Hot water, kWh	1290020	1290020	0
Unregulated/process loads	1071873	1071873	0
Peak Electric, kW	2973.2	2778.8	-6.54
Annual Emissions			
CO_2, lbs	8572851	8023466	-6.41
SO_2, lbs	50391	47162	-6.41
NO_x, lbs	26152	24476	-6.41
Construction Costs	**$82,087,992**	**$82,496,384**	**0.5**
Life-Cycle Cost	**$100,265,040**	**$99,382,231**	**-0.88**

In this revised scenario, the initial construction cost of the PV system is higher than the existing system, but the difference here is that the life cycle cost is lower, meaning there is a point during the lifespan of building operation where the energy savings from the PV panels will be enough to reduce total utility costs.



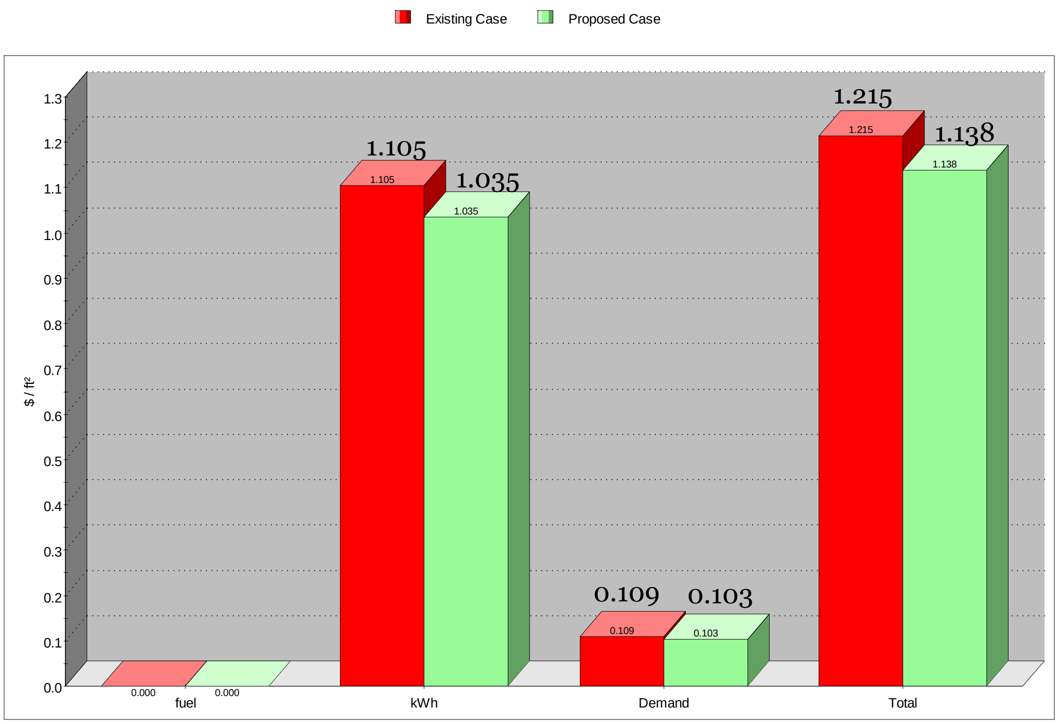
Annual Energy Use – 200 Watt Panels

Cost Summary Report - 200 Watt Panels

Scheme Name	Existing Case	Proposed Case	Difference
Construction	$82,087,989	$82,496,385	-$408,397
Fixed	$78,750,000	$78,750,000	$0
EE strategies	$0	$582,936	-$582,936
HVAC installation	$3,337,989	$3,163,449	$174,539
Mortgage payment	$7,530,966	$7,568,433	-$37,467
HVAC replacement	$2,503,491	$2,372,587	$130,904
Annual fuel	$0	$0	$0
Annual electric	$546,526	$512,000	$34,526
Annual maintenance	$225,000	$225,000	$0

Life Cycle Cost Results	Existing Case	Proposed Case	NetPresentValue
Capital	$16,027,146	$16,106,883	-$79,737
Property taxes	$5,926,513	$5,955,998	-$29,485
Mortgage	$77,531,169	$77,916,895	-$385,726
Utilities	$25,128,064	$23,540,635	$1,587,429
Maintenance	$8,122,171	$8,122,171	$0
HVAC replacement	$4,357,429	$4,129,585	$227,844
Tax deductions	-$36,827,452	-$36,389,936	-$437,516
Life-Cycle Cost	**$100,265,040**	**$99,382,231**	**$882,809**
Internal Rate of Return, IRR,	**16.78%**		

Energy10 determined the payback period for this revised system to be 12 years, a much more reasonable time frame than 108 years. In this situation, the owner pays a higher initial cost, but saves in the end. I was correct in my thinking that the panels did not have a high enough power output to make a difference in the overall building mechanical loads or utility costs.



Annual Energy Cost – 200 Watt Panels

Conclusion & Recommendation

The results of the Energy10 analysis showed that the PV panels were not strong enough to make much of a difference in the energy consumption of Wisconsin Place. If 200Watt panels were used in place of the 50 Watt panels, more positive impacts would result. The problem with using 200 Watt modules is that they do not meet the size requirements to fit within the aluminum window frames. More solar cells in an array produce more energy. However, the larger panels that contain more photovoltaic cells are too large to fit in the frames.

The problem could also be remedied by using more of the 50 Watt panels on the façade, but my concern is that they would block too much light from entering the apartments as well as obstruct the city views tenants pay so much to obtain.

In conclusion, I would not recommend the PV glass replacement because it does not generate enough energy to save tenants in utility costs. This was a good idea in theory, but the calculations show it is not worth the hassle in this instance. At any rate, the research presented in this analysis states numerous benefits to using photovoltaic technology with little to no drawbacks. I would encourage all building owners to consider Building Integrated Photvoltaics on their next project.

Summary & Conclusions

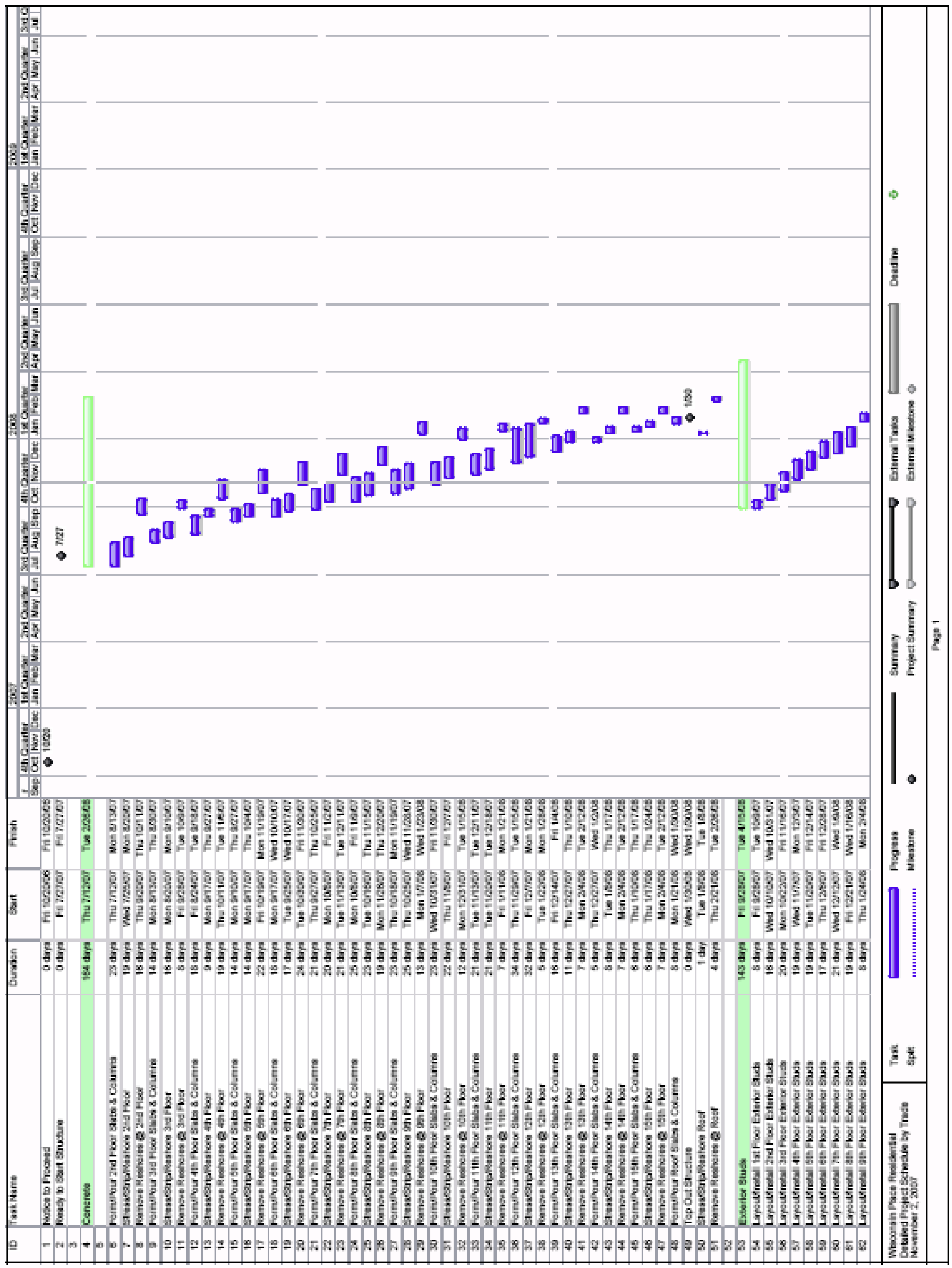
The main area that was investigated on the Wisconsin Place project in Chevy Chase, Maryland was the building façade. Prefabrication played a major part in alleviating site congestion problems and reducing overall schedule time.

The depth study identified the advantages and disadvantages to prefabrication and the reasons owners shy away from the topic in design meetings. The main deterrents for prefabrication are owner commitment in the beginning stages of design and the increased coordination and cost associated with prefab. CII provided easy-to-follow guidelines for owners to help them decide if prefabrication is right for a particular project. My precast panel research ultimately led me to the Slenderwall® panel system, which was a real winner in Analysis 1. I think it is important to keep the industry on their toes when it comes to construction innovations like the brick robot. This is a potential technology that could have a large impact on the way they do business, no matter how 'outside the box' it seems.

Analysis 1 turned out to be a feasible alternative in every sense of the word. Not only does the precast Slenderwall® brick system reduce the schedule time by 22 weeks, it also costs less when all ancillary tasks like hoist and scaffolding removal are considered. This alternate cladding system also satisfied my goal of simplifying the façade construction by combining the exterior stud erection with the masonry. Finally, these panels proved to be more thermally resistive than the existing hand-laid brick system. Slenderwall® is a very unique system, and it was rewarding to investigate a product that I knew nothing about and determine it to be an extremely effective substitution.

Analysis 2 focused more on energy savings through façade adjustments. Photovoltaic panels replaced the foot level panels of the façade as a way to convert solar energy to electrical power for Wisconsin Place. In theory, this seemed like a brilliant idea that would reduce utility costs in the long run. After using Energy10 to simulate the PV panel replacement, I concluded that the 50 Watt panels were not powerful enough to produce the amount of energy the building requires. In addition to this, the payback on investment was a staggering 108 years, so this option was unfortunately disregarded. As a suggestion, the owner could introduce more solar panels to the building in the form of skylights or solar shades.

APPENDIX A: EXISTING PROJECT SCHEDULE



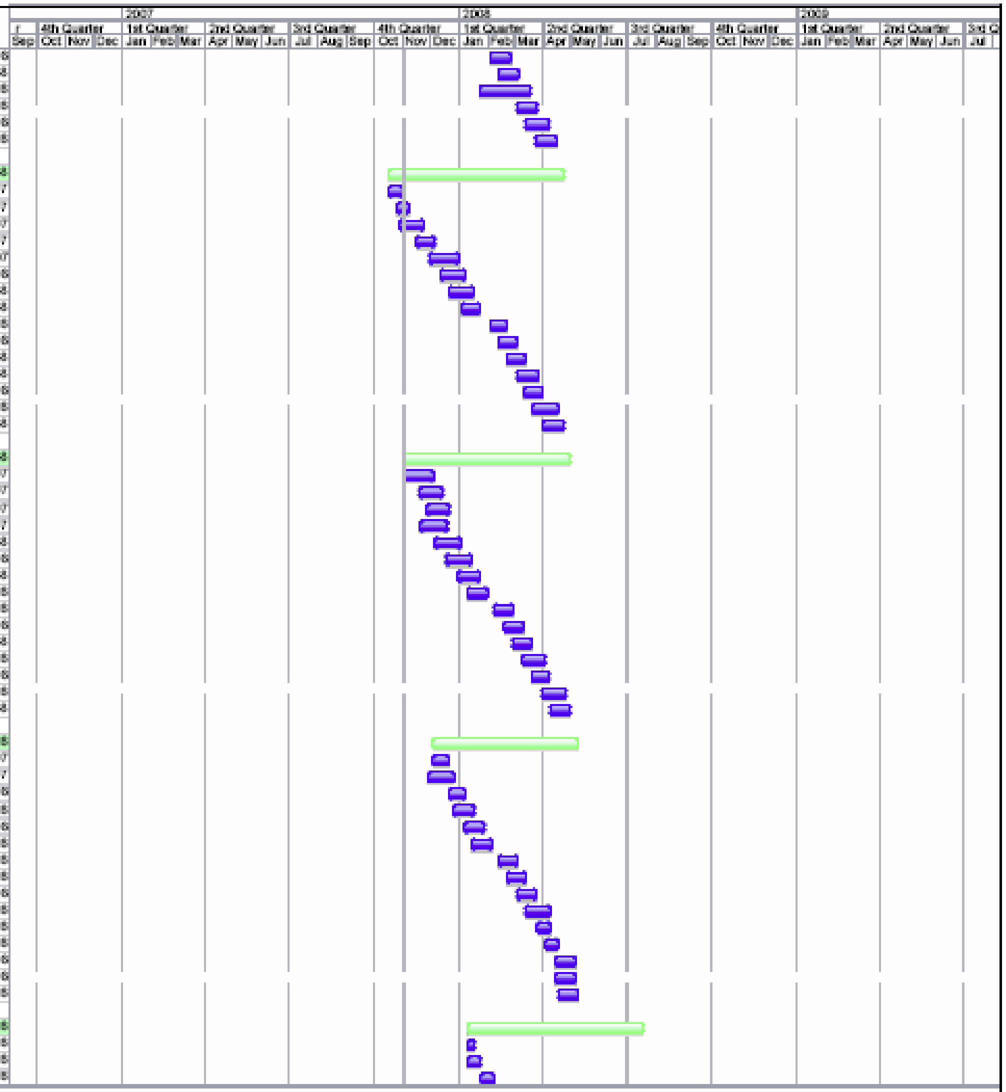
ID	Task Name	Duration	Start	Finish
1	Notice to Proceed	0 days	Fri 10/20/06	Fri 10/20/06
2	Ready to Start Structure	0 days	Fri 7/27/07	Fri 7/27/07
3				
4	Concrete	164 days	Thu 7/12/07	Tue 2/26/08
5				
6	Form/Pour 2nd Floor Slabs & Columns	23 days	Thu 7/12/07	Mon 8/13/07
7	Stress/Strip/Reshore 2nd Floor	19 days	Wed 7/25/07	Mon 8/20/07
8	Remove Reshores @ 2nd Floor	16 days	Thu 9/20/07	Thu 10/11/07
9	Form/Pour 3rd Floor Slabs & Columns	14 days	Mon 8/13/07	Thu 8/30/07
10	Stress/Strip/Reshore 3rd Floor	16 days	Mon 8/20/07	Mon 9/10/07
11	Remove Reshores @ 3rd Floor	8 days	Fri 9/28/07	Tue 10/9/07
12	Form/Pour 4th Floor Slabs & Columns	16 days	Fri 8/24/07	Tue 9/18/07
13	Stress/Strip/Reshore 4th Floor	9 days	Mon 9/17/07	Thu 9/27/07
14	Remove Reshores @ 4th Floor	19 days	Thu 10/11/07	Tue 11/6/07
15	Form/Pour 5th Floor Slabs & Columns	14 days	Mon 9/10/07	Thu 9/27/07
16	Stress/Strip/Reshore 5th Floor	14 days	Mon 9/17/07	Thu 10/4/07
17	Remove Reshores @ 5th Floor	22 days	Fri 10/19/07	Mon 11/19/07
18	Form/Pour 6th Floor Slabs & Columns	18 days	Mon 9/17/07	Wed 10/10/07
19	Stress/Strip/Reshore 6th Floor	17 days	Tue 9/25/07	Wed 10/17/07
20	Remove Reshores @ 6th Floor	24 days	Tue 10/30/07	Fri 11/30/07
21	Form/Pour 7th Floor Slabs & Columns	21 days	Thu 9/27/07	Thu 10/25/07
22	Stress/Strip/Reshore 7th Floor	20 days	Mon 10/8/07	Fri 11/2/07
23	Remove Reshores @ 7th Floor	21 days	Tue 11/13/07	Tue 12/11/07
24	Form/Pour 8th Floor Slabs & Columns	25 days	Mon 10/8/07	Fri 11/9/07
25	Stress/Strip/Reshore 8th Floor	23 days	Tue 10/16/07	Thu 11/15/07
26	Remove Reshores @ 8th Floor	19 days	Mon 11/26/07	Thu 12/20/07
27	Form/Pour 9th Floor Slabs & Columns	23 days	Thu 10/18/07	Mon 11/19/07
28	Stress/Strip/Reshore 9th Floor	25 days	Thu 10/25/07	Wed 11/28/07
29	Remove Reshores @ 9th Floor	13 days	Mon 1/7/08	Wed 1/23/08
30	Form/Pour 10th Floor Slabs & Columns	23 days	Wed 10/31/07	Fri 11/30/07
31	Stress/Strip/Reshore 10th Floor	22 days	Thu 11/8/07	Fri 12/7/07
32	Remove Reshores @ 10th Floor	12 days	Mon 12/31/07	Tue 1/15/08
33	Form/Pour 11th Floor Slabs & Columns	21 days	Tue 11/13/07	Tue 12/11/07
34	Stress/Strip/Reshore 11th Floor	21 days	Tue 11/20/07	Tue 12/18/07
35	Remove Reshores @ 11th Floor	7 days	Fri 1/11/08	Mon 1/21/08
36	Form/Pour 12th Floor Slabs & Columns	34 days	Thu 11/29/07	Tue 1/15/08
37	Stress/Strip/Reshore 12th Floor	32 days	Fri 12/7/07	Mon 1/21/08
38	Remove Reshores @ 12th Floor	5 days	Tue 1/22/08	Mon 1/28/08
39	Form/Pour 13th Floor Slabs & Columns	16 days	Fri 12/14/07	Fri 1/4/08
40	Stress/Strip/Reshore 13th Floor	11 days	Thu 12/27/07	Thu 1/10/08
41	Remove Reshores @ 13th Floor	7 days	Mon 2/4/08	Tue 2/12/08
42	Form/Pour 14th Floor Slabs & Columns	5 days	Thu 12/27/07	Wed 1/2/08
43	Stress/Strip/Reshore 14th Floor	8 days	Tue 1/8/08	Thu 1/17/08
44	Remove Reshores @ 14th Floor	7 days	Mon 2/4/08	Tue 2/12/08
45	Form/Pour 15th Floor Slabs & Columns	6 days	Thu 1/10/08	Thu 1/17/08
46	Stress/Strip/Reshore 15th Floor	6 days	Thu 1/17/08	Thu 1/24/08
47	Remove Reshores @ 15th Floor	7 days	Mon 2/4/08	Tue 2/12/08
48	Form/Pour Roof Slabs & Columns	8 days	Mon 1/21/08	Wed 1/30/08
49	Top Out Structure	0 days	Wed 1/30/08	Wed 1/30/08
50	Stress/Strip/Reshore Roof	1 day	Tue 1/8/08	Tue 1/8/08
51	Remove Reshores @ Roof	4 days	Thu 2/21/08	Tue 2/26/08
52				
53	Exterior Studs	143 days	Fri 9/28/07	Tue 4/15/08
54	Layout/Install 1st Floor Exterior Studs	8 days	Fri 9/28/07	Tue 10/9/07
55	Layout/Install 2nd Floor Exterior Studs	16 days	Wed 10/10/07	Wed 10/31/07
56	Layout/Install 3rd Floor Exterior Studs	20 days	Mon 10/22/07	Fri 11/16/07
57	Layout/Install 4th Floor Exterior Studs	19 days	Wed 11/7/07	Mon 12/3/07
58	Layout/Install 5th Floor Exterior Studs	19 days	Tue 11/20/07	Fri 12/14/07
59	Layout/Install 6th Floor Exterior Studs	17 days	Thu 12/6/07	Fri 12/28/07
60	Layout/Install 7th Floor Exterior Studs	21 days	Wed 12/12/07	Wed 1/9/08
61	Layout/Install 8th Floor Exterior Studs	19 days	Fri 12/21/07	Wed 1/16/08
62	Layout/Install 9th Floor Exterior Studs	8 days	Thu 1/24/08	Mon 2/4/08

Wisconsin Place Residential
Detailed Project Schedule by Trade
November 2, 2007

Task · Split · Progress · Milestone · Summary · Project Summary · External Tasks · External Milestone · Deadline

Page 1

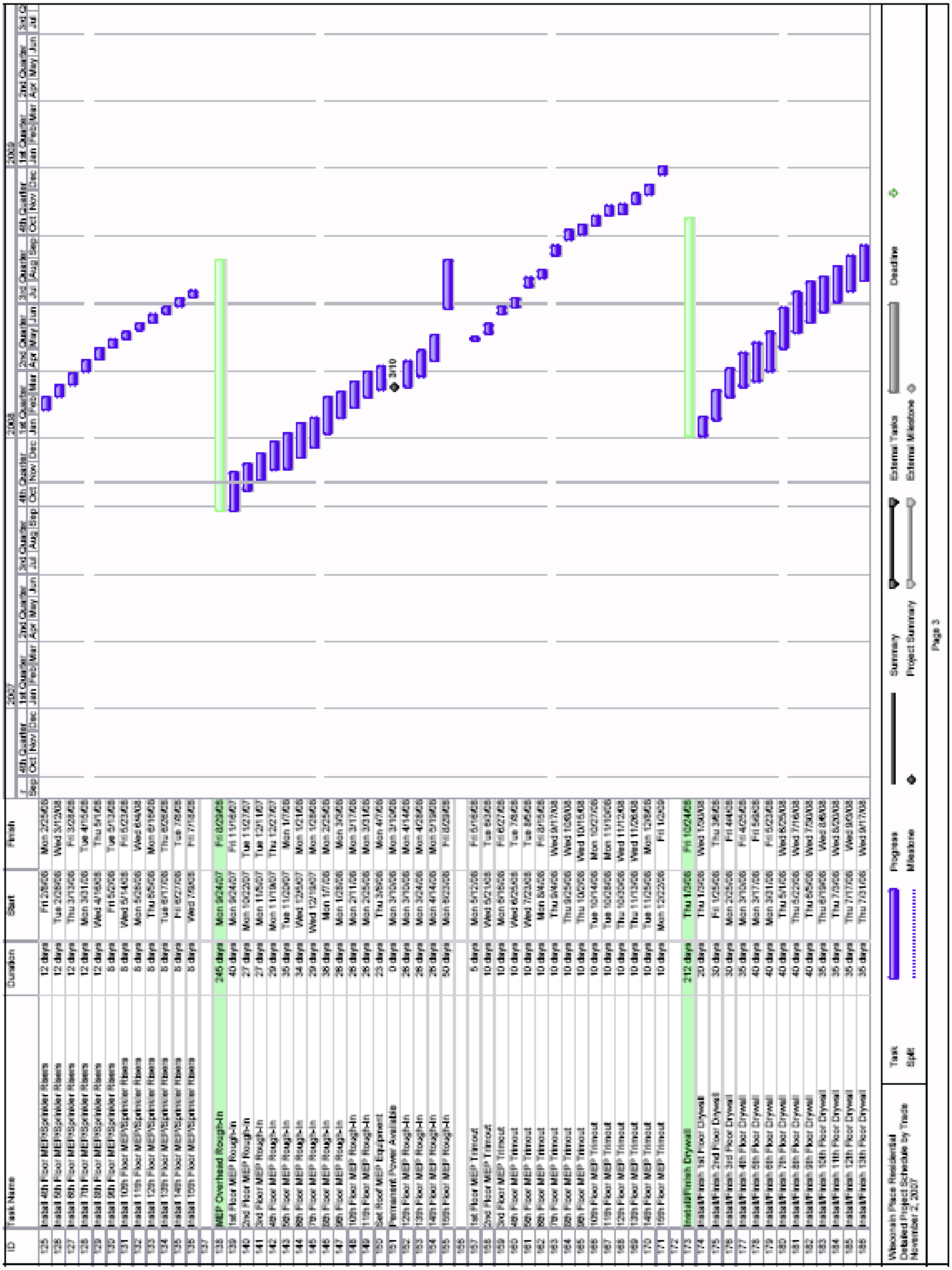
ID	Task Name	Duration	Start	Finish
63	Layout/Install 10th Floor Exterior Studs	16 days	Mon 2/4/08	Mon 2/25/08
64	Layout/Install 11th Floor Exterior Studs	16 days	Wed 2/13/08	Wed 3/5/08
65	Layout/Install 12th Floor Exterior Studs	39 days	Thu 1/24/08	Tue 3/18/08
66	Layout/Install 13th Floor Exterior Studs	16 days	Tue 3/4/08	Tue 3/25/08
67	Layout/Install 14th Floor Exterior Studs	16 days	Thu 3/13/08	Mon 4/7/08
68	Layout/Install 15th Floor Exterior Studs	17 days	Mon 3/24/08	Tue 4/15/08
69				
70	**Waterproofing**	136 days	Wed 10/17/07	Wed 4/23/08
71	Apply 1st Floor Waterproofing	11 days	Wed 10/17/07	Wed 10/31/07
72	Apply 2nd Floor Waterproofing	9 days	Fri 10/26/07	Wed 11/7/07
73	Apply 3rd Floor Waterproofing	20 days	Mon 10/29/07	Fri 11/23/07
74	Apply 4th Floor Waterproofing	14 days	Fri 11/16/07	Wed 12/5/07
75	Apply 5th Floor Waterproofing	22 days	Fri 11/30/07	Mon 12/31/07
76	Apply 6th Floor Waterproofing	19 days	Wed 12/12/07	Mon 1/7/08
77	Apply 7th Floor Waterproofing	19 days	Fri 12/21/07	Wed 1/16/08
78	Apply 8th Floor Waterproofing	14 days	Fri 1/4/08	Wed 1/23/08
79	Apply 9th Floor Waterproofing	14 days	Mon 2/4/08	Thu 2/21/08
80	Apply 10th Floor Waterproofing	14 days	Wed 2/13/08	Mon 3/3/08
81	Apply 11th Floor Waterproofing	14 days	Fri 2/22/08	Wed 3/12/08
82	Apply 12th Floor Waterproofing	17 days	Tue 3/4/08	Wed 3/26/08
83	Apply 13th Floor Waterproofing	14 days	Wed 3/12/08	Mon 3/31/08
84	Apply 14th Floor Waterproofing	20 days	Fri 3/21/08	Thu 4/17/08
85	Apply 15th Floor Waterproofing	17 days	Tue 4/1/08	Wed 4/23/08
86				
87	**Brick & Precast/Cast Stone**	130 days	Thu 11/1/07	Wed 4/30/08
88	Layout/Install 1st Floor Brick & Precast/Stone	24 days	Thu 11/1/07	Tue 12/4/07
89	Layout/Install 2nd Floor Brick & Precast/Stone	20 days	Mon 11/19/07	Fri 12/14/07
90	Layout/Install 3rd Floor Brick & Precast/Stone	19 days	Tue 11/27/07	Fri 12/21/07
91	Layout/Install 4th Floor Brick & Precast/Stone	22 days	Tue 11/20/07	Wed 12/19/07
92	Layout/Install 5th Floor Brick & Precast/Stone	20 days	Thu 12/6/07	Wed 1/2/08
93	Layout/Install 6th Floor Brick & Precast/Stone	20 days	Tue 12/18/07	Mon 1/14/08
94	Layout/Install 7th Floor Brick & Precast/Stone	18 days	Mon 12/31/07	Wed 1/23/08
95	Layout/Install 8th Floor Brick & Precast/Stone	16 days	Thu 1/10/08	Thu 1/31/08
96	Layout/Install 9th Floor Brick & Precast/Stone	15 days	Fri 2/8/08	Thu 2/28/08
97	Layout/Install 10th Floor Brick & Precast/Stone	15 days	Tue 2/19/08	Mon 3/10/08
98	Layout/Install 11th Floor Brick & Precast/Stone	15 days	Thu 2/28/08	Wed 3/19/08
99	Layout/Install 12th Floor Brick & Precast/Stone	19 days	Mon 3/10/08	Thu 4/3/08
100	Layout/Install 13th Floor Brick & Precast/Stone	13 days	Thu 3/20/08	Mon 4/7/08
101	Layout/Install 14th Floor Brick & Precast/Stone	20 days	Mon 3/31/08	Fri 4/25/08
102	Layout/Install 15th Floor Brick & Precast/Stone	16 days	Wed 4/9/08	Wed 4/30/08
103				
104	**Aluminum Windows & Doors**	113 days	Tue 12/4/07	Thu 5/8/08
105	Install 1st Floor Aluminum Windows & Doors	13 days	Tue 12/4/07	Thu 12/20/07
106	Install 2nd Floor Aluminum Windows & Doors	20 days	Thu 11/29/07	Wed 12/26/07
107	Install 3rd Floor Aluminum Windows & Doors	12 days	Fri 12/21/07	Mon 1/7/08
108	Install 4th Floor Aluminum Windows & Doors	17 days	Wed 12/26/07	Thu 1/17/08
109	Install 5th Floor Aluminum Windows & Doors	16 days	Mon 1/7/08	Mon 1/28/08
110	Install 6th Floor Aluminum Windows & Doors	16 days	Tue 1/15/08	Tue 2/5/08
111	Install 7th Floor Aluminum Windows & Doors	15 days	Wed 2/13/08	Tue 3/4/08
112	Install 8th Floor Aluminum Windows & Doors	15 days	Fri 2/22/08	Thu 3/13/08
113	Install 9th Floor Aluminum Windows & Doors	15 days	Tue 3/4/08	Mon 3/24/08
114	Install 10th Floor/Aluminum Windows & Doors	19 days	Thu 3/13/08	Tue 4/8/08
115	Install 11th Floor Aluminum Windows & Doors	10 days	Wed 3/26/08	Tue 4/8/08
116	Install 12th Floor/Aluminum Windows & Doors	10 days	Fri 4/4/08	Thu 4/17/08
117	Install 13th Floor/Aluminum Windows & Doors	15 days	Tue 4/15/08	Mon 5/5/08
118	Install 14th Floor Aluminum Windows & Doors	15 days	Tue 4/15/08	Mon 5/5/08
119	Install 15th Floor/Aluminum Windows & Doors	15 days	Fri 4/18/08	Thu 5/8/08
120				
121	**MEP/Sprinkler Risers**	136 days	Fri 1/11/08	Fri 7/18/08
122	Install 1st Floor MEP/Sprinkler Risers	5 days	Fri 1/11/08	Thu 1/17/08
123	Install 2nd Floor MEP/Sprinkler Risers	10 days	Fri 1/11/08	Thu 1/24/08
124	Install 3rd Floor MEP/Sprinkler Risers	10 days	Fri 1/25/08	Thu 2/7/08



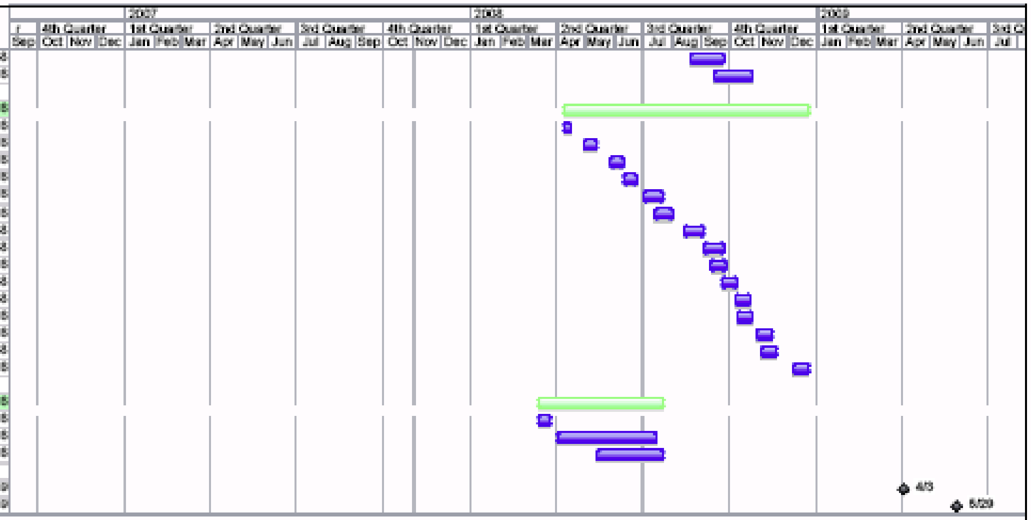
Wisconsin Place Residential
Detailed Project Schedule by Trade
November 2, 2007

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

Page 2



ID	Task Name	Duration	Start	Finish
187	Install/Finish 14th Floor Drywall	25 days	Thu 8/21/08	Wed 9/24/08
188	Install/Finish 15th Floor Drywall	30 days	Mon 9/15/08	Fri 10/24/08
189				
190	Painting	185 days	Wed 4/9/08	Tue 12/23/08
191	Paint 1st Floor Walls	5 days	Wed 4/9/08	Tue 4/15/08
192	Paint 2nd Floor Walls	10 days	Wed 4/30/08	Tue 5/13/08
193	Paint 3rd Floor Walls	10 days	Wed 5/28/08	Tue 6/10/08
194	Paint 4th Floor Walls	10 days	Wed 6/11/08	Tue 6/24/08
195	Paint 5th Floor Walls	15 days	Wed 7/2/08	Tue 7/22/08
196	Paint 6th Floor Walls	15 days	Mon 7/14/08	Fri 8/1/08
197	Paint 7th Floor Walls	15 days	Thu 8/14/08	Wed 9/3/08
198	Paint 8th Floor Walls	15 days	Thu 9/4/08	Wed 9/24/08
199	Paint 9th Floor Walls	12 days	Thu 9/11/08	Fri 9/26/08
200	Paint 10th Floor Walls	12 days	Tue 9/23/08	Wed 10/8/08
201	Paint 11th Floor Walls	12 days	Tue 10/7/08	Wed 10/22/08
202	Paint 12th Floor Walls	12 days	Thu 10/9/08	Fri 10/24/08
203	Paint 13th Floor Walls	12 days	Thu 10/30/08	Fri 11/14/08
204	Paint 14th Floor Walls	12 days	Tue 11/4/08	Wed 11/19/08
205	Paint 15th Floor Walls	12 days	Mon 12/8/08	Tue 12/23/08
206				
207	Elevators	94 days	Thu 3/13/08	Tue 7/22/08
208	Set Rooftop Elevator Equipment	9 days	Thu 3/13/08	Tue 3/25/08
209	Install Shaftwork for Elevators 1-5	75 days	Wed 4/2/08	Tue 7/15/08
210	Install Cabs 1-5	50 days	Wed 5/14/08	Tue 7/22/08
211				
212	Substantial Completion	0 days	Fri 4/3/09	Fri 4/3/09
213	Final Completion	0 days	Fri 5/29/09	Fri 5/29/09

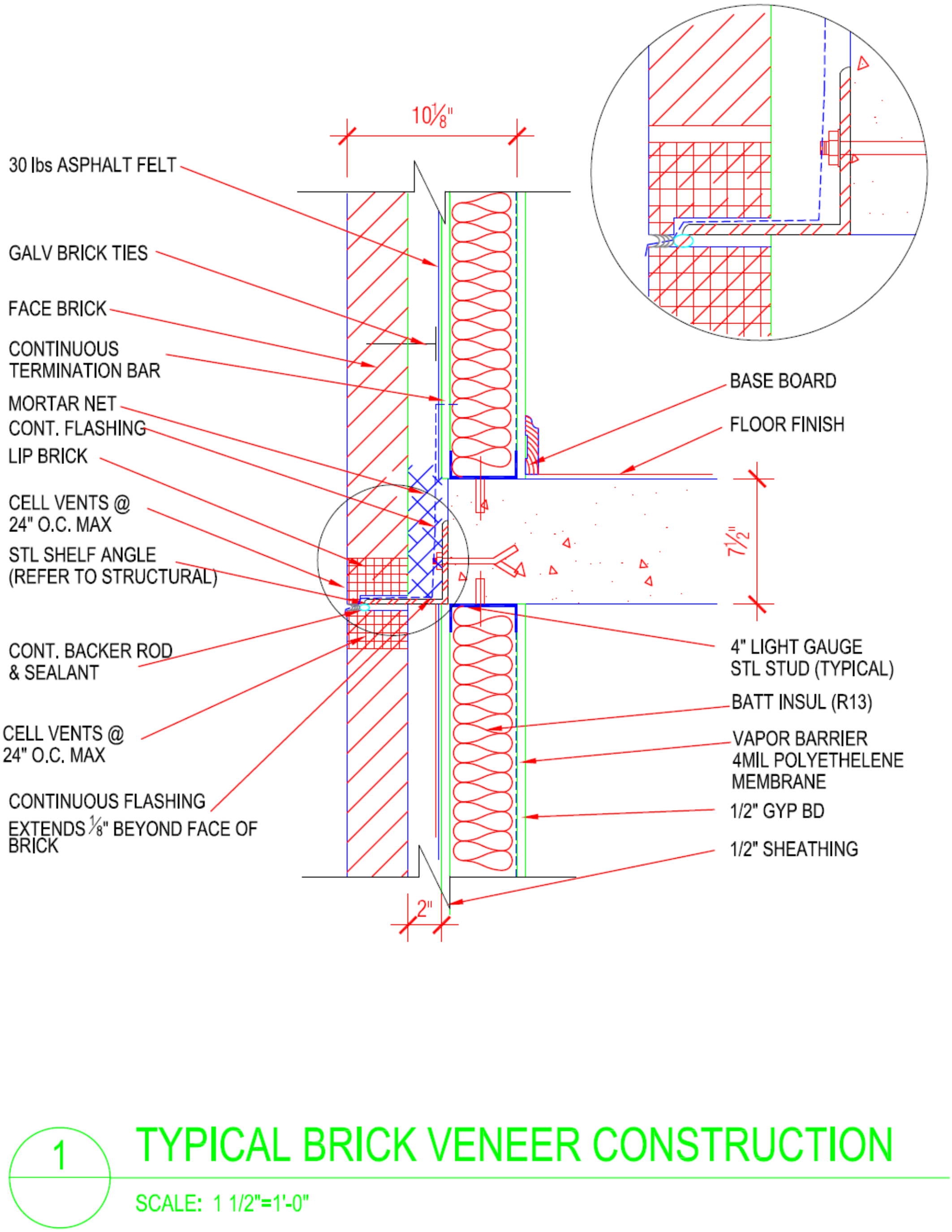


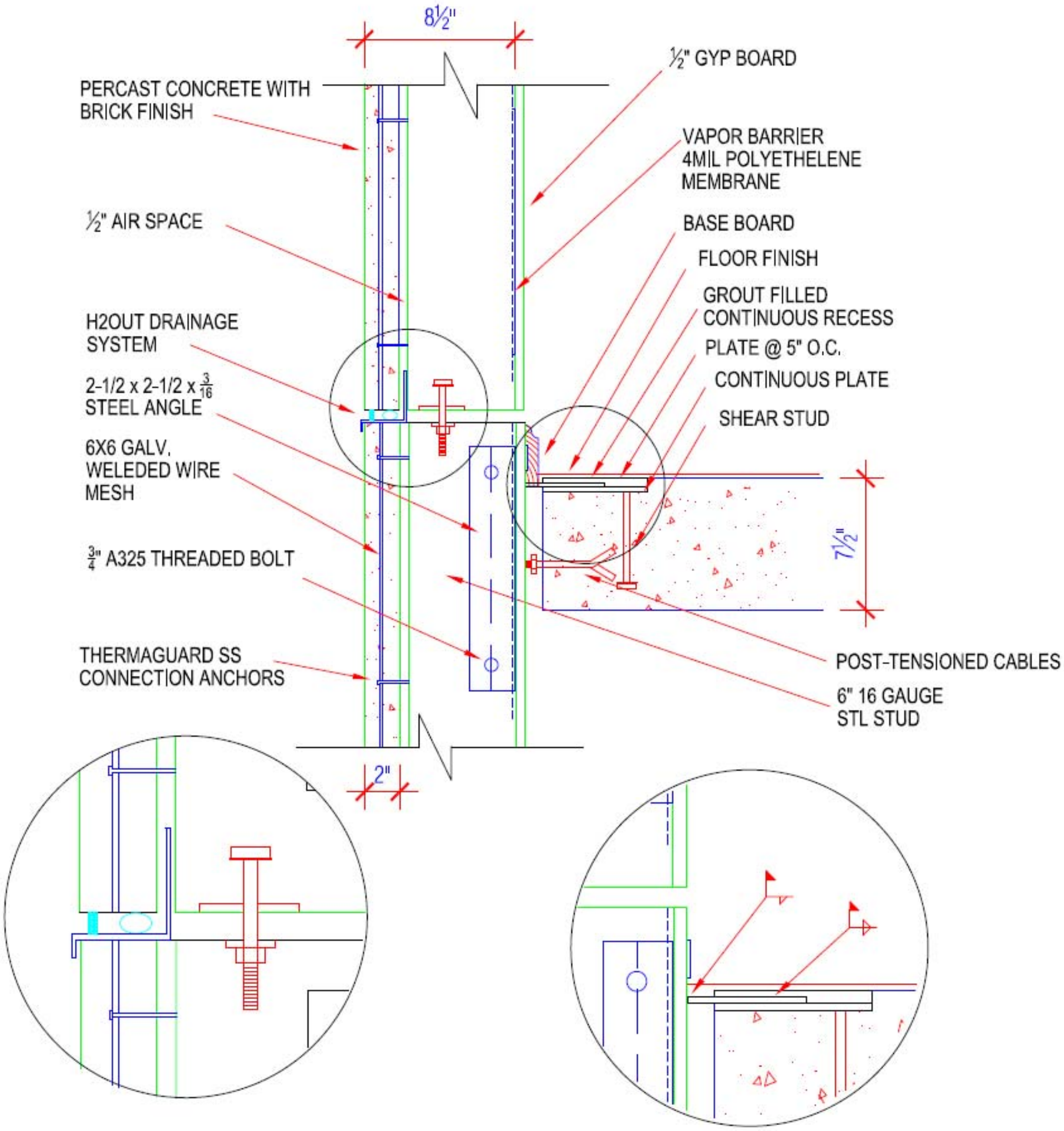
Wisconsin Place Residential
Detailed Project Schedule by Trade
November 2, 2007

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Page 4

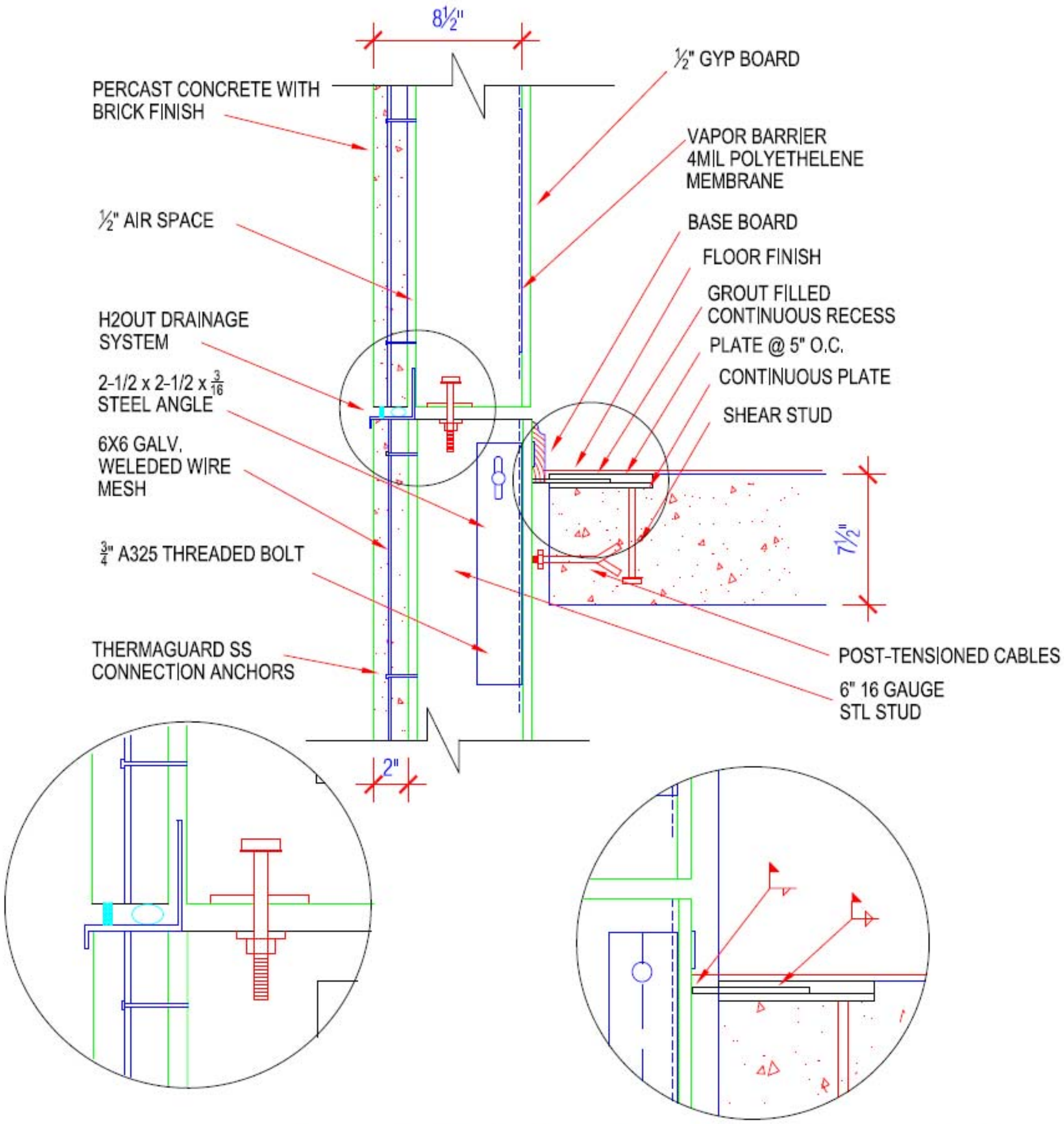
APPENDIX B: SLENDERWALL PANEL DETAILS





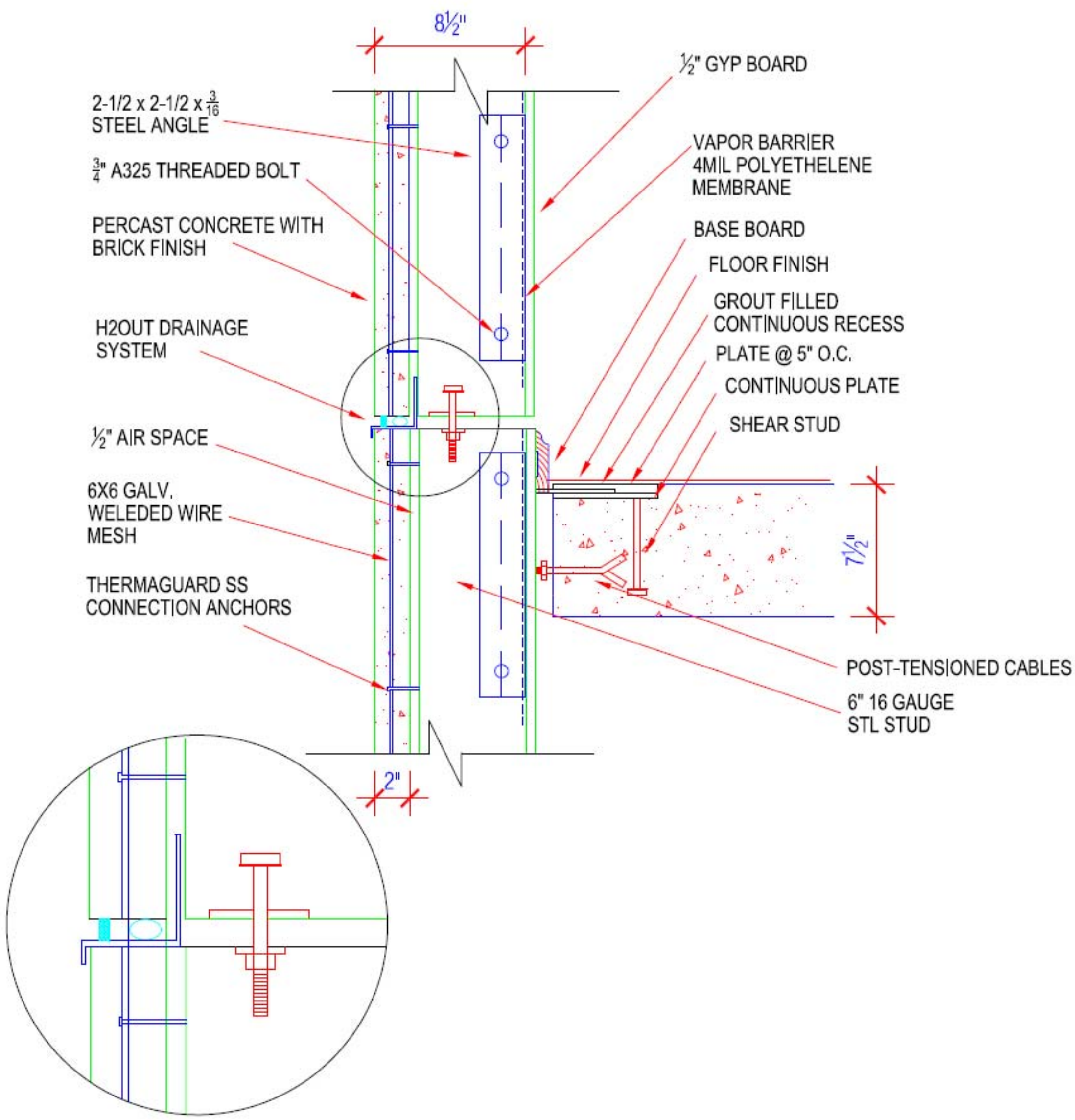
2 TYPICAL PRECAST GRAVITY CONNECTION

SCALE: 1 1/2"=1'-0"



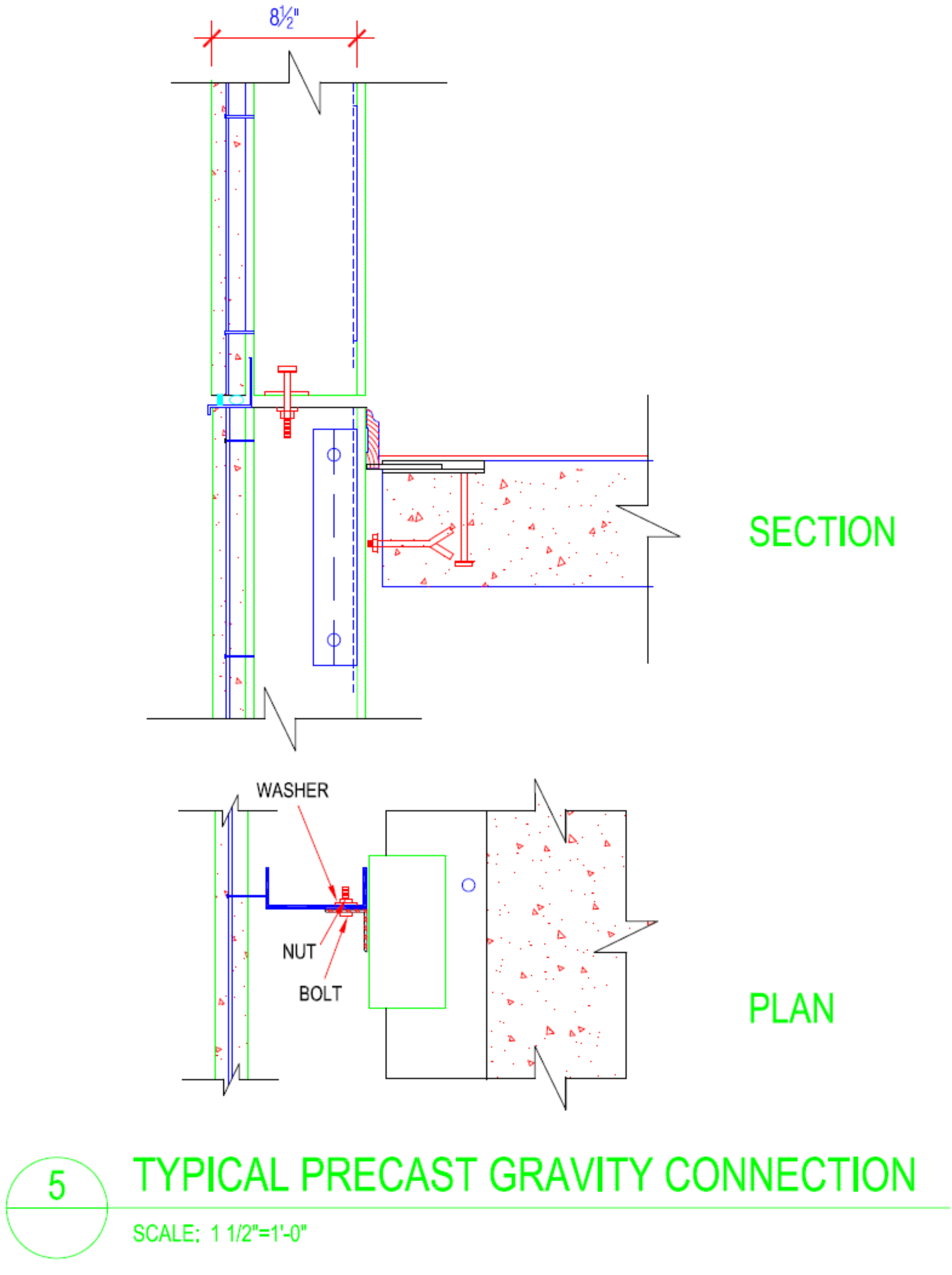
3 TYPICAL PRECAST TIE-BACK CONNECTION

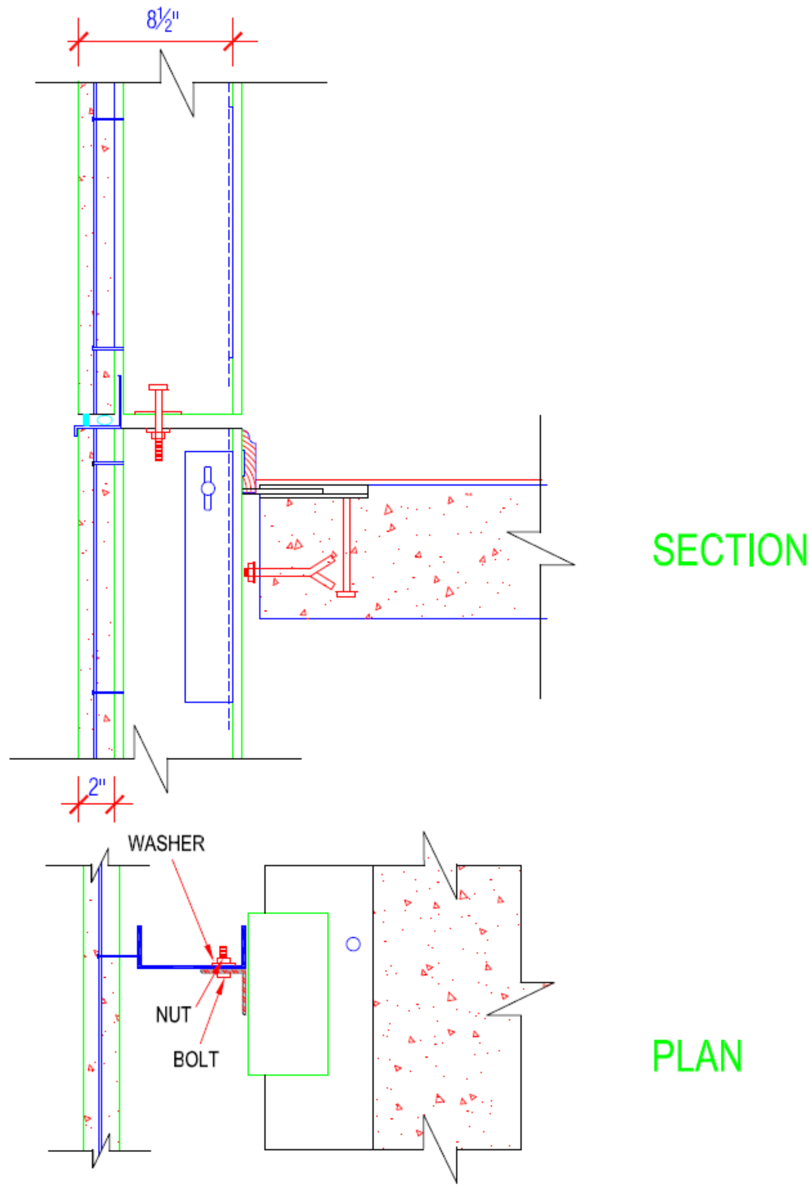
SCALE: 1 1/2"=1'-0"



4 TYPICAL PANEL TO PANEL CONNECTION

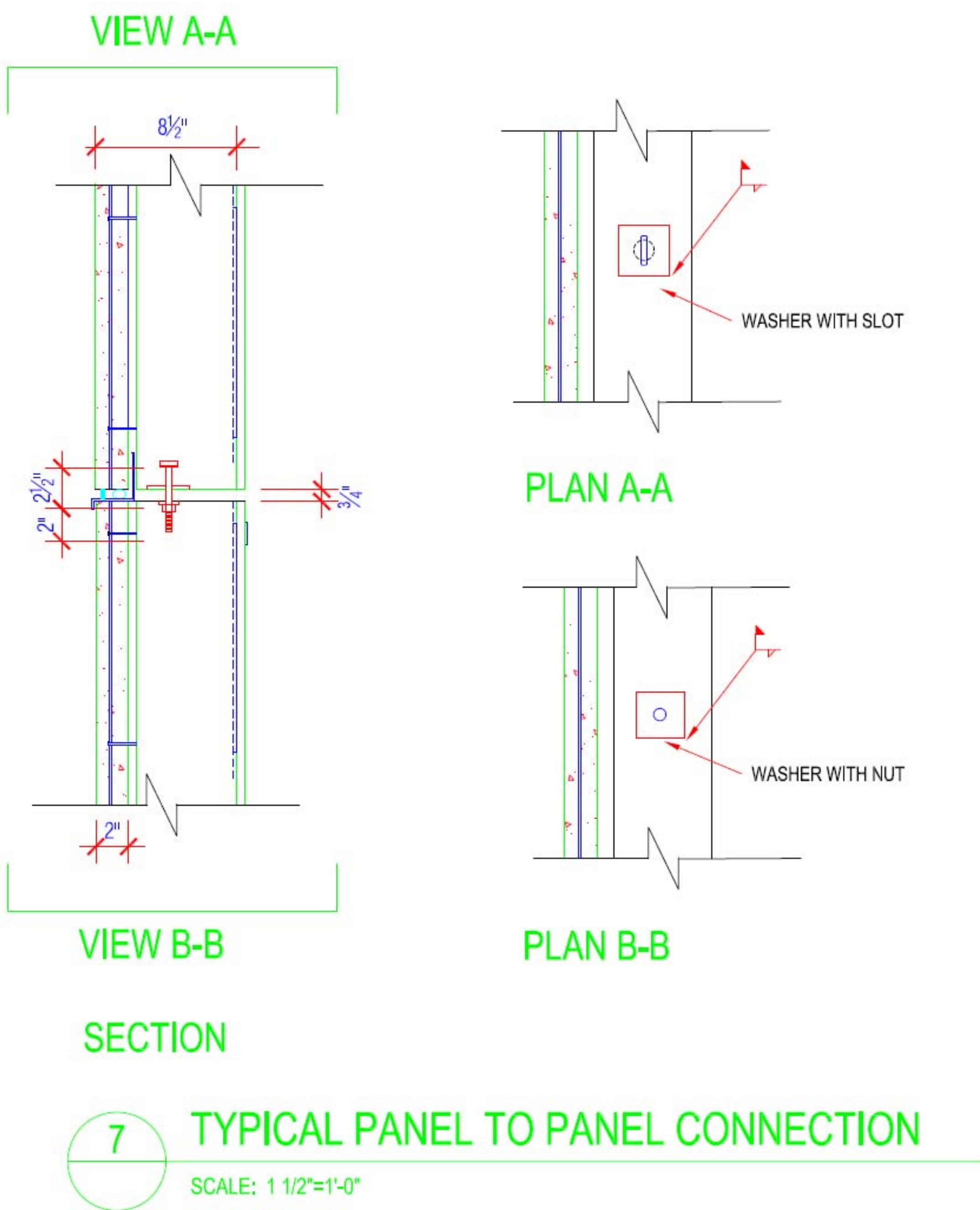
SCALE: 1 1/2"=1'-0"

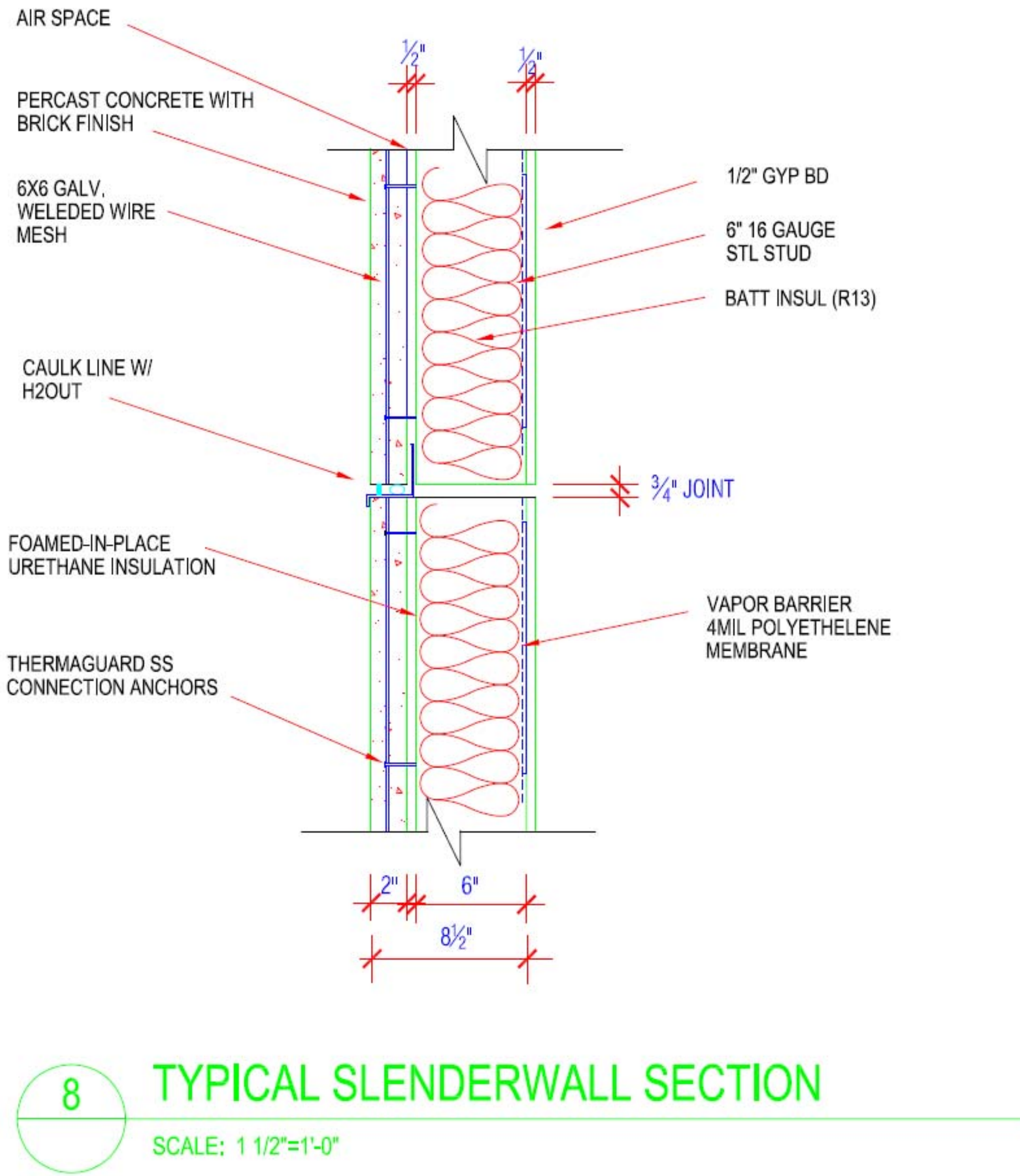

8½"
SECTION
WASHER
NUT
BOLT
PLAN
5
TYPICAL PRECAST GRAVITY CONNECTION
SCALE: 1 1/2"=1'-0"



6 TYPICAL PRECAST TIE-BACK CONNECTION

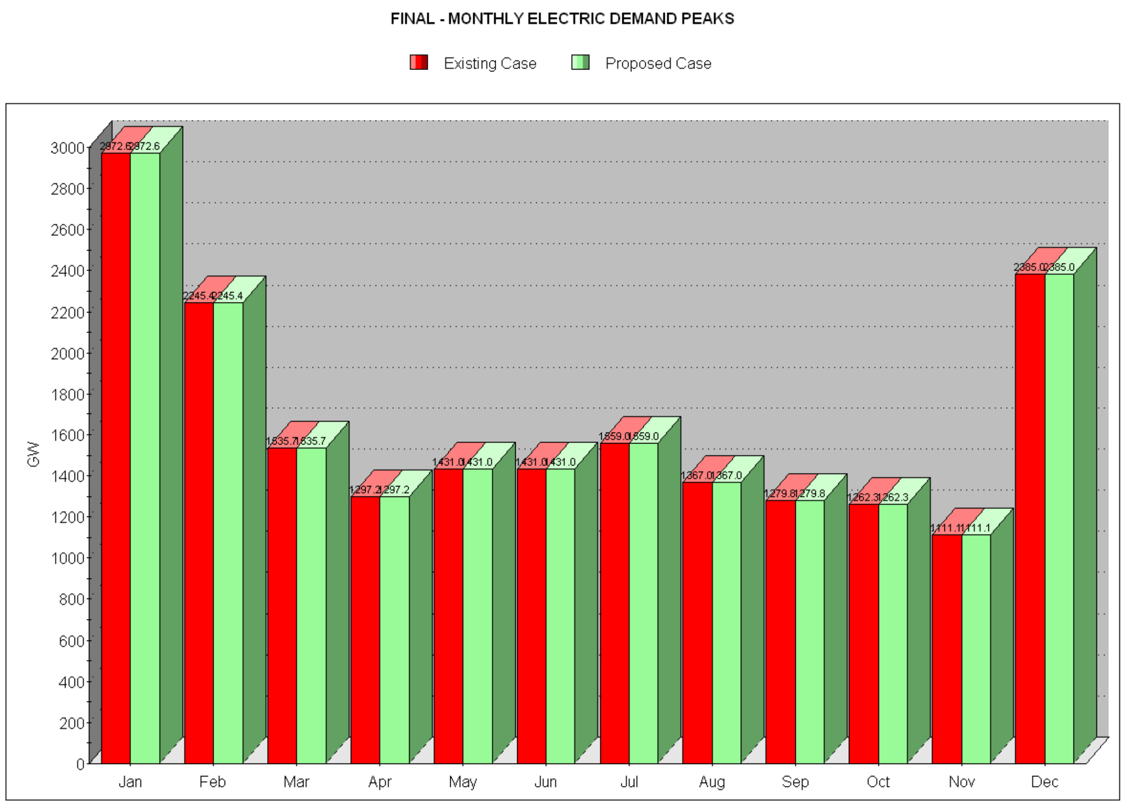
SCALE: 1 1/2"=1'-0"

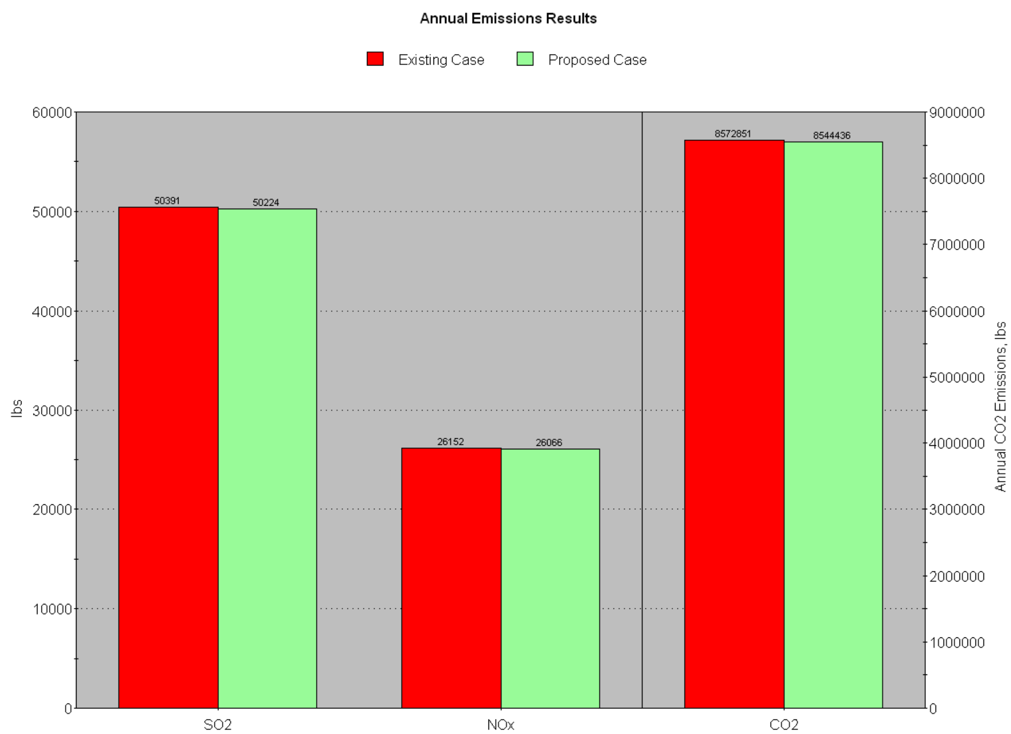

VIEW A-A
8½"
2½"
2"
3/4"
2"
VIEW B-B
PLAN A-A
WASHER WITH SLOT
PLAN B-B
WASHER WITH NUT
SECTION
7
TYPICAL PANEL TO PANEL CONNECTION
SCALE: 1 1/2"=1'-0"


AIR SPACE
PERCAST CONCRETE WITH BRICK FINISH
6X6 GALV. WELEDED WIRE MESH
CAULK LINE W/ H2OUT
FOAMED-IN-PLACE URETHANE INSULATION
THERMAGUARD SS CONNECTION ANCHORS
½"
½"
1/2" GYP BD
6" 16 GAUGE STL STUD
BATT INSUL (R13)
¾" JOINT
VAPOR BARRIER 4MIL POLYETHELENE MEMBRANE
2"
6"
8½"
8
TYPICAL SLENDERWALL SECTION
SCALE: 1 1/2"=1'-0"

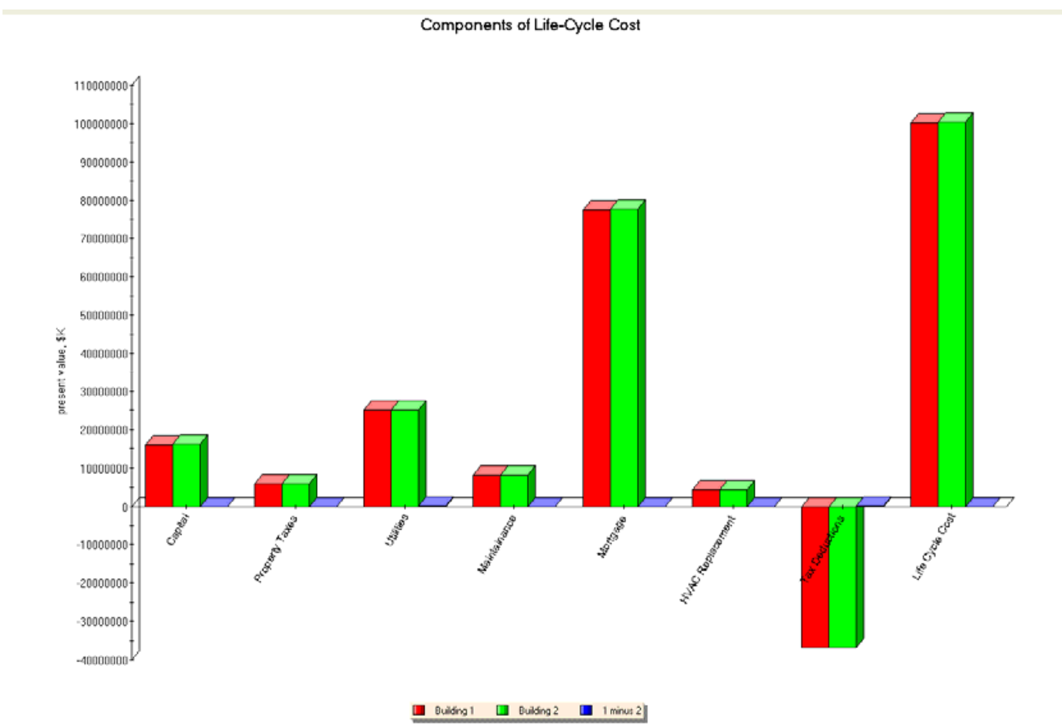
APPENDIX C: ENERGY10 RESULTS

Energy10 Output Graphs for 50 Watt Panels



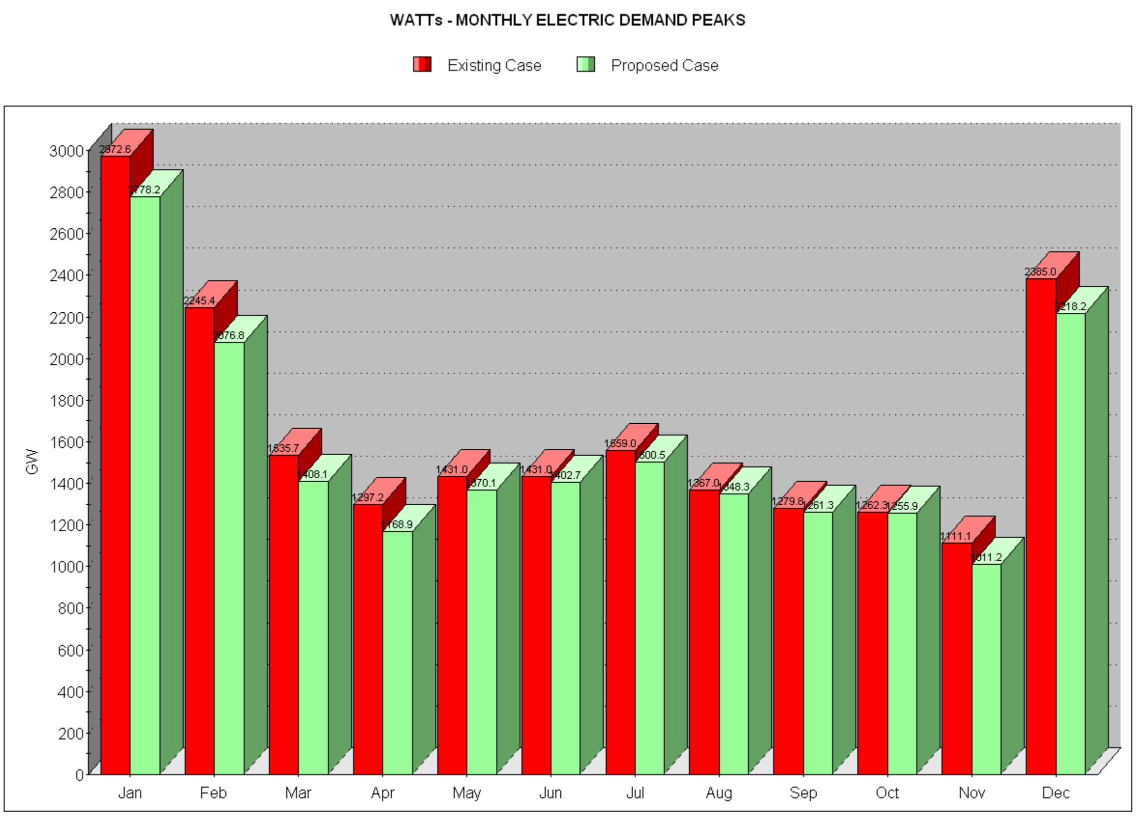


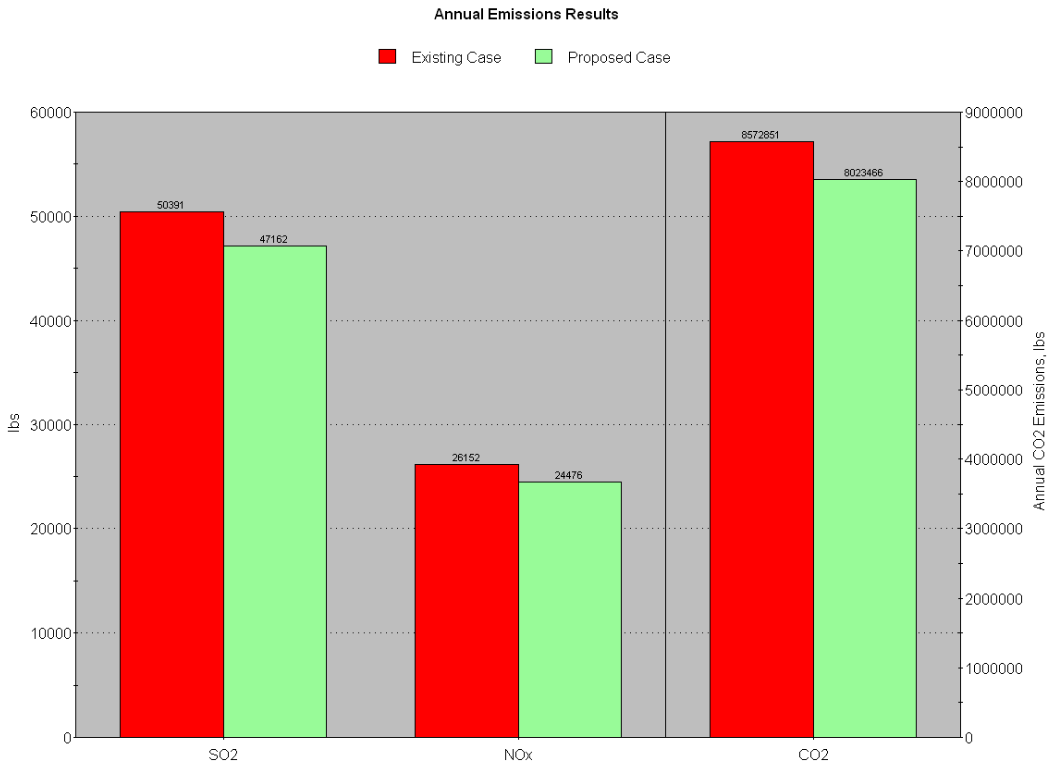
Annual Emissions Results
Existing Case
Proposed Case
lbs
Annual CO2 Emissions, lbs
60000
50000
40000
30000
20000
10000
0
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
50391
50224
26152
26066
8572851
8544436
SO2
NOx
CO2



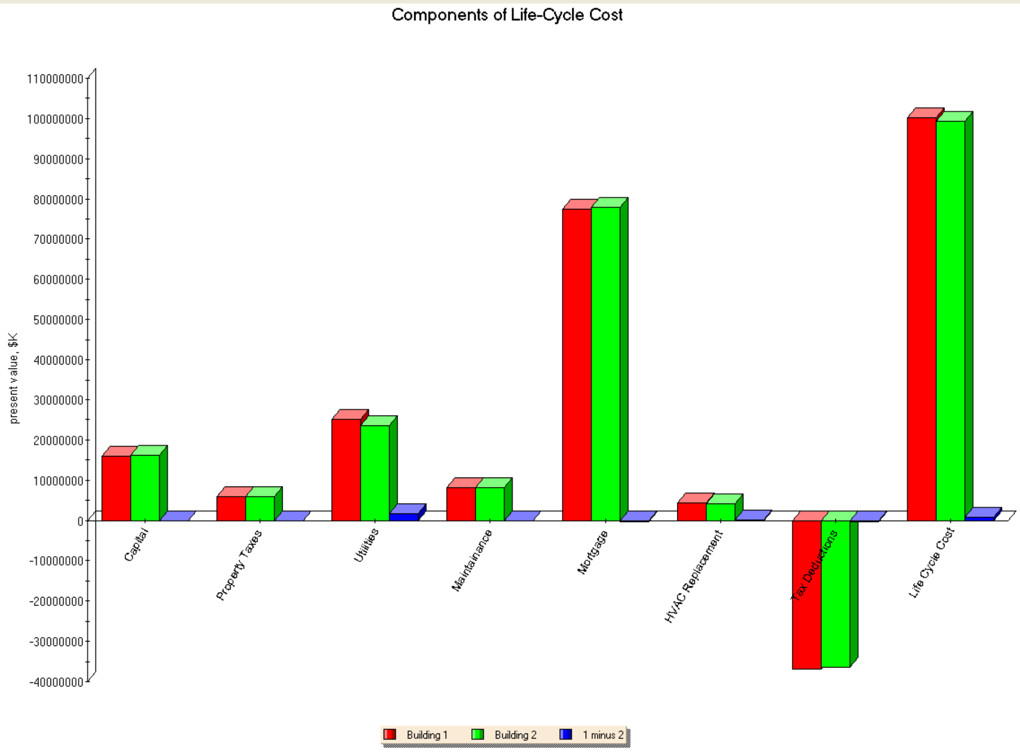
Components of Life-Cycle Cost
present value, $K
110000000
100000000
90000000
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
-10000000
-20000000
-30000000
-40000000
Capital
Property Taxes
Utilities
Maintenance
Mortgage
HVAC Replacement
Tax Deductions
Life Cycle Cost
Building 1
Building 2
1 minus 2

Energy10 Output Graphs for 200 Watt Panels





Annual Emissions Results
Existing Case
Proposed Case
60000
50000
40000
30000
20000
10000
0
lbs
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
Annual CO2 Emissions, lbs
50391
47162
26152
24476
8572851
8023466
SO2
NOx
CO2



Components of Life-Cycle Cost
110000000
100000000
90000000
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
-10000000
-20000000
-30000000
-40000000
present value, $K
Capital
Property Taxes
Utilities
Maintainance
Mortgage
HVAC Replacement
Tax Deductions
Life Cycle Cost
Building 1
Building 2
1 minus 2