Analysis: Prefabrication of Curtain Wall System

Introduction

With new building construction designs becoming more complex and unorthodox, the way construction managers and subcontractors sequence and erect building envelopes will need to adapt. The days of square facades consisting of primarily masonry units and windows are a thing of the past. With the implementation of CAD systems and sophisticated cutting applications for steel members utilized on such projects as Walt Disney Concert Hall, designs which were once thought impossible can now be made easily and efficiently at locations not on the project site. The Walt Disney Concert Hall project could not have been completed without the use of integrated CAD systems for the designers and contractors. As is seen in this example, current building skins can have an array of materials, elevations, and curvatures. These systems can range from architectural pre-cast, full glass and glazing, metal panels, and even outlandish materials such as wood blades at the New Census Bureau Headquarters. Since designers and owners always desire their new facilities to stand alone, especially in commercial construction, different and unique skin systems are being developed everyday.

Figure 1.1: Walt Disney Concert Hall, California

These often unique and challenging systems require thorough planning and sequencing of the different trades working on the façade, as well as deliveries, crane locations, safety, and even productivity concerns. As with any other building system under construction, unforeseen issues equate to losses in time, money, and worker morale. There are many new problems which were not even considered previously. If these concerns are not properly addressed and corrected the project may end up costing more than originally budgeted. Some examples include:

- Radius point of curved curtain walls is often located outside of the project site.

- Urban construction where space needed to erect these systems is limited.
- Shakeout areas for large members prior to erection.
- Curvatures of support members can not be achieved by on site means, advanced equipment is a requirement.
- New designs require field tests to ensure compliance with codes and regulations.
- Many trades working on the façade require large workspaces and proper sequencing to prevent stacking, re-work, and crane usage.

To alleviate many of these problems, construction managers are often employing prefabricated components to the façade systems. These can range from window systems, to pre-cast concrete, to masonry units. Panels or units are constructed off-site at warehouses, plants, or facilities either rented or owned by the subcontractors. The capabilities of the facilities can range from production of complete panels, or simply fabricated the components which could not be erected on site. Many subcontractors are embracing this change in philosophy and opening permanent prefabrication facilities to attract new and rewarding opportunities. One company which is using utilizing this new approach is Harmon Inc., and their work will be referenced numerously in this analysis. Figures 1.2 and 1.3 are from Harmon's prefabrication facility located in Glen Burnie, Maryland.

Figure 1.2: Component Delivery

Figure 1.3: Unitizing Stations

This enormous 100,000 square foot facility can handle prefabricated efforts from delivery of materials to final shipment of unitized pieces. Located in close proximity to the management headquarters, project engineers and managers can quickly and easily check production of components and ensure proper

manufacturing techniques. Figure 1.4 shows some of the positive and negative aspects of a prefabricated approach to envelope construction.

Figure 1.4: Advantages vs. Disadvantages of Prefabricated Systems

Advantages	*Disadvantages*
Productivity	***Productivity***
Warehouse facilities can operate during inclimate weather and winters Workers are more productive in controlled environment Components fabricated more efficiently, does not require cutting or measuring on-site	Double handling of materials from material manufacturers to project site
Labor Cost	***Labor Cost***
Warehouse workers have lower wages than skilled curtain wall workers on-site Skilled curtain wall employees are utilized only for difficult construction processes	May require more labor in order to fully operate the warehouse facility (i.e. material handling) Additional engineering and management costs of project to properly manage facility operations Associated design costs of each component for fabrication
Material Cost	***Material Cost***
Buy in bulk and fabricate appropriate lengths in warehouse, no cutting costs from manufacturer Deliveries to warehouse may be large and not require small incremental shipments to jobsite	Related costs of double handling materials from manufacturer to prefab facility to site
Equipment Cost	***Equipment Cost***
Mobilization costs of specialized equipment such as cutters, adhesive devices, etc. Possibility to buy equipment in lieu of paying high rental costs for each project	Costs of crane or large capacity lifting mechanisms (if not provided by GC/CM) Hire expertise to maintain equipment if purchased
Quality	***Quality***
Customer can tour facility and be guaranteed of the final product, not just a mock-up Closely monitor unitized components for quality issues Numerous tests can be completed prior to full scale installation Closed environment eliminates chaos of erection on-site and possible mistakes	Erected by less qualified labor under management supervision, must be closely monitored Small changes due to construction issues are difficult to manage once in production Finished panels may be damaged or destroyed during transportation

Advantages	Disadvantages
Schedule	**Schedule**
Accelerate schedule by starting production before erection begins Erection on-site much quicker with unitized panels, building enclosed faster Minimizes on-site field test, eliminates wasted days	Small delays in warehouse production can cause idle workers at the jobsite Changes of on-site systems may cause production changes
Safety	**Safety**
Warehouse activites may be closely monitored by management team Hazardous activities may be seperated from other labor forces Ability to enforce all safety issues, does not have to worry about other workers	Dangers associated with using a crane for erection of panels Must have separate safety programs for warehouse facility and jobsite
Sustainability	**Sustainability**
Recycle materials back to manufacturer directly, decrease costs Minimize environmental impact at jobsite	Additional energy consumption of prefabrication facility Double handling of material by trucks or other methods of transportation

As is seen in the previous figure, there are numerous advantages and disadvantages to imposing this aspect of construction. There are an assortment of benefits in areas such as cost, safety, schedule, logistics, and many others; however, the decision is still one that needs to be carefully considered and evaluated. The focus of this analysis will be to utilize a prefabricated envelope system for the aluminum curtain wall construction of the Center for Health Research and Rural Advocacy. The analysis will include a description of the unitized panel and prefabrication facility, and address impacts on the schedule and cost estimates. Along with these issues, the structural integrity of the façade retention systems will be checked to ensure adequate support to the increased mass of the system and a mechanical analysis of increasing the R-value of the building skin.

Background

The curtain wall for the Center for Health Research and Rural Advocacy is the defining characteristic of the North and East facades. In comparison to the other envelope system employed on the project, this aluminum curtain wall is the most expensive and has the longest schedule duration. Construction of highly glazed curtain wall systems is very labor intensive, this aspect allows for the possibility of some

savings in a prefabricated approach. Figures 1.5 and 1.6 display the costs and schedules of the different exterior skin systems.

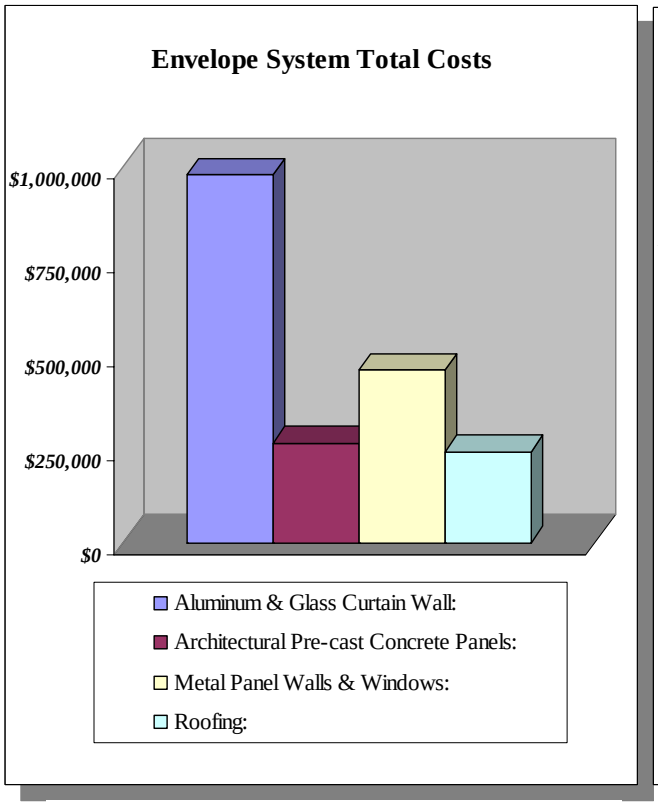

Figure 1.5: System Costs

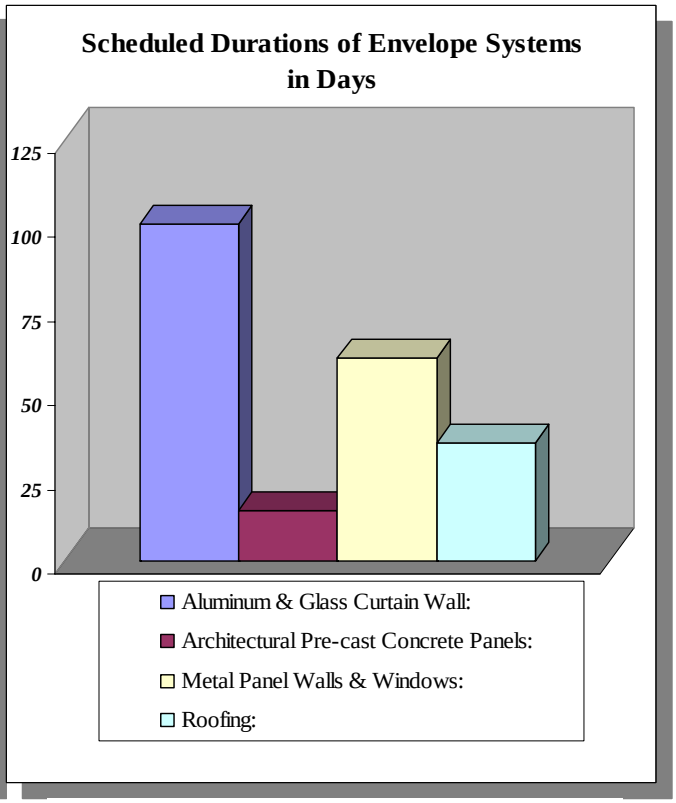

Figure 1.6: Construction Durations

Please reference Appendix B.1 for specific system costs of material and labor. The main feature of this expansive glazing is it allows for large amounts of natural light to inhabit the structure and promote a healthy work environment. One-eighth inch thick extruded aluminum 6063-T5 is the main component of the framing system with common dimensions of 2-1/2" x 7-1/2". The sizing is of fairly common sizing so as to not require new dyes for the manufacturer. Costs of unique dye molds can be expensive and require a long submittal verification process. Glazing consists of insulating glass of ¼" float heat strengthened glass exterior lite; ½" air space, and ¼" clear float glass interior lite. Spandrel glass consists of ¼" tinted heat strength glazing with reflective coating surface.

Since the façade curves and arcs along the Centre Street elevation, the construction manager has decided that it will be too difficult to prefabricate components. The conception of prefabrication being utilized only for highly repeatable units has mainly fueled this decision. Site logistics is also an extremely challenging aspect and additional crane usage may have a negative impact on the unitized effort. Once

the structural steel and floor slabs are complete, maneuvering the boom around the Weis Research and Geisinger Hospital will be challenging and hazardous. These issues and more will be discussed in the impact discussion of the analysis.

Prefabricated Units

When developing a unitized system, the contractor must employ engineering resources and additional planning of the system under construction. These extra resources are used to create more specific tools and techniques for sequencing, erection, and quality of the desired components. As is typical for commercial construction projects, the subcontractor creates shop drawings for submittal and on-site erection purposes. These shop drawings are expanded upon for a unitized system and morph into highly specific production sheets as would be seen in a manufacturing facility. Each window or system is tagged with its own individual number for easy reference and labeling. The following figure demonstrates which entities create the additional tools utilized during a prefabricated approach.

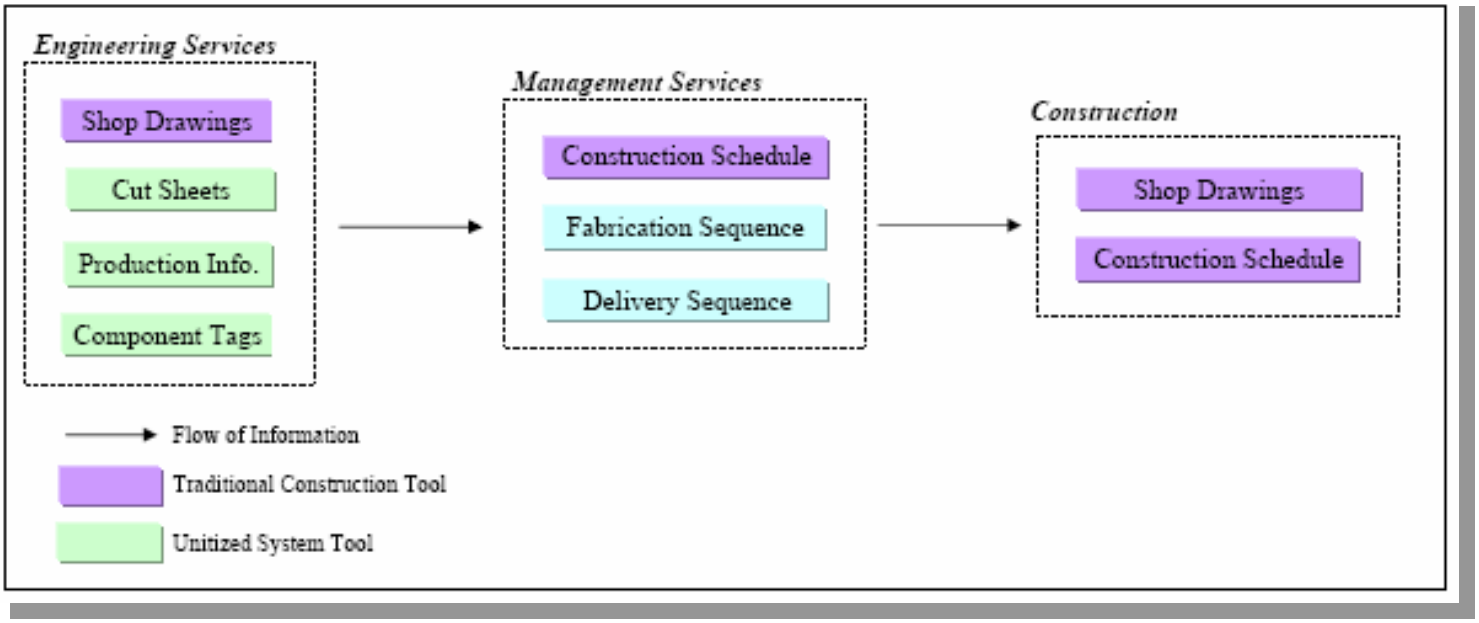

Figure 1.7: Tools Utilized for Typical Construction Projects and Unitized Systems

Harmon Inc. utilizes all of these additional tools to ensure a smooth production and erection of the façade system. The subsequent figures are examples of documentation for one of their projects which is currently under production.

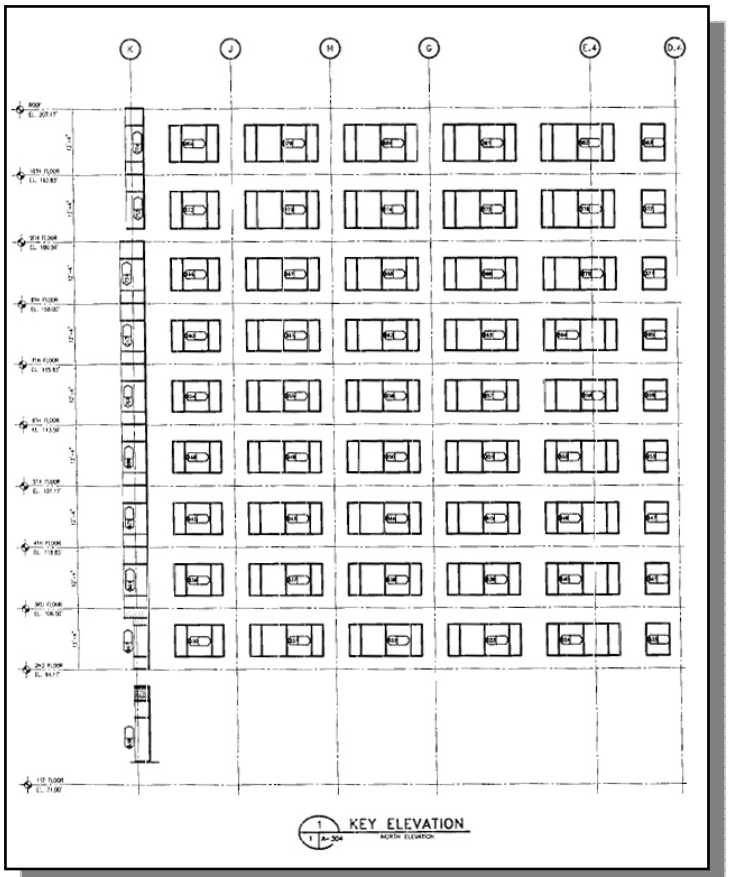

Figure 1.8: Key Elevation with Component Tags

This elevation has individual tags for each window component system to be manufactured in the prefabrication facility. Each tag is related to a specific production sheet of that component. Figure 1.9 shows an example of the individual window section and elevation referenced in the overall plan. Each tag also has a quantity related for production so that the components may be fabricated all at once. This minimizes having to change machinery and allows for a more lean type process. Figure 1.10 is an interface elevation for a unit. This section may be referenced numerous times throughout cut sheets.

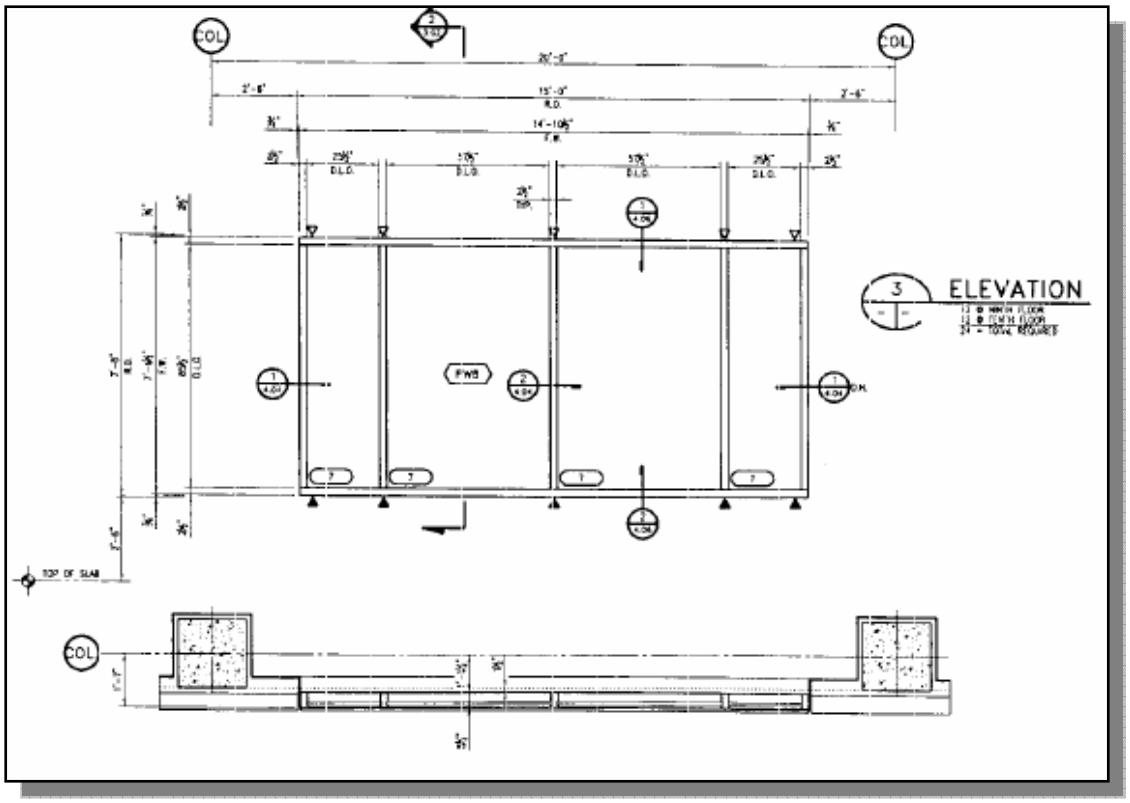

Figure 1.9: Referenced Panel Tag from Key Elevation

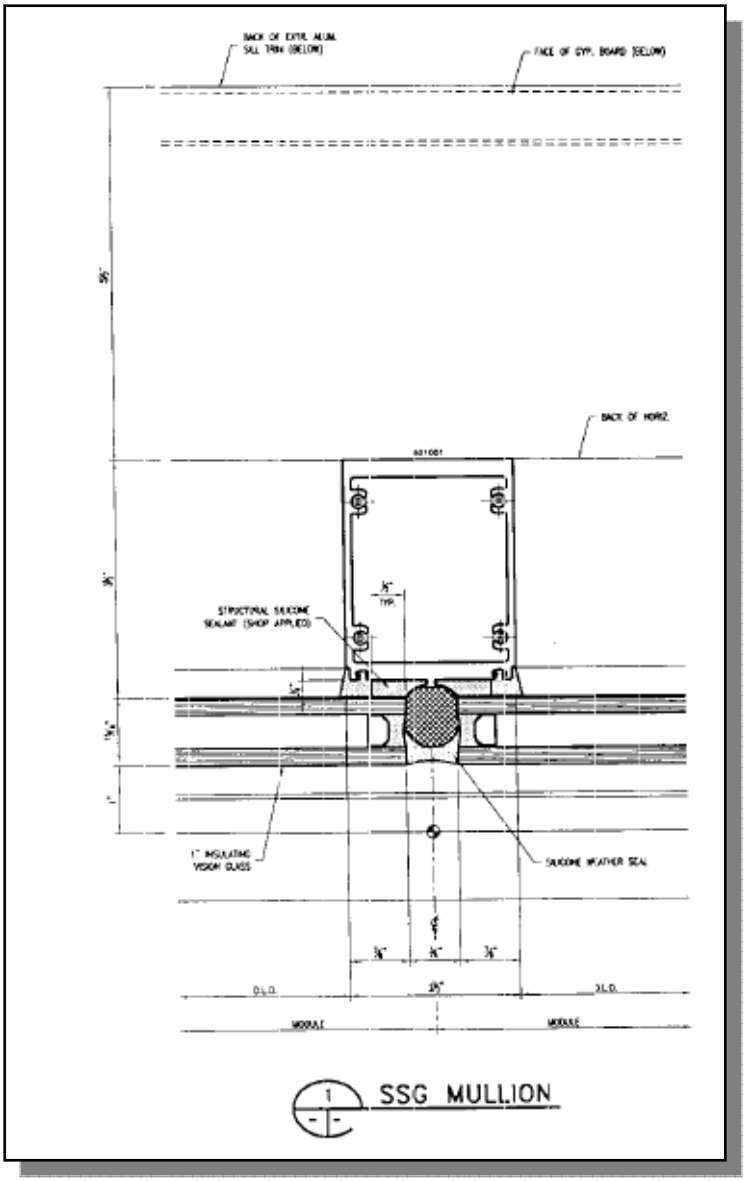

Figure 1.10: Referenced Section Detail from Cut Sheets

Using this technique for the Center for Health Research and Rural Advocacy, the 13,000 square foot aluminum curtain wall system will be broken up into manageable size elements. The design of the mullions is included in each of the panels to eliminate the framing system entirely. One extremely important aspect of a unitized construction is the usage of silicone to act as the adhesive agent and water tight component. The last thing an owner wants out of the envelope system is leakage, so applying the silicone in a controlled environment allows for proper sealing and hold. Silicone application requires testing of the batch through a sticky test. Silicone is applied to the material in a strip and allowed to set for an extended period of time. Once the silicone has hardened, it is removed and compared to the required forces. This testing is completed more easily in the fabrication environment than on-site.

Figure 1.11 displays a typical unitized component for the Center for Health Research and Rural Advocacy project. This would be one individual unit tag with approximately eighty repeated units. Additional panels would be engineered for corner locations, elevation changes, and the café atrium.

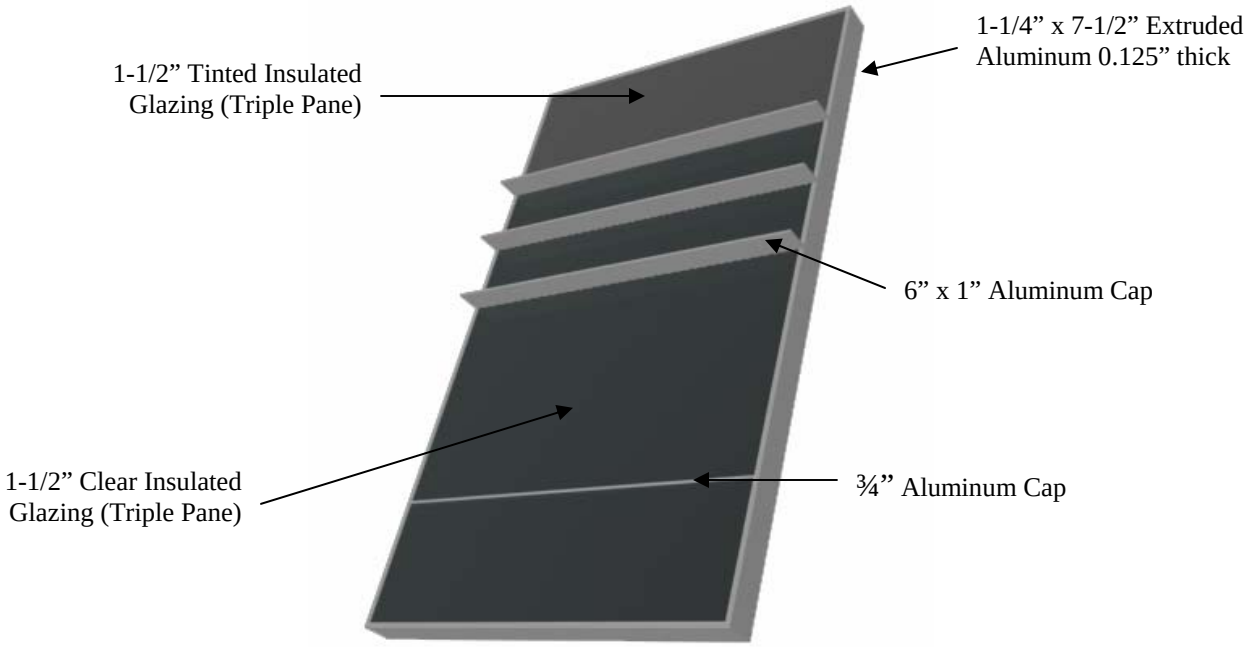

Figure 1.11: Typical Unitized Panel for Aluminum Curtain Wall

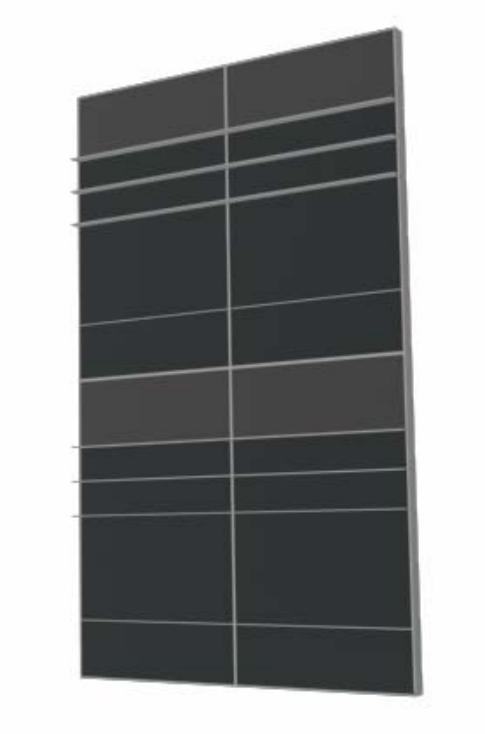

Figure 1.12: Finished Panel Arrangement

The 13' by 8' typical unit above is a repeated component throughout the project; however, as discussed earlier it does not represent all of the curtain wall pieces. This unit only accounts for 80 panels on the project, with an addition 38 panels required for corners, lobby and vestibule areas, and curved elevation locations. Since the panel consists of 70% of the curtain wall area, small savings in production and material costs can add up significantly.

The figure to the left is one of a string of panels erected together. This two story façade encompasses the south elevation and the main entrance lobby to the north. Spandrel glass at the top of each panel is tinted to minimize distracting glares from the midday sun. The clear insulated glass below provides a

comforting view for the employees from their open air offices. Also noticeable in Figure 1.12 is the addition of triple pane insulated and tinted glazing. Triple pane glass is extremely heaving and difficult for stick-built installation; however, it has numerous thermal advantages which will be studied later in this analysis. Since the erection of these panels is in a fabrication facility where proper equipment may be utilized, the addition of the triple pane glass can be easily managed. The structural integrity of the entire system will also be checked to ensure this does not cause unwanted deflection or fracture of structural components.

Once a deliverable quantity of the prefabricated units is complete, they will be made ready for transportation. Transportation is most often on flatbed trucks with custom racks built to hold the unitized panels. Flat panels can be delivered prone, while corner and highly detailed panels will be delivered up-right. Of utmost importance is the proper sequencing of the panels on the trucks. This ensures that the crane will not need to unload panels in shakeout areas prior to erection. The crane can simply lift the panels into position directly off the flat bed.

Figure 1.13: Flat Bed Delivery Staging

Schedule Impact

One main advantage of the unitized system is the minimizing of on-site erection time. This has many benefits such as enclosing the facility faster from the weather, which may be a significant issue in areas of Pennsylvania and the Northeast. For crowded and difficult logistical sites, contractors can benefit from smaller crew sizes during erection of the curtain wall system and achieve similar if not better schedule results.

The project schedule developed by Geisinger Facilities for the curtain wall construction is highly detailed. Tasks are broken up between column lines with durations related to the square footage of glazing. This is an efficient way to separate out the activities since all four elevations are extremely diverse and would be difficult to assess if the tasks are on schedule. Aluminum framing takes approximately seventy days with an additional thirty days for installation of the glazing and sealants. With the curtain wall construction stipulating when the facility is permanently enclosed, it is essential these activities are completed in a timely manner. Drywall and additional interior work may begin as soon as the façade is completed. Please reference the schedule created for the CHRRA project on the next page.

The current curtain wall construction schedule has some interesting aspects. Five days are needed to field test the system to ensure compliance with codes and regulations. The majority of this field testing may be completed at an off-site testing facility saving a majority of those days. There are numerous companies which can perform the testing services at their facilities. One local company facility is Architectural Testing, Inc. located in York, Pennsylvania. This is a mere 100 miles from the subcontractor Kawneer's plant facility in Bloomsburg, Pennsylvania. A unitized component could be fabricated in Bloomsburg and shipped to York relatively inexpensively

Additionally, the glazing and sealant construction starts when framing is finished. If the project schedule becomes condensed, this aspect could easily be accelerated by adding another crew to perform the glass and glazing erection when framing moves to another column line. This would save an additional thirty days to the schedule and building enclosure milestone.

The schedule following the actual sequence schedule has been developed for the CHRRA project if a unitized construction approach was taken. These are activities which occur on site and do not include warehouse facility planning and sequencing which is completed by the contractor and not governed by the construction management team. Erection sequencing has been determined according to case study projects provided by Harmon Inc. On-site workforce includes one crane operator, three ironworkers, and two sealant installers. This labor crew can install 11 unitized panels in one day.

Since erection of the unitized components will be governed by the number of panels between column lines, it will be significantly easier to determine if the schedule is being met. The schedule of on-site activities has been reduced from almost 100 days to a little less than 13 days. Granted this number is misleading because many of those remaining 87 days will be spent in the fabrication facility, it however still displays the scheduling advantage of such a program. This would allow the construction manager to accelerate the schedule by 30 days, since the metal panel erection will still require 70 on-site days. A one month saving on the project duration can save a hefty amount of general conditions costs. Deliveries are easily organized by days with trucks comprised of 10 or 11 panels. Employing a three flat bed rotation, one flat bed can be fully loaded and awaiting delivery to site, while another is being loaded with panels, and finally the other is being unloaded at the project site. This ensures that the crew on-site will always have a delivery of panels ready for at least one day in advance which may help alleviate any unforeseen accidents.

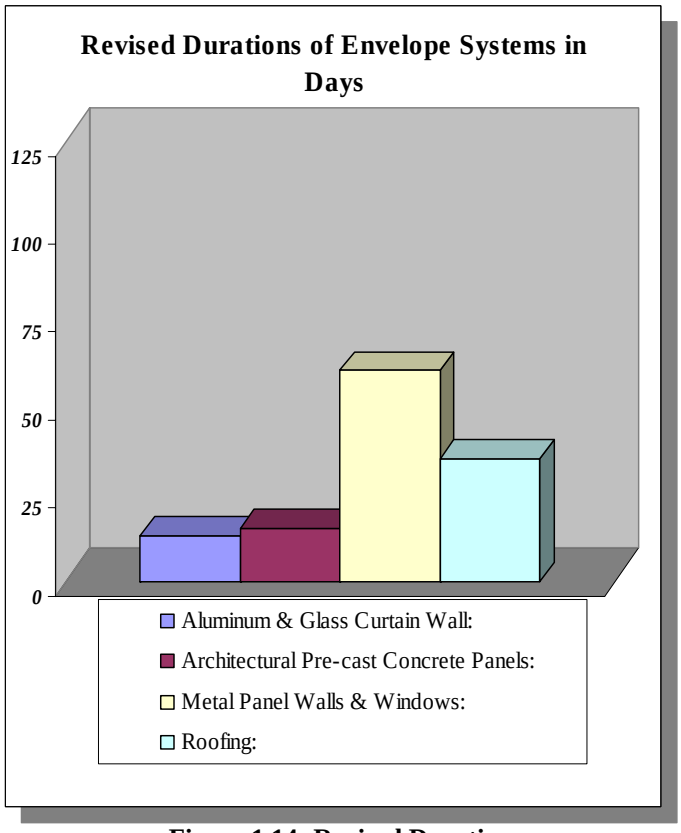

Figure 1.14: Revised Durations

The field test can also be reduced to one day since many of the testing procedures have already been conducted at a third party testing facility. Single day tests will be much less sophisticated and can be completed without disturbing the panel erection operation.

Cost Impact

Utilizing a prefabricated approach for curtain wall construction has some monetary advantages, especially if the activity is on the critical path. By minimizing on-site erection time for the aluminum curtain wall construction, the activity is no longer on the critical path. The metal panel walls and windows, which begin construction at the same time as the aluminum curtain wall, now becomes the controlling activity on the schedule. Since the final roofing tie-ins where scheduled to follow aluminum glazing, the tie-ins can now begin upon completion of the metal panel system. This simple recalculation of the critical path will save forty days on the project which is of considerable monetary value for general condition costs.

There are some additional costs associated with the unitized approach if the selected contractor does not already have the infrastructure set up to perform a job in this manner. Subcontractors need to be informed of this type of delivery prior to bidding to make sure that all parties are bidding on the same construction process. According to interviews with individuals at Harmon, Inc., the first costs of setting up a prefabrication facility can be made up quickly and easily in schedule and manpower savings. Harmon's preferred delivery method has shifted to almost 95% unitized systems manufactured off-site. Since Kawneer, the aluminum curtain wall subcontractor, was selected based on a stick-built system, the related costs of setting up a prefabricated system are going to be explored. Please reference the new budget costs for the Center for Health Research and Rural Advocacy on the following page.
Note: Triple pane glass for the unitized system is not included in this sheet. It is to be compared in a later section.

As is seen in the revised budget for the curtain wall, there is a savings of approximately $100,000 in manpower costs associated with using cheaper labor in a warehouse environment as opposed to skilled labor on-site. The skilled laborers are only needed for on-site erection of the panels which takes 13 days, which is much less than the originally 100 days needed. Costs linked with starting a prefabrication facility for a single job are included in the rental section and additional labor costs in the revised budget. These costs include renting a large facility which can accept material deliveries and have ample space for lay-down of completed panels before shipment. Since the on-site erection takes 13 days and the warehouse facility requires 40 days to unitize. These costs required to start the manufacturing facility equal the savings garnered through wage rates.

Revised Budget for Aluminum Curtain Wall Construction

Center for Health Research and Rural Advocacy
Danville, Pennsylvania

Material

Item No.	Item Description	Unit	Total Units	Unit Cost	Total Cost	Original Budget	Deviation	Notes
M001	2-1/2" x 7-1/2" Extruded Aluminum 6063-T5 .125" Thic	LF	4280	$16	$68,480	$68,480	$0	
M002	5/8" Insulating & Spandrel Glazing	SF	13,750	$36	$495,000	$495,000	$0	
M003	Column Covers	EA	6	$2,700	$16,200	$16,200	$0	
M004	Aluminum Doors & Glazing	EA	8	$5,000	$40,000	$40,000	$0	
				Total	**$619,680**	$619,680	$0	

Labor

Item No.	Item Description	Unit	Total Units	Unit Cost	Total Cost	Original Budget	Deviation	Notes
L001	(6) Skilled Laborers for On-Site Construction ($48/Hr)	Days	15	$384	$34,560	$261,120	$226,560	(10) Laborers - 70 Days; (4) Laboreres - 30 Days
L002	(1) Superintendent On-Site ($55/Hr)	Days	20	$440	$8,800	$44,000	$35,200	(1) Superintendent - 100 Days
L003	(1) Project Manager ($60/Hr)	Days	120	$480	$57,600	$57,600	$0	
L004	(1) Warehouse Manager ($55/Hr)	Days	120	$440	$52,800	$0	($52,800)	Not Originally in Budget
L005	(8) Assembly Laborers for Warehouse ($42/Hr)	Days	40	$336	$107,520	$0	($107,520)	Not Originally in Budget
	*Hourly Rates from ISEC Incorporated; New Census Bureau Project			**Total**	**$261,280**	**$362,720**	**$101,440**	

Rentals: Equipment and Facility

Item No.	Item Description	Unit	Total Units	Unit Cost	Total Cost	Original Budget	Deviation	Notes
E001	Additional Crane Rental	Month	1	$12,200	$12,200	$0	($12,200)	
E002	Forklift	Month	3	$700	$2,100	$2,600	$500	Pneumatic Tire cheaper than All-Terrain
E003	Warehouse Rental (3 Months @ $1.1/SF)	SF	20,000	$1.5	$90,000	$0	($90,000)	
E004	Additional Equipment Rental Contingency	EA	1	$10,000	$30,000	$0	($30,000)	
	*From General Conditions Estimate in Existing Conditions			**Total**	**$104,300**	**$2,600**	**($101,700)**	

General Condition Savings ($37,456 per Month)

Item No.	Item Description	Unit	Total Units	Unit Cost	Total Cost	Original Budget	Deviation	Notes
GC001	General Condition Savings for Revised Schedule	Weeks	8	($9,364)	($74,912)	$0	$74,912	
	*From General Conditions Estimate in Existing Conditions			**Total**	**($74,912)**	**$0**	**$74,912**	

Grand Total	**$910,348**	**$985,000**	**$74,652**	Cost savings using unitized construction method

CENTER FOR HEALTH RESEARCH AND RURAL ADVOCACY
DANVILLE, PENNSYLVANIA
MICHAEL VERGARI
CONSTRUCTION MANAGEMENT
ADVISOR: DR. RILEY

The Center for Health Research and Rural Advocacy will use 130 unitized panels for the aluminum curtain wall which is about the breakeven point for a unitized façade. More units would increase the savings and fewer units would make the option more expensive to implement. For Geisinger Facilities, the major monetary funds which are saved using this prefabricated approach are in the general conditions costs accrued over the life of a project. By being able to delete 40 days from the critical path, this equates into two months of general conditions cost, including items such as temporary utilities and site facilities.

Savings from using a unitized system would have been even larger if subcontractors would have bid on this approach. This would ensure that the contracted entity could perform a unitized system at a competitive cost without the additional facility setup expenses. Without having to pay for change orders in regards to the manufacturing plant, the savings to the Geisinger Health System would have been in the area of $175,000, or a 1% savings on the project.

Mechanical Analysis of Extra Glazing

An additional area to differentiate between the two construction approaches is the mechanical savings of utilizing a triple-pane glass system. All glazing types have different rates for the amount of heat retained between the inside and outside panes. Single pane glass has very low R-values since most of the heat is transferred from the warm inside to the outside through direct contact. R-values of double pane alternatives range from 1 to 3, which can be considered as the windows ability to resist heat transfer. Triple pane glazing is even more efficient and can have a value as high as 9. This can equate to significant savings in energy usage as well as comfort of the building occupants. If the window promotes heat transfer, the inner side of the glass will be significantly warmer than the ambient air temperature in the facility. This will cause undesirable air currents moving throughout the project.

Triple pane glazing combines the use of three layers of lites with ½" air spaces filled with argon gas. The argon gas inhibits additional transfer of heat from glass to glass. UV transmittance is also significantly lower with triple pane glass and can be as low as 5%, compared to 20% transmittance of double pane alternatives.

Calculations

Simply comparing R-values does not adequately display the entire mechanical efficiency of the system. Using the equation for heat transfer:

$$Q_{Glass} = (T_o - T_i) * A / R_{Glass}$$

Where:

Q_{Glass} = *Heat Transfer Rate*
T_o = *Outside Ambient Air Temperature*
T_i = *Inside Ambient Air Temperature*
A = *Area of Glazing*
R_{Glass} = *Heat Transfer Coefficient*

Double Pane Glass:

Heating: Q = (10 – 68) * 13,750 SF / 2 = (398,750) BTU/hr
Cooling: Q = (88 – 72) * 13,750 SF / 2 = 110,000 BTU/hr

Triple Pane Glass:

Heating: Q = (10 - 68) * 13,750 SF / 9 = (88,611) BTU/hr
Cooling: Q = (88 – 72) * 13,750 SF / 9 = 24,450 BTU/hr

The indoor ambient air temperature for the summer is assumed to be 72^{0F} and the winter is 68^{0F}. Outdoor temperatures for Danville, Pennsylvania are taken from the 97.5 percentile temperature for that season.

Some interesting results come from the linear relationship of the R-value and the heat transfer rate. A 400% increase in R-value equates to more than 1/4 the heat transfer rate during the winter, or gained during the summer. Upon adding one additional pane of glass and ½" air space with argon, the R-value of the system went up by a factor of 4.

Since large aluminum curtain walls utilize large panes of glass, large amounts of heat are lost through this medium as well as the additional headaches caused by drafts and cold glass. One remedy for this is installing a radiant heating system around the base of the curtain wall to reduce unwanted drafts and heat loss. The Center for Health Research and Rural Advocacy design team offset this aspect with the use of a Sterling/VB-AR-PM finned tube radiation system. Figure 1.16 is an example of a finned tube radiation system. Two specific types of these are used around the curtain wall; one of which employs two rows of coils and the other only a single row. The double row gives off 1,540 BTU/HR*FT and the single gives off a relative 1,010 BTU/HR*FT. By performing a take-off of the linear feet of each type of radiant heat application, it can be determined if the additional triple pane glass can offset the need for the radiant heating system, or at least to size them down.

Figure 1.16: Finned Tube Radiation System

Finned Tube Radiation Take Off

Type	LF	BTU/HR*FT	Total BTU/HR	$ Cost/LF	$ Cost
1 Row	380	1,010	383,800	$82	$31,160
2 Row	202	1,540	311,080	$101	$20,402
		Total	694,880		$51,562

Glazing Calculations

Type	SF	Total BTU/HR
2 Panes	13750	(398,750)
3 Panes	13750	(88,611)
	Savings	(310,139)

All 1 Row Radiation

Type	LF	BTU/HR*FT	Total BTU/HR	$ Cost/LF	$ Cost
1 Row	382	1,010	385,820	$82	$31,324
3 Panes			310,139		
		Total	695,959		$31,324
		Difference	**(1,079)**		**$20,238**

Figure 1.17: Mechanical Costs of Replacing 2-Row Finned Tube Radiation

As can be seen in the preceding calculations, approximately $20,000 would be saved by using the 1-Row radiant heaters coupled with the triple pane glass; however, this must be compared with the additional costs in material for triple pane glazing. The total LF of radiant heaters can be minimized in order to maintain a properly sized system.

Many triple pane glass costs can be competitively priced with low-e double pane glass, but since a high quality gas filled glazing is needed to achieve the R-value of 9, there is a price premium. Triple pane will cost approximately 5% more than its high quality double-pane counterpart. With the 1-1/4" glazing costing 5% more than the traditional 2-pane glass, this equates to an additional $24,750 in material costs on top of the budgeted $495,000. The net costs of the proposed system are an additional $4,750.

Conclusion

After engaging in the mechanical analysis of utilizing the triple pane panelized system, it is difficult to make a distinction based on the cost of the triple pane glazing. Triple pane also has several mechanical advantages over traditional double pane, including lower UV transmittance, heat transfer, and comfortable areas for users, which may help garner the additional funding. Cooling load will also decrease due to less solar heat gain during the summer months. This will create a more efficient system and allow for savings in energy costs during the life-cycle of the facility. Since the triple pane is still a viable option, the integrity of the structure must be checked to ensure system compliance with codes and safety requirements.

Structural Analysis of Extra Glazing

When checking for alternative construction approaches or system alterations, it is important to ensure that the integrity of the system has not been jeopardized. This can range from structural impacts to mechanical changes and even to acoustical issues. The proposal of the triple pane glass in lieu of the insulated glazing will increase the weight of the curtain wall system on the structural frame. Figure 1.18 is a detail of the curtain wall connection at typical locations.

The typical connection to the prefabricated aluminum panels at the curtain wall occurs through a 4" wide by ½" thick steel plate welded to the flange of the column. Two ¾" bolts are fitted in the slots, which allow for vertical correction if floor to ceiling heights are not correctly field verified. As is the case with unitized systems, the interfaces between the panels and other systems are often the most difficult field conditions, thus flexibility must be built into each panel assembly. These flexible aspects must be included since steel and concrete contractors have tolerances in erection which the curtain wall contractor must interact with.

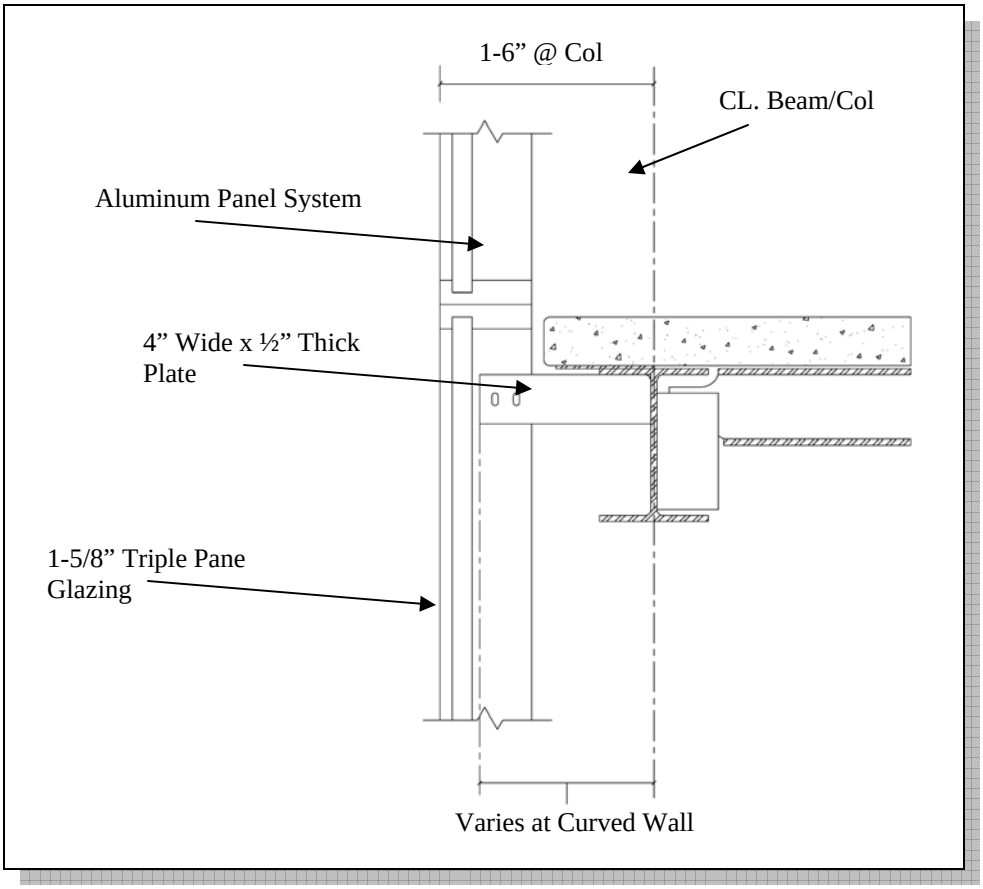

Figure 1.18: Structural Detail at Curtain Wall Connection

One of the disadvantages of triple pane glazing is the additional weight imposed on the structural members. With ¼" double pane glazing weighing 7.0 lbs/SF without the framing members, the additional sheet of glass brings the weight of the glazing up to 10.4 lbs/SF. Aluminum 6063 T-5, 2-1/2" x 7-1/2" and .125" thick framing members weigh 1.76 lbs/SF which equates to 96.8 lbs of aluminum

framing. The structural system must support the weight of typical panel consisting of 13' x 8' triple pane glazing and 55 SF of .125" thick aluminum equal to panel weighing 1,178.4 lbs. This compared to the original design of double pane glazing weighing 824.5 lbs. An additional 354 lbs of force imposed on the bolt and weld connections may cause some structural instability.

The first structural analysis will involve checking the ¾" bolt connections between the curtain wall and the steel beams. Checking the bolts for direct shear from the 1.18 kips of force from each aluminum frame; each bolt needed to support .6 kips. Using the AISC Manual of Steel Construction: Third Edition, the A325 bolt, with exclusion of threads from shear plane, is able to withstand 15.9 kips of direct shear force. Following the direct shear, both the bearing and tear-out of the bolt arrangements were checked to see the force able to withstand. Both tests yielded positive results with the strength of the plate far outweighing the load on the bolt arrangement. Appendix B.2 has the calculations for the bolt shear, bearing, and tears out.

Since the connection of the panel to the frame will not fail, the next analysis will be to determine if the structural columns supporting the curtain wall will withstand the additional loading. This will be determined by calculating the total loads on a column with the additional weight of the panelized triple pane system included. Column F-10.1 will be used for the calculation since it is one of only four columns which are required to carry three stories of the panelized curtain wall. If the additional weight does not require resizing the member, the additional columns will assume to be compliant. This column is also required to support the open space office area with a 70 PSF live load. Appendix B.3 has the structural calculations for the column. The following figures are the summary of the calculations for the structural impacts.

Bolt Connections

Property	*Design Load*	*Actual Load*	
Shear	15.9 Kips	0.589 Kips	**ok**
Bearing	52.2 Kips	0.589 Kips	**ok**
Tear Out	53.3 Kips	0.589 Kips	**ok**

Column

Property	*Design Load*	*Actual Load*	
Compression	569 Kips	55.6 Kips	**ok**
Buckling	50 Ksi	28.11 Ksi	**ok**
Flexure	1	0.46	**ok**

Figure 1.19 Structural Analysis Results

Upon checking the structural system for impacts regarding the addition of triple pane glazing, the implications are not major. The structural integrity of the design has not been jeopardized and actually passes the major tests. Since triple pane only accounts for an additional 4 lbs/SF of the curtain wall area, the major design systems are not affected. This additional weight on the structural column is only a small percentage of the total compressive load it supports.

Conclusion

The aluminum curtain wall construction was an obvious area for analysis based on its large cost and schedule constraints. Comprising six percent of the total project cost and a duration of 100 days, small savings in cost or schedule acceleration would greatly influence the flow of the construction project. Performing simple value engineering ideas like prefabrication proved to be a valuable asset for the construction management team.

Many preconceived notions of prefabricating systems were discussed in this analysis, ranging from cost and schedule data, to mechanical and structural implications. Often it is difficult to draw a concrete conclusion from so many different areas of analysis, but the unitizing of the curtain wall for the Center for Health Research and Rural Advocacy appears to be a winning combination. The schedule of on-site construction alone is a strong argument for implementation, with related savings in general conditions costs the topping on the cake. Since Geisinger Facilities operates on a budget from the parent Health Services, these savings can be held to counteract unforeseen conditions, change orders, or extreme quality issues. At the end of the day, if the monetary savings are not used, the funds will go back to Geisinger Health Services and another successful project would have been completed.

In addition to the unitized panels, adding triple pane glass and deleting the radiant heaters around the aluminum curtain wall is a wash. Since the mechanical heat loss was not reduced enough to completely eliminate the radiant heaters, at least 1-Row finned tube radiation would be required at some locations. Ultra-violet transmittance would be decreased, which has some benefits in the large open air work areas, but would building occupants notice the difference between 20% transmittance and 5%. The weight of the triple pane system does not cause any additional requirements for the structure, so its implementation is purely based on the owner's perception of the advantages. After performing the analysis, the standard conclusion would be to simply use the original design intent of the insulated glazing with double pane technology. This would alleviate any additional headaches with approval of new shop drawings and design criteria.