ANALYSIS 2|PREFABRICATED FAÇADE

BACKGROUND

The concept of building components to be assembled off site, and shipped onto the project ready for final placement is known as “Prefabrication”. This concept can be applied to different systems in the building including structural, mechanical, plumbing, and the envelope. Concrete buildings can have structural components poured in a controlled environment and then trucked onto the site when they are needed. Plumbers can have pipe ordered, cut, and threaded in the shop and then delivered to site ready for installation. Envelopes can be completely fabricated in a warehouse, safe from the elements, and then dropped off at the site just in time to be put in place. While this practice is gaining in popularity, especially as BIM takes hold and fabricators are seeing the returns on digital fabrication, it is not used widely. Precast facades are one of the more prevalent uses of prefabrication.

Prefabricated facades are an alternative to other traditional envelopes such as hand-laid brick, EIFS, and curtain wall systems. The ability to have higher quality control standards in a more controlled setting during fabrication, allow work to take place offsite thus reducing site congestion, and the fast pace of installation are all factors that make prefab systems desirable for construction projects. The vast finishes for prefab systems increases its appeal to architects for new structures, and this same flexibility also allows it to match existing facades which makes it a good candidate for expansions.

The advantages previously mentioned would be an asset on any construction site. At DCH, three traits factored into the decision to analyze a precast system as an alternate façade: increased installation rate compared to hand laid brick, the ability to match existing facades, and the reduced site congestion.

GOAL

There are three goals for this prefabricated façade section:

1. Analyze impacts of the envelope change on the site logistics, schedule, and cost of the DCH project.
2. Assess impact on structure due to building envelope.
3. Increase envelope insulation properties to aid mechanical system performance.

SYSTEM SELECTION CRITERIA

The project at DCH is an expansion that boasts roughly 37,000 square feet of exterior wall area and it is immediately adjacent to the current hospital. Therefore, the ability of a system to match the brick façade on the existing structure is not only an important issue, but it is in fact the critical issue.

Other factors that will be considered:

- Cost of system
- Weight of the system
- Insulation properties of the system

Two alternative systems are being compared against these criteria as shown in Table 7-CarbonCast vs. Nitterhouse vs. Brick. The best suited alternative will be further investigated looking at its impacts on the previously stated goals.

TABLE 7-CARBONCAST VS. NITTERHOUSE VS. BRICK

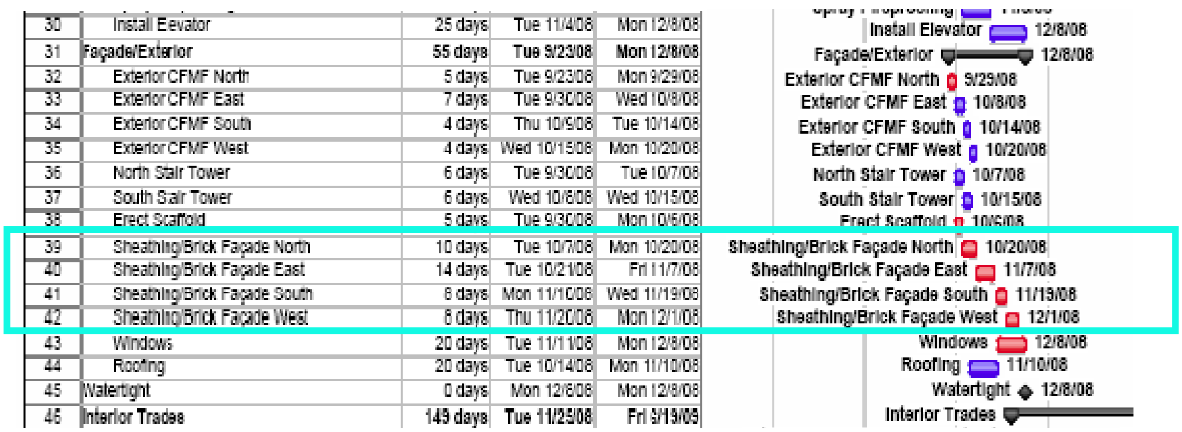
Criteria	CarbonCast	Nitterhouse	Brick Facade
Ability to Match Existing?	A variety of brick finishes can be matched through the use of Thin Brick inlays[1]to the system	Also, using ThinBricks, this product can match a variety of finishes.	Existing building is hand laid brick, so matching is easy
Cost of System?	$37/SF delivered and installed	$35/SF delivered and installed	$28/SF installed
Weight of System?	65 lbs/SF	75 lbs/SF	42 lbs/SF
Insulation properties?	R-Value: 5.4	R-Value: 0.48	R-Value: 0.44

Based on the selection criteria above, even though the cost of the CarbonCast system is $2/SF more than the product from Nitterhouse, the slightly reduced weight, and significantly higher, more than 10 times higher, R-value will hopefully make up this price difference. Therefore, the CarbonCast system will be selected and analyzed more in depth for its impact on the project.

[1] Thin Brick inlays- the practice of using 5/8" thick bricks in cast concrete to recreate a hand-laid brick appearance

SCHEDULE ANALYSIS

One factor for selecting the CarbonCast system was its speed of erection. The current hand-laid brick façade lies on the critical path. Delays early in the project have made getting the building dried in an even more important item. . An excerpt from the CPM schedule, below in Figure 11-Exceprt from CPM Showing Façade Construction on Critical Path, shows that the construction of the envelope lies on the critical path of the project and is the key to getting the project watertight.



30	Install Elevator	25 days	Tue 11/4/08	Mon 12/8/08
31	Façade/Exterior	55 days	Tue 9/23/08	Mon 12/8/08
32	Exterior CFMF North	5 days	Tue 9/23/08	Mon 9/29/08
33	Exterior CFMF East	7 days	Tue 9/30/08	Wed 10/8/08
34	Exterior CFMF South	4 days	Thu 10/9/08	Tue 10/14/08
35	Exterior CFMF West	4 days	Wed 10/15/08	Mon 10/20/08
36	North Stair Tower	6 days	Tue 9/30/08	Tue 10/7/08
37	South Stair Tower	6 days	Wed 10/8/08	Wed 10/15/08
38	Erect Scaffold	5 days	Tue 9/30/08	Mon 10/6/08
39	Sheathing/Brick Façade North	10 days	Tue 10/7/08	Mon 10/20/08
40	Sheathing/Brick Façade East	14 days	Tue 10/21/08	Fri 11/7/08
41	Sheathing/Brick Façade South	8 days	Mon 11/10/08	Wed 11/19/08
42	Sheathing/Brick Façade West	8 days	Thu 11/20/08	Mon 12/1/08
43	Windows	20 days	Tue 11/11/08	Mon 12/8/08
44	Roofing	20 days	Tue 10/14/08	Mon 11/10/08
45	Watertight	0 days	Mon 12/8/08	Mon 12/8/08
46	Interior Trades	143 days	Tue 11/25/08	Fri 3/13/09

FIGURE 11-EXCERPT FROM CPM SHOWING FACADE CONSTRUCTION ON CRITCAL PATH

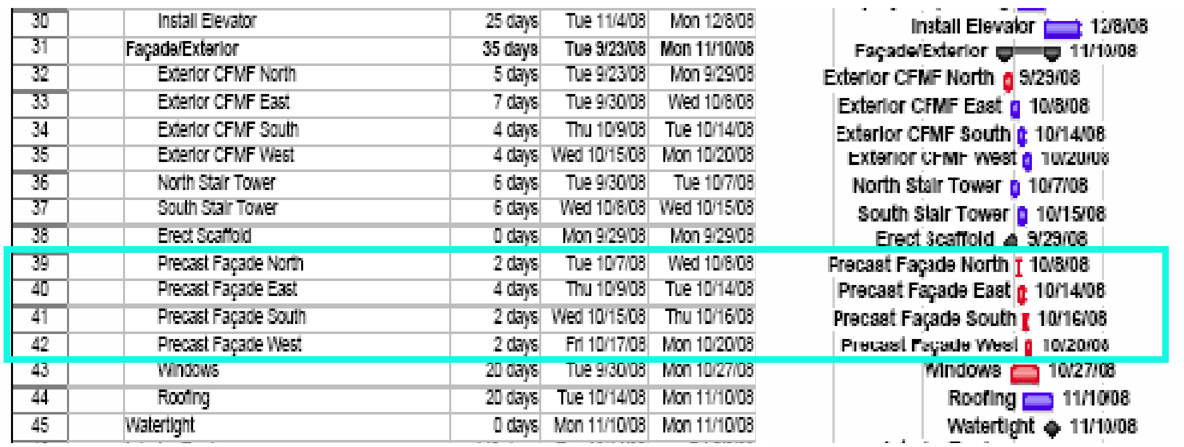
Shortening the duration of critical path activities will generally shorten the overall duration of the project, provided it doesn't move other tasks onto the path. Shown below in Table 8-Comparison of Durations, is a side by side analysis of the durations it would take to complete the façade construction. Making the change from the hand-laid façade to a precast system can shorten the envelope construction time to 25% of its original duration.

TABLE 8-COMPARISON OF DURATIONS

Façade System	Duration (In working days)
Hand-laid Brick Façade	40
Precast	10
Net Difference	Save 40 Days

The duration of the precast system is based on three independent interviews with suppliers of the precast façade. They indicated a typical production rate of erecting 10-30 panels per day. To err on the side of caution, a production rate of 15 panels per day was used for schedule calculations. Maximum panel sizes for shipment without special permitting requirements is 12' x 28'. This yields a maximum square footage of 336 square feet per panel. Not all panels will cover this theoretical maximum, therefore to again err on the side of caution, we will assume

75% effective coverage, or 252 SF per panel. Using the gross building envelope area of 37,127 SF, calculated from the Revit Take off shown in Table 24-Revit Take Off of Exterior Wall Area shown in Appendix V | Take-off Data, 148 panels will be used to cover the building. Based on the previously mentioned production rate of 15 panels per day, the duration shown in Table 8, 10 Days, is reached.



30	Install Elevator	25 days	Tue 11/4/08	Mon 12/8/08
31	Façade/Exterior	35 days	Tue 9/23/08	Mon 11/10/08
32	Exterior CFMF North	5 days	Tue 9/23/08	Mon 9/29/08
33	Exterior CFMF East	7 days	Tue 9/30/08	Wed 10/8/08
34	Exterior CFMF South	4 days	Thu 10/9/08	Tue 10/14/08
35	Exterior CFMF West	4 days	Wed 10/15/08	Mon 10/20/08
36	North Stair Tower	6 days	Tue 9/30/08	Tue 10/7/08
37	South Stair Tower	6 days	Wed 10/8/08	Wed 10/15/08
38	Erect Scaffold	0 days	Mon 9/29/08	Mon 9/29/08
39	Precast Façade North	2 days	Tue 10/7/08	Wed 10/8/08
40	Precast Façade East	4 days	Thu 10/9/08	Tue 10/14/08
41	Precast Façade South	2 days	Wed 10/15/08	Thu 10/16/08
42	Precast Façade West	2 days	Fri 10/17/08	Mon 10/20/08
43	Windows	20 days	Tue 9/30/08	Mon 10/27/08
44	Roofing	20 days	Tue 10/14/08	Mon 11/10/08
45	Watertight	0 days	Mon 11/10/08	Mon 11/10/08

FIGURE 12-CPM EXCERPT SHOWING NEW DATES WITH PRECAST FACADE

Comparing Figure 12-CPM Excerpt Showing New Dates with Precast Facade to the previous dates in Figure 11 illustrates how much time can be saved. The completion date for the façade moves from December 1, 2009, back all the way to October 20, 2009. This six week savings also translates directly to the finish dates of the entire project. The project originally moved off site February 12, 2010, but can now demobilize January 1, 2010. This six week shortening of duration in the facade directly translates into the demobilization date and allows the owner to occupy and begin its revenue flow six weeks sooner.

COST ANALYSIS

Changing out a façade system will not only impact the schedule on a project, but can also have an impact on the financial aspect as well. The overall cost to procure and install the system will be analyzed, as will savings associated with the decreased overhead and possible extra costs due to impacts on other trades.

The initial costs of the system delivered and installed are compared below to the original cost of the masonry façade in Table 9-Cost Comparison of Brick and CarbonCast.

TABLE 9-COST COMPARISON OF BRICK AND CARBONCAST

System	Unit Cost	Total Cost
Hand Laid Brick	From Contract	$ 1,052,419
CarbonCast	$37 per SF	$ 1,373,699
$ Difference		$ 321,280
% Difference of Façade Cost		% 30.5
% Difference of Total Project Cost		%0.94

It is true that CarbonCast is the more expensive system to produce and install. The dollar value per SF used above was provided courtesy of HighConcrete, Inc. A 30% increase in the cost of a particular system is a large increase, but this corresponds to only a %0.94 increase in the overall building cost, which is not incredibly large. .Table 9 only considers the cost of material, delivery, and installation. It does not consider the savings that are outlined below in Table 10-General Conditions Savings.

TABLE 10-GENERAL CONDITIONS SAVINGS

GC Savings	
GC Costs per Week	$ 14,430
Total Weeks Saved	6
Total Saved	$ 86,588,

Scaffolding is no longer needed to install the façade of the DCH project, however, this poses another problem for the sheathing installation. Anning-Johnson, the drywall contractor, was also under contract to install the exterior sheathing. One of the agreements of the deal was that they would be able to utilize the scaffolding provided by the masonry contractor to install the bricks. Since the brick façade is not being used, clearly there will be no mason's scaffolding for them to use. In order to install the sheathing, a boom lift must be rented. This will add to the cost on the order of $3,100 for a four week period, which should be sufficient enough time to complete this sheathing.

Several costs and savings must be considered to determine the final impact of switching to a new system. Table 11-Summary of Financial Impact looks at all the costs and savings associated with the new precast system that have been previously outlined.

TABLE 11-SUMMARY OF FINANCIAL IMPACT

Summary	
Total Added Cost of System	$ 321,280
Total Overhead Savings	$ 86,588
Added Cost for Lift	$ 3,100
Net Cost	$ 237,792
Net Cost as % of Façade	% 22.5
Net Cost as % of Total Project	% 0.69

STRUCTURAL IMPACT

A new façade has the potential to greatly affect the structural system in a building. Significant reductions in dead load can help to reduce member sizes and in turn will decrease the cost of the building. Conversely, a substantial increase in the façade weight will result in an increase in member sizes which will raise the total cost of the project.

CONNECTION DETAILS

First, in order to determine how the load will affect the structure, it must be determined how the gravity load will be transferred to the superstructure. The CarbonCast system, as provided by High Concrete, uses a column connection detail as shown in Figure 13-Typical Panel to Column Connection Detail.

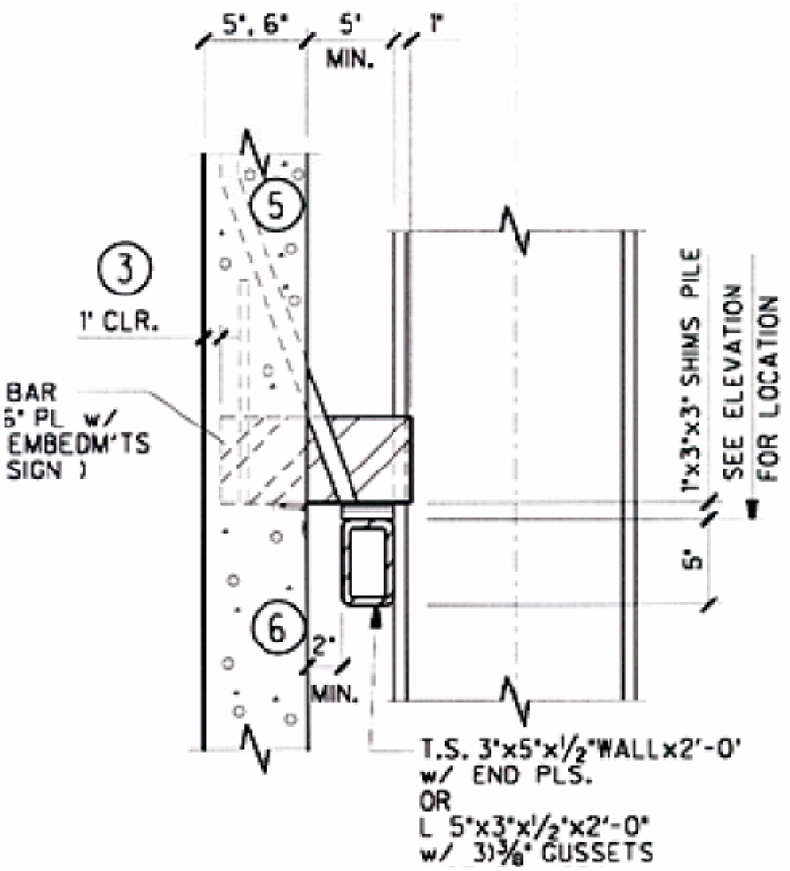


FIGURE 13-TYPICAL PANEL TO COLUMN CONNECTION DETAIL (COURTESY OF HIGHCONCRETE.COM)

This detail shows that the load will transfer directly into the columns and down to the foundation. Hand-laid brick façade would have to transfer to the exterior beam by way of a steel angle before being transferred into the columns. Hopefully, by eliminating this load transfer, the exterior beams can be downsized.

STRUCTURAL CALCULATIONS

Given Parameters and Assumptions (See Appendix VI | Detailed Structural Calculations for complete calculations):

- From IBC 2003, Live Load design weight: 100 PSF for typical floors
- From ASCE 7-05 Table 4-2: Live Load Element Factor, K_{LL}= 2 for Edge Beams and 4 for Exterior Columns
- Allow 15 PSF dead load for suspended HVAC/Electrical/Plumbing
- From Vulcraft Composite Deck Catalog: 43 PSF for 5" LW Concrete deck on 1.5", 20 Ga. Steel deck

Exterior Beam Calculation:

The typical exterior edge beam for the DCH project must support the loads from its tributary floor area, illustrated in Figure 14-Tributary Area for Typical Edge Beam, as well as the exterior brick façade. The current beam size of W16x36 is typical for the edge beams and has a maximum LRFD moment capacity of 240 kip-ft.

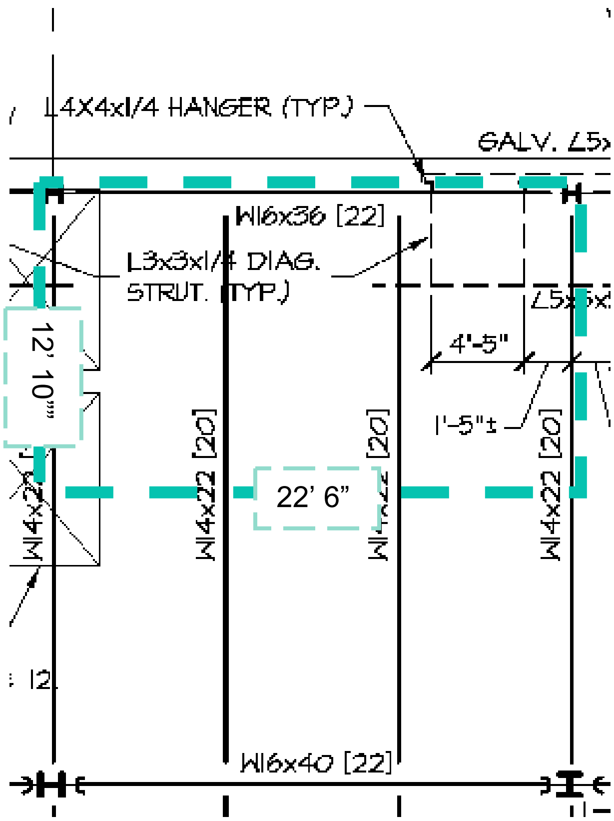


FIGURE 14-TRIBUTARY AREA FOR TYPICAL EDGE BEAM

Using the LRFD method, the beam will be designed to:

$$\Phi M_n > M_u$$

The reduced live load based on the tributary area equals 87.5 PSF. The total deal load used for the calculations is equal to 58 PSF. Using the equation for load combination 2 from ASCE, the total design load is:

$$1.2D + 1.6L = 1.2(58) + 1.6(87.5) = 209.6 \text{ psf}$$

Based on the calculations put forth in Appendix IV, this design load translates into

$$M_u = 151.2 \text{ kip ft}$$

for the live loads and structure self-weight. This does not include the weight of the brick façade, which based on detailed calculations in the appendix, adds an additional 41.2 kip-ft to the design moment. The final equality for the LRFD design:

$$\Phi M_n = 240 \text{ kip ft} > 192.4 \text{ kip ft} = M_u$$

Based on the above equality, it is clear that even with the design load of the brick façade included, that the beam is sized to a much larger capacity, indicating that loads other than gravity loads are controlling the design of the typical exterior beam. This fact also means that reducing the load on the beam from the brick façade by transferring it directly to the columns with the precast system does not impact the size of the typical edge beam.

Column Calculation:

In order to assess the impact on the columns of the structure, the new loads imposed by the change in façade will be analyzed along the entirety of one typical exterior column tower.

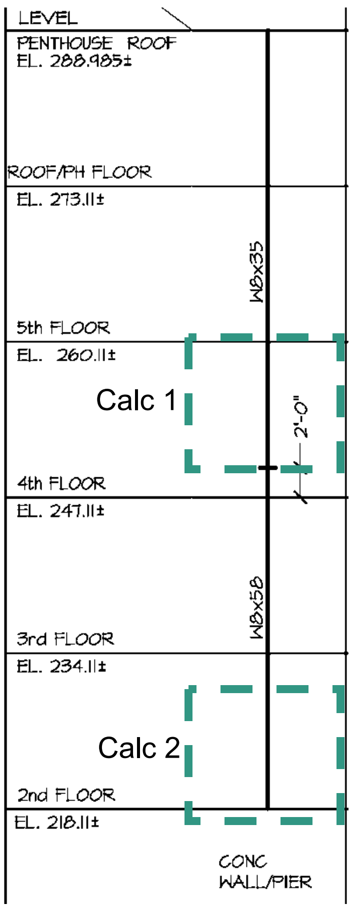


FIGURE 16-TYPICAL EXTERIOR COLUMN TOWER

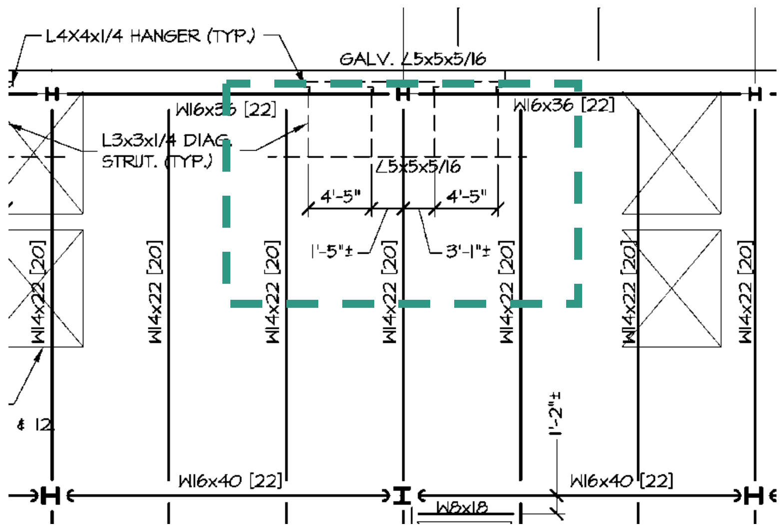


FIGURE 15-TRIBUTARY AREA FOR EXTERIOR COLUMN

Two critical areas will be evaluated for the new loading conditions. These areas, boxed out in Figure 16-Typical Exterior Column Tower, are the areas that carry the most load for each column size, and thus must be checked to ensure that they can withstand the imposed loads

As with the beam calculations, the same parameters and assumptions will be followed that are established at the beginning of this subsection.

Using the LRFD method, this column will be designed to:

$$\Phi_c P_n > P_u$$

The reduced live load based on the tributary area equals 50 PSF. The total deal load used for the calculations is equal to 58 PSF. Using the equation for load combination 2 from ASCE, the total design load is:

$$1.2D + 1.6L = 1.2(58) + 1.6(50) = 149.6 \text{ PSF}$$

Based on the calculations put forth in Appendix VI, this design load translates into

$$P_u = 186.2 \text{ kips}$$

for the live loads and structure self-weight. The P_u value above also includes the 57 kips that is added from the CarbonCast façade system. The final equality for the LRFD design:

$$\text{For W8x35:} \quad \Phi_c P_n = 300 \text{ kips} > 186.2 \text{ kips} = P_u$$

Similar, calculations were conducted to analyze the second highlighted area from Figure 16. The detailed calculations can be found in the appendix. The final equality for the LRFD for the second set of calculations:

$$\text{For W8x58:} \quad \Phi_c P_n = 514 \text{ kips} > 296.7 \text{ kips} = P_u$$

Based on the above equalities, the current column design will be able to support the change in the façade system. Therefore, even with the additional dead loads from the heavier system, no redesign must occur in order to facilitate the change.

MECHANICAL IMPACT

A new façade does not only affect the structure, but it can also impact the mechanical system of a building as well. If the R-Value is increased, the spaces will not gain as much heat from the exterior during the summer and will not lose as much heat to the outside during the winter. This change can impact both the boiler and the chiller size needed for the project.

The first step is to determine the R-value for each façade system. Tables 12 and 13 show the component break down of each wall system and the corresponding R-values attributed to that material.

TABLE 12-R-VALUE CALCULATION FOR BRICK FAÇADE (OLD SYSTEM)

Brick Façade			
Component	**R-Value**	**Thickness (in.)**	**Total R-Value**
Outside Air Film	0.17	-	0.17
Brick	0.11	4	0.44
Air Gap	0.94	1	0.94
Ext. Gyp Board	0.63	0.63	0.40
Batt Insulation	3.14	6	18.84
Int. Gyp Board	0.63	0.63	0.40
Inside Air Film	0.68	-	0.68
		Total	**21.86**
		U-Value	**0.0457**

TABLE 13-R-VALUE CALCULATION FOR CARBONCAST (NEW SYSTEM)

CarbonCast			
Component	**R-Value**	**Thickness (in.)**	**Total R-Value**
Outside Air Film	0.17	-	0.17
Concrete	0.08	3	0.24
XPS (Extruded Polystyrene)	5.00	1	5.00
Concrete	0.08	2	.16
Ext. Gyp Board	0.63	0.63	0.40
Batt Insulation	3.14	6	18.84
Int. Gyp Board	0.63	0.63	0.40
Inside Air Film	0.68	-	0.68
		Total	**25.88**
		U-Value	**0.0386**

In each of the tables, the U-value, or heat flow through an assembly, is calculated by the formula: $U = 1/R_{total}$. This U-value will be the basis for the comparison of the systems performance in insulating the building. Table 14-Temperature Design Considerations, shows the temperature for summer and winter design conditions in Washington, DC, and these calculations will assume 72 degree inside air at all times.

TABLE 14-TEMPERATURE DESIGN CONSIDERATIONS

Design Temperatures (F)		
	Summer	**Winter**
Outside Air (T_o)	95	0
Inside Air (T_i)	72	72
Temp. Difference (ΔT)	23	72

Using the equation for heat transfer, $h = A * U * \Delta T$, the affects of the new system compared to the existing system. Since windows are not being changed for either system, their effect on the heat transfer calculations has been omitted. Tables 15 and 16 show the impacts of the assemblies on the heat gain and heat loss of the DCH building and this impact on energy costs of operation. Table 17-Analysis of Savings and Payback Period analyzes the total savings and determines the payback period for the costs of this system that is not covered by the overhead savings. The cooling season and heating for Maryland area were both assumed to be 4 months.

TABLE 15-SUMMER HEAT GAIN CALCULATIONS

Summer Heat Gain					
System	Area (SF)	U-Value	ΔT (F)	Heat Gain (MBTU's)	Heat Gain (Tons)
Brick Façade	37,127	0.0457	23	114,263	9,522
CarbonCast	37,127	0.0386	23	96,511	8,043
				Difference (Tons)	**1,479**
				Difference (kWh)	**5,198**
				Savings @ $.128 per kWh	**$ 665.32**

TABLE 16-WINTER HEAT LOSS CALCULATIONS

Winter Heat Loss				
System	Area (SF)	U-Value	ΔT (F)	Heat loss (MBTU/Season)
Brick Façade	37,127	0.0457	72	357,692
CarbonCast	37,127	0.0386	72	302,121
			Difference (MBTU)	**55,571**
			Difference (kWh)	**16,271**
			Savings @ $.128 per kWh	**$ 2,082.73**

TABLE 17-ANALYSIS OF SAVINGS AND PAYBACK PERIOD

Savings Analysis	
Cooling Savings	$ 665.32
Heating Savings	$ 2,082.73
Total Annual Savings	$ 2,748.05
Payback Period	86.24 years

While the savings from the improved insulation in the façade are not substantial, they are a move in the positive direction. Ideally, a payback period would not be 86 years, but rather only a few years to make it a worthwhile investment. This payback period is based on the time it would take for the annual savings to recoup the additional $237,000 from Table 11. However, the mechanical gains are a nice incentive considering the already proven schedule gains.

CONCLUSIONS AND RECOMMENDATIONS

Changing the envelope of a building has wide reaching effects on a project. In this specific case, the construction duration was shortened by six weeks, resulting in savings on overhead and allowing the revenue stream to start sooner for the hospital. Structural systems and mechanical systems can also be impacted by a new façade. In this case, while there were no significant gains in these systems, the new façade did not adversely impact them either. In fact, there even proved to be a cost benefit in the operations cost of the facility through energy savings.

Considering all the effects on the project, the switch to precast does not seem to be advisable. Even though the positives of a reduced schedule and the slight mechanical benefits are encouraging, the upfront initial costs are too high to make this a worthwhile investment.