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Dear AE Faculty,

Enclosed is my Senior Thesis final notebook representing the requirements for the completion of AE 481W and AE 482. This Construction Management focused thesis has a proposal that I feel is progressive and forward thinking. The topics researched, though based in engineering principles, are not necessarily formed in practical application, but are however something I feel can drive the construction industry in the 21^{st}Century. Thank you for allowing me the opportunity to creatively seek solutions to the current state of our industry.

A special thanks to **all** the professors I had in preceding course work at Penn State AE!

Best Regards,

Josh Nicholson

Executive Summary

The Pennsylvania State University's Office of the Physical Plant (OPP) commissioned for the design and construction of an 811 bed undergraduate dormitory complex on the southeast corner of its University Park Campus. The OPP selected Hayes Large Architects to provide design and document development along with Turner Construction Company to provide pre-construction and construction management services for the project. Eastview Terrace Housing Project is being delivered as a CM at risk with a fast-tracked schedule to adhere to a July 2004 absolute completion date.

This paper represents the culmination of two semesters of study into the investigation of this facility; it's planning, design, and construction. The first section attempts to outline the parameters in which the facility was planned, designed, and currently constructed. This includes the existing conditions with respect to design and construction, project team and selection thereof, schedule, and budget. (Fall 2002) The second section is an adaptation of construction engineering principles of project delivery, value engineering, constructability, and systems engineering and integration. These areas are investigated with respect to the existing conditions and constraints determined in the first section.

Topics researched and applied to this thesis include:

- Project delivery system selection (research topic)
- Production planning/implementation in construction
- Absorption & adsorption chiller alternatives
- Prefabricated bathroom units

The above areas are investigated under two defining project constraints determined early in program development by Penn State OPP. These include: 1) an exceptionally short construction schedule (23-months) and 2) an attempt to find a best value in mechanical systems engineering. These were determined from the project Request for Proposal (RFP) and from discussions I had with OPP.

Acknowledgments

I would like to thank the following people, companies, organizations, and friends for their support, expertise, and assistance in this endeavor:

- ♦ My Family
- ♦ AE Friends
- ♦ Dr. Michel Horman (Advisor)
- ♦ AE Faculty
- ♦ Penn State OPP
- ♦ Turner Construction Company
- ♦ Larry Bair (PSU OPP)
- ♦ Jon Whitmore (Turner Construction)
- ♦ Brinjac Engineering
- ♦ Hayes Large Architects
- ♦ Jonathan Teicher (Hayes Large)
- ♦ Mike Kenig (Holder Construction Co.)
- ♦ Steve Maruszewski (PSU OPP)
- ♦ Glenn Lelko (PSU OPP)
- ♦ Hensel Phelps Construction Co.
- ♦ Dr. Eric Burnett
- ♦ Lee Shu Hao (Housing & Development Board – Singapore)
- ♦ Georgia State Financing and Investment Commission
- ♦ Penn State University (for the degree)

Project Design Considerations

Introduction

The Eastview Terrace Housing project is a multi-building complex that will reside on the corner of University Drive and College Avenue at Penn State University in State College Pennsylvania. The completed project will consist of seven dormitory-style buildings raising various levels above grade and a separate chiller plant. The 336,602 square foot complex has a $75,000,000 budget with an estimated $65,000,000 in construction costs. The construction schedule is slated to run from June 2002 to July 2004 and is currently in structural steel erection.

Some of the most unique features of this building correlate directly to the highly sloped site. Hayes Large Architects, the architects for this project, wanted to use this site feature to create "an intimate community scale and terracing reminiscent of Mediterranean hill towns." This means each level of a particular building will exit to a different elevation on the site, much like the current dormitories of West Halls on campus. The seven buildings, labeled 'A' through 'G' at the present, will house 811 beds divided among 62 clusters within the buildings to create a "small scale identity." Each building will consist of a structural steel frame with composite metal decking and a brick curtain wall façade.

Primary Project Team:

Owner:	Penn State Office of the Physical Plant
Architects:	Hayes Large Architects Childs Bertman Tseckares, Inc. Wallace Roberts & Todd, LCC
Construction Manager:	Turner Construction Company
MEP Engineers:	Brinjac Engineering, Inc.
Geotechnical:	Gannett Fleming, Inc.

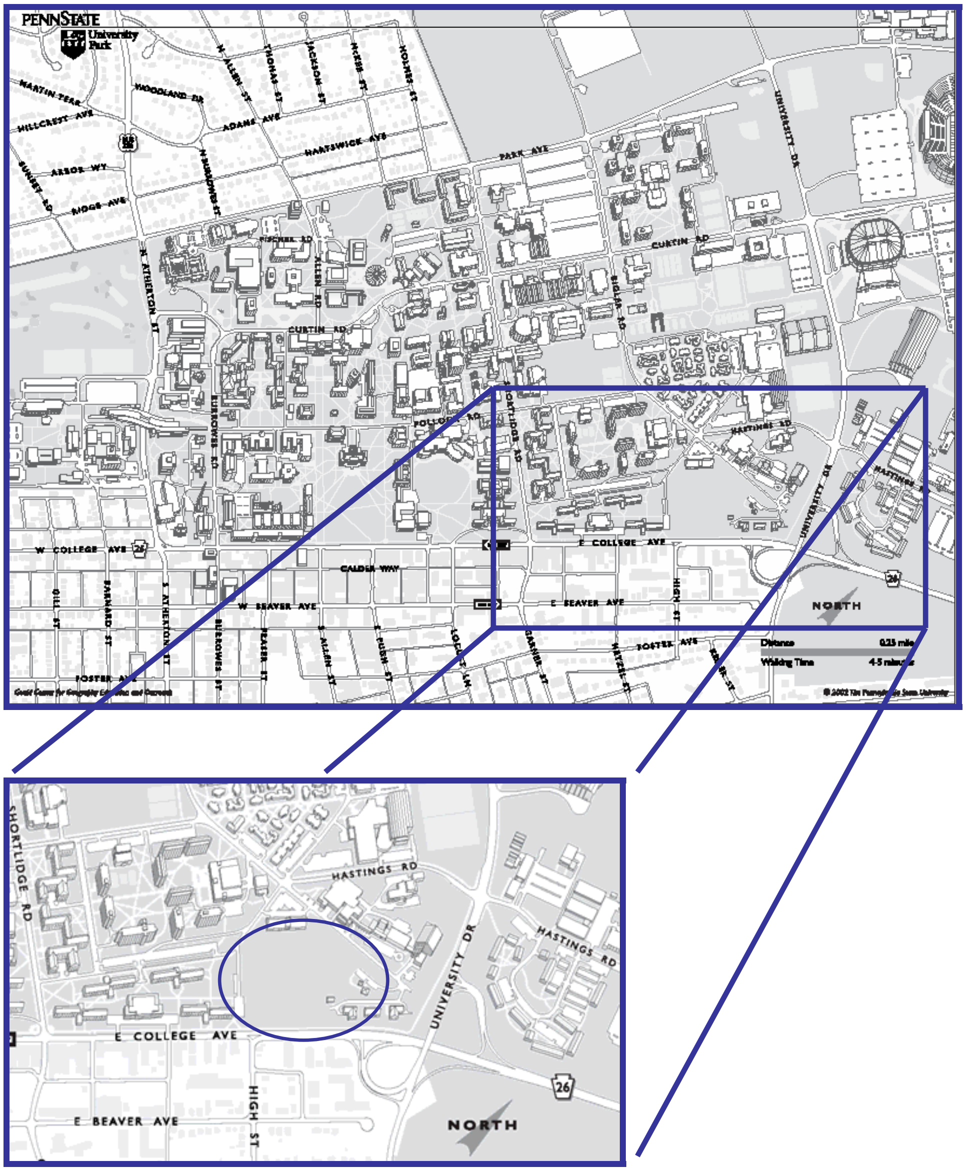
Dates of Construction:
May 2002 – July 2004

Budget:
Project Budget - $75,000,000
Construction Costs Estimate - $65,000,000 -GMP

Historical:

The original site contained 30 single story WWII era housing units that have been demolished and removed. The recommendation to restore was addressed by Penn State but the use of asbestos building materials and the overall deterioration of the buildings made restoration unrealistic.

Location and Site:



Penn State University - www.psu.edu

The buildings will be located on a 13-acre plot in the southeast corner of Penn State's University Park Campus along University Drive and East College Avenue. The seven buildings will form a U-shape, which opens to College Avenue by way of a major landmark stair that leads into the central courtyard above. The site has a large slope that will be graded into terracing or levels at which each separate build will be built. In the middle of the site, an underground water detention facility will be erected to control site storm water and prevent excessive erosion. Please see the appendix for a building layout drawing.

Architecture:

Eastview Terrace will be reminiscent of a Mediterranean hill town. The use of terracing on the site will create a unique topography similar to that of existing West Halls in the Northwest corner of campus. The buildings will range from three to four stories, depending on the level of grade, plus a basement. A grassy commons area in the middle of the buildings will tie them together. To create a smaller community scale to such a large complex, the dorms are broken into 62 “pods” that will contain approximately 11 students each. Each floor will contain two or three pods, depending on the building configuration, that consisting of 11-15 dorm rooms, a laundry facility, kitchenette, living room, and study lounge. The rooms will all have private baths. One of the more unique features of the buildings will be a suspended footbridge connecting the two second-floor pods of building “A”. There are also trellis details suspended above exterior sitting areas to bring a more human scale to this large complex.

Applicable Codes, Permits, and Approvals:

- 1996 BOCA Building Code regulates State College building construction
- Land Development Plan Approval
- Highway Occupancy Permit
- Erosion and Sedimentation
- Sewer Module
- Pennsylvania Labor and Industry Review
- Site Construction Permit
- Foundation and Steel Permit
- Building Construction Permit

Building Envelope:

The exterior will be face brick façade with custom metal architectural accents at corners and around windows. A typical wall section will consist of a 4” face brick veneer, 2” air space, 2” rigid insulation, vapor retarder, 5/8” exterior gypsum, 6” metal (16 ga) studs @ 16” o.c., and 5/8” interior gypsum.

Electrical:

Six 3-phase electrical service connections feed all seven structures with buildings ‘A’ and ‘G’ sharing connections. The service sizes for each building are listed below:

Building	Service Size
A and G	1660 KVA
B	750 KVA
C	1060 KVA
D	750 KVA
E	1060 KVA
F	845 KVA

Lighting:

General site illumination will come from 277-volt metal halide pole-mounted fixtures. These single lamp fixtures will have daylight cutoff optics. Other various wall mounted, pendant, and recessed exterior lights will be 120-volt florescent fixtures with cold temperature start ballasts. Interior lights will all be T8 fluorescent fixtures in various styles and wattages. Exit signs will be surface mounted LED fixtures.

Mechanical:

There was a push during the Mater Programming phase to find a best value for the mechanical systems used on Eastview. A study by LDR International, Inc recommended the use of hot and chilled water fan coil units serviced from a central plant. The University "questioned the merits of this recommendation" and asked Brinjac Engineering to perform the same study. However, being that lifetime maintenance costs were extensively lower for that particular option; this study provided the same results. The study, entitled "Eastview Terrace Housing HVAC System Life Cycle Study," was used as a reference from which to go into further investigation of the particular components.

Eastview's seven buildings will be serviced from the chiller plant and central campus steam lines. The maximum plant load for both heating and cooling is 7163 MBH and 611.2 tons respectively. The chiller plant will feature three 400-ton centrifugal chillers, which will also serve two existing dormitories adjacent to the site. I chose to look at a couple of value engineering options with regard to the centrifugal chillers used at Eastview. This continues in the initial push, by the project team, to find a clear best value for the system. The discussion of this is contained in the MEP Design considerations section of this document.

Structural:

- ♦ Structural steel framing
- ♦ Composite metal decking
- ♦ Spread/strip footing foundations

Fire Protection:

- ♦ Wet pipe sprinkler system per NFPA 13
- ♦ Automatic residential sprinkler heads rated at 200-275°F
- ♦ Water Flow, Supervisory, and Alarm Pressure switches connected alarm
- ♦ Standpipe system per BOCA 1996 & NFPA 14

Vertical Transportation:

Buildings will have an elevator in each pod.

Telecommunications:

All rooms will have phone, cable, and high-speed internet connections.

Existing Construction Conditions

Project Delivery Background

Contracts

Since Eastview's project delivery is fast-tracked, there is not a formal signed Guaranteed Maximum Price contract between Penn State and Turner Construction Company at the moment. Turner will deliver the GMP as a Construction Manager at Risk, meaning they will hold all contracts with subcontractors under the GMP. The bid packages will be released in three separate phases. The first phase being the site work and underground utilities and the second includes everything within the scope of the actual buildings. The last phase will include final grading, landscaping, sidewalks, and parking lots. The GMP will not include an incentive clause but will include liquidated damages to assure adherence to the strenuous schedule. Owner controlled insurance policies or OCIP will be provided through Penn State and will include workers compensation and general liability insurance. Turner will require the building envelop subcontractor and any sub with a contract over $100,000 to provide a performance bond under dual oblige to Turner and Penn State.

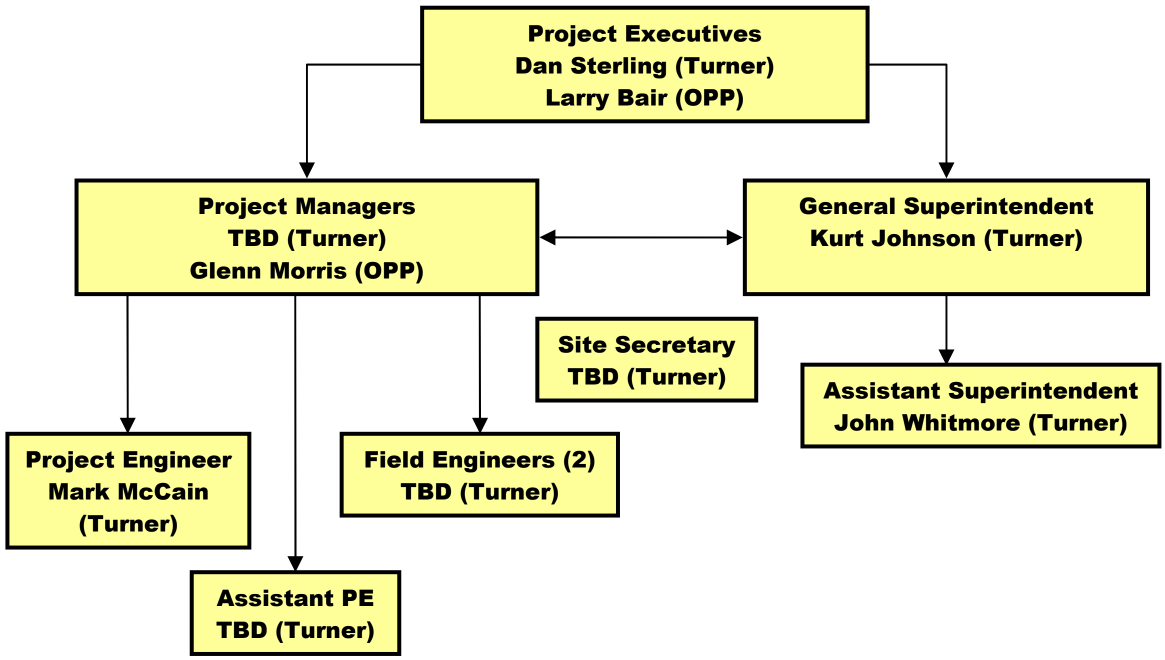
Contractor Selection

With Eastview Terrace Housing being a fast-tracked project under a GMP contract, contractor selection becomes very important. Project quality and scope can be sacrificed due to the GMP and a shortened schedule. As it is, Penn State and its Office of the Physical Plant are very experienced owners when it comes to building construction. However, managing a $70 million contract involving seven buildings and extensive site utilities is something the OPP does not have the expertise or resources to handle. Yet the capacity to be involved in every phase of the project from design to completion and the ability to have a close watch over the construction are within reason. Therefore, Penn State chose a construction manager delivery for Eastview as it does for the majority of its large projects. OPP produced a shortlist of three construction managers who have had previous experience with work on campus and invited them to interview. Turner Construction was picked on the merits of project team selection and prior work experience. Turner completed the Hetzel Union Building, a large student union building, in 1999 and is currently working on the new Information Systems Technology (IST) building on west campus. This information is important to note and correlates to the project delivery selection research addressed later on in this thesis.

Staffing Plan

I have made a flowchart below of the staffing plan by Turner Construction on the Eastview Terrace project. The unique thing about working with an experienced owner such as Penn State is that they have the ability to have close dealings with the construction process through its own Office of the Physical Plant. This means they have a project manager/executive and an onsite project manager representative for each project. I have shown this relationship in the staffing flowchart that follows.

Eastview Terrace Housing - Construction Staffing Plan



Schedule Summary

The full duration of this schedule runs from May 2001 till late July 2004. Eastview Terrace is on a fast tracked accelerated schedule. The design phase started in the summer of 2001 and will be complete by the end of October 2002, while the construction phase began in mid August 2002 and will continue until late July 2004. To begin construction, the existing structures on site had to be demolished. There was also an oil contamination reported in the sub-surface investigation, which lead to a soil remediation process that started in mid May 2002 and has caused a brief lag in the schedule. Considering the amount of work that must take place and the small 23-month time frame given for the construction, this makes for a very tight schedule. I will address this important issue further by looking at a production schedule and the use of prefabricated bathroom units during construction. This impact is discussed under the production scheduling section. The existing construction summary schedule is provided in the appendix.

Project Cost Summary

Activity Name	Cost	Sq.Ft	%Total
General Requirements	$1,868,500	$5.64	2.88%
Temporary Facilities	$658,500	$1.99	1.01%
Construction Contingency	$1,401,000	$4.23	2.16%
Site Utilities and Rough Grading	$15,175,867	$45.83	23.35%
Cast-in-Place Concrete	$257,000	$0.78	0.40%
Masonry & Precast	$4,872,000	$14.71	7.50%
Structural Steel	$229,000	$0.69	0.35%
Metal Fabrications	$1,213,000	$3.66	1.87%
Rough Carpentry	$659,000	$1.99	1.01%
Finish Carpentry	$838,000	$2.53	1.29%
Metal Panels	$466,000	$1.41	0.72%
Roofing & Water Proofing	$786,000	$2.37	1.21%
Doors, Frames, Hardware	$1,523,000	$4.60	2.34%
Aluminum Entrances & Windows	$1,929,000	$5.83	2.97%
Drywall, Acoustical, & SOFP	$8,513,000	$25.71	13.10%
Ceramic Tile	$451,000	$1.36	0.69%
Flooring	$761,000	$2.30	1.17%
Painting	$705,000	$2.13	1.08%
Specialties	$48,000	$0.14	0.07%
Toilet Accessories	$234,000	$0.71	0.36%
Equipment	$85,000	$0.26	0.13%
Window Blinds	$93,000	$0.28	0.14%
Vertical Transportation	$782,000	$2.36	1.20%
Fire Protection	$549,000	$1.66	0.84%
Plumbing	$4,187,000	$12.64	6.44%
HVAC	$7,249,000	$21.89	11.15%
Electrical	$5,772,000	$17.43	8.88%
Landscaping	$1,969,000	$5.95	3.03%
Totals	**$64,984,867**	**$196.24**	**100.00%**

Construction Management Studies

Project Delivery Selection Research

Introduction

Project delivery selection is an important decision to owners from the very onset of conceptual design. Building construction has a certain inherent risk due to project uncertainties and complexities. How an owner chooses to approach and allocate this risk is at the heart of project delivery selection. It can be argued that there is no "perfect" project delivery method. And in all practicality this is the case since there are no two identical projects or owners. Traditionally many owners were one-dimensional in their approach to project delivery, choosing the more familiar design-bid-build method. This method placed most of the risk upon the contractor but intrinsically gave the contractor less identity with the project. Thus, change orders picked apart the quality and budget. Recently, there has been a growing trend among owners and builders alike to recognize the inherent advantages and disadvantages of alternative project delivery methods. Some owners, it seems, have now developed formal guidelines at the administrative level to assist project managers in selecting the most appropriate project delivery.

My research topic was to approach project delivery selection from an owner's prospective. The goal of this section is to look at how a few owners are currently approaching this complex subject. I will look at a case study into the Georgia State Financing and Investing Commission and their recommendation guidelines entitled, "Selecting the Appropriate Project Delivery Method." I will also review selection guidelines from Penn State Office of the Physical Plant.

Background

There is a growing philosophy in the construction industry that represents finding a "best-value" for a project as opposed to a lowest cost or bottom line. In a traditional design-bid-build (DBB) approach, the objective was to minimize costs through competitive hard bid procurement. Finding a rise in costly litigation procedures, change order and schedule run-ons, and a general drop in construction quality from using a DBB approach, many owners sought alternatives in the use of construction managers and design build agencies. These two approaches use a "team" concept early on in project development to establish a best value for the building. Instead of making cost the driving force in decision making, many owners are using what Mike Kenig, Vice Chairman of Holder Construction Company, describes as "value-based" decision making towards project delivery. Kenig explains it like this:

"The construction industry for years has taken a "traditional approach" to projects by keeping a clear separation between the design and the construction phases. A more effective method, however, is a "team approach," where everyone works collaboratively from the start and the process is driven by "value-based" decision making rather than "cost-based" decision making."

Kenig contends that there are only two basic approaches to project delivery, the traditional bid and the "team" approach. The traditional basically assumes the contractor will have no input during design phases of the project. Where as, with the team approach a construction manager or design build agency will provide construction experience to the program earlier in design development.

The logical question is then, "what does all this have to do with risk?" The point is to not redistribute the risk but to essentially begin reducing the risk by properly addressing it earlier and more logically. If many of the risks are understood early in program development and an owner knows decisively how to deal with them, a traditional approach can suffice. However, if an owner is inexperienced or if the program is not well defined it may be beneficial to look at the team aspect. Of course there are many other considerations within project delivery selection other then what rest on the surface. I will now look at two owners and the current approach to project delivery.

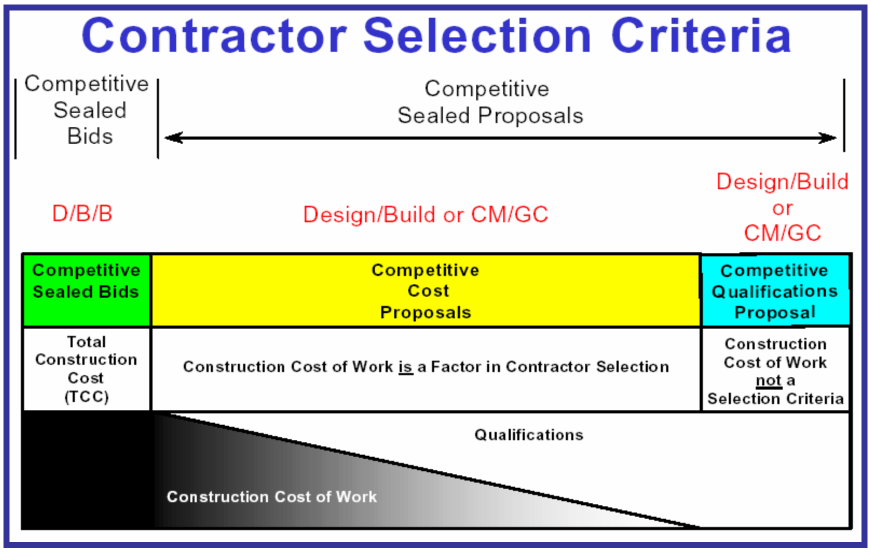
Case Study: Georgia State Financing and Investment Commission

In order to better assist the selection of a most suited project delivery for certain "Using Agencies" during predesign, the Georgia State Financing and Investment Commission developed a manual, "Selecting the Appropriate Project Delivery Method." The manual was the collaborative efforts of industry professionals from around the state of Georgia as well as individuals from involved State Agencies. The stated goal of the manual was to "assist the Using Agency in establishing a common vocabulary, understanding the project delivery options and then determining an appropriate project delivery method for each particular project." This comprehensive manual starts by establishing a common vocabulary by defining the concept of project delivery and the methods thereof. The manual then defines decision-based factors that contribute to project delivery selection. These include project related and "external" factors as well as other "contributing" factors.

The delivery "methods" discussed within the manual are determined based on the procurement arrangements. In other words, how the "risk and performance…have been transferred to another party (or parties)." The manual argues there are three types of methods and three types of solicitations for project delivery. The solicitations are either "bid" based or "proposal" based. In bid-based solicitations, decisions are made on lowest costs from a competitive sealed bid. In proposal-based, decisions are either made on a competitive cost proposal or a competitive qualifications proposal. The table below shows these solicitations and how they relate to the three delivery methods.

Delivery Method	Competitive Sealed Bid	Competitive Sealed Proposal	
		Competitive Cost	Competitive Qualifications
Design-Bid-Build (DBB)	X		
CM/GC		X	X
Design/Build (D/B)		X	X

This then correlates to what the manual describes as "construction selection criteria." The selection is based upon varying degrees of the contractor's cost of work or the contractor's qualifications. A traditional DBB is thus solely a cost of work selection and a D/B or CM with competitive qualifications is generally a qualifications selection depending on they type of solicitations used. The chart below illustrates this idea:



Georgia State Financing and Investment Commission

The project delivery methods are then defined under each degree of contractor selection criteria. The definitions include: the number of contracts, relationship of project phases, contractor selection criteria, ability to bring contractor on during design, risk allocation, and definition of design/construction phases.

The next section addresses decision "factors" that contribute to the selection of a delivery method. These factors are subdivided into, "project related", "external", and "contributing" factors. The manual says project related factors must be considered first. Then there are external factors that can limit or even prevent the use of a certain delivery method. State regulations play a large part in exactly how a project can be delivered and these are the external factors. Contributing factors are specific to the project team itself and the experience there of.

Project Related Factors	**External Factors**	**Contributing Factors**
♦ Project Complexity and Scope Definition ♦ Need/Desire for Contractor Input ♦ Schedule ♦ Potential for Changes during Construction	♦ State Budget and Funding Cycle ♦ Availability/Capability of In-house Resources ♦ Regulatory and Statutory Requirements	♦ Owner Control and Risk Allocation ♦ Recommendations/Experience

Georgia State Financing and Investment Commission

The last section was to be an attempt at compiling a "decision tree" that tied everything together. The committee has at this time not produced the decision tree. I spoke with Mike Kenig about the reasons surrounding the delay. He said the general consensus among the members is that there can never be a "magic tree" that would be able to tie every aspect of project delivery selection together nicely.

Penn State Office of the Physical Plant – Selection Procedures

I talked with Steve Maruszewski, who is Director of Design & Construction at Penn State OPP, about this subject. He said there are no such formal guidelines established on this subject at OPP. Decisions are based solely on a project-by-project basis. The delivery team "brainstorms" to evaluate all aspects of the project in which to make an experienced decision.

Below is a list of several factors important to project delivery at Penn State:

- Strength of program
- Ability to control end user input and political environment
- Complexity
- Schedule
- Completion level of documents related to schedule
- Need for early firm price
- Quality
- Budget, etc…

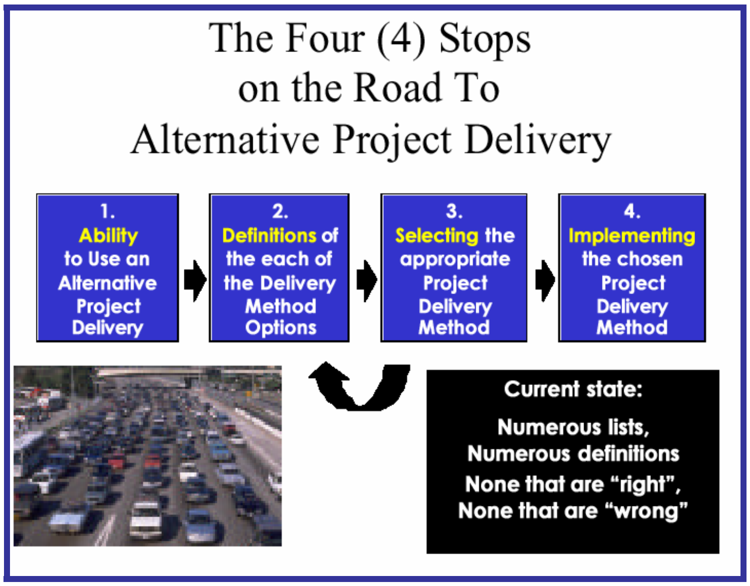
The following delivery methods have all been used by Penn State:

- Design/Bid/Build
- Design Build w/Best Value - selection based on technical qualifications and cost
- Design Build w/Bridging Documents - selection based on cost
- Construction Management - Agency
- Construction Management - At Risk
- Construction Management - At Risk w/competitive GMP

Maruszewski says, "In general, we go brainstorm the above criteria along with other criteria specific to each project and make an evaluation before deciding on the delivery method for major projects. We often leave the door open to change methods based on changes in funding availability, schedule, etc." Penn State obviously considers carefully the method in which they choose. As with any agency using public monies, this can sometimes be a very political decision.

Summary

I feel these two case studies show that not only are owners using alternative project delivery methods, but also seeking ways in which to educate managers on the *successful* use of the alternatives. I tried, unsuccessfully, to find another owner developing the sort of guidelines that the Georgia State Financing and Investment Commission have done. Many of the problems with using alternative delivery systems has to do with a) an owner's ability use them and b) understanding how to use them successfully. Mike Kenig claims there are "four stops on the road to alternative project delivery." The first, being the ability to use alternative project delivery. The second is an understanding or definition of each delivery method. The final two steps are selecting and implementing the appropriate method. Kenig feels that most owners recognize they have the ability to use alternative project delivery, step 1, but skip automatically to step 3, selecting the appropriate method. The guidelines by the Georgia State Financing and Investment Commission are an excellent example of how owners are now recognizing there must be ways in which to educate managers of not only alternative delivery methods but how to successfully use them.



Mike Kenig – Holder Construction Company

Production Scheduling

Introduction

Early in the conceptual design of Eastview Terrace it was decided, by Penn State's Housing and Food Services division, it would want the completed facility handed over to them for the fall 2004 semester. With the design development phase slated to wrap up in early 2002, it was clear the project should go to construction as soon as possible. Site clearing and demolition started in the summer of 2002, which left approximately 24 months to complete the construction and commissioning of all seven Eastview Terrace buildings. The project delivery team approached this problem by first choosing a construction manager early on in design and by also fast-tracking the design/construction process. The following section attempts to approach this problem on a more micro level by looking at part of the construction schedule from a production point of view. A trend over the last several years has been to look at construction under the principles of production. The Lean Construction Institute (LCI), founded by Glenn Ballard and Greg Howell, has been a leader in applying these principles to construction projects through research. The Institute's website, leanconstruction.org, is a wealth of knowledge on this subject and was an invaluable source of information and guidance.

It must also be noted that this problem is also approached in this thesis through the prefabrication of a certain assembly within the construction. One principle of production management is to "minimizing the number of steps, parts, and linkages." I felt that prefabricated bathroom units, though not readily available in the United States, would make an excellent complement to the implementation of a production schedule. This subject is briefly touched upon in the following section; however, a more detailed analysis of prefabricated systems is examined under the MEP Studies section.

Production within Construction

To begin to investigate using a production schedule, I think it is important to define exactly what production is and how it should be viewed within a building construction sense. Production as defined by the new production model is, "a flow of material and/or information from raw material to the end product. In this flow, the material is processed (converted), it is inspected, it is waiting, or it is moving. These activities are inherently different. Processing represents the conversion aspect of production; inspection, moving and waiting represent the flow aspect of production." It is therefore advantageous to look at construction as a *flow* of work through a job site or building structure (Koskela 1992). Construction, within the manufacturing sense, is defined as fixed position manufacturing. Meaning the product is too large to move through workstations so the workstations, or crews, move through the product. Hence, construction is also a combination of fabrication and assembly that must take place on a localized site (Ballard and Howell 1998).

Production Principles Examined

I will now investigate ask how it is these flows can be planned and controlled in practice. Koskela states, "The key to efficient site assembly is planning and control…" The new production philosophy suggests there are eleven principles for flow process design and improvement.

They are listed below:

1. Reduce the share of non value-adding activities.
2. Increase output value through systematic consideration of customer requirements.
3. Reduce variability.
4. Reduce cycle time.
5. Simplify by minimizing the number of steps, parts, and linkages.
6. Increase output flexibility.
7. Increase process transparency.
8. Focus control on the complete process.
9. Build continuous improvement into the process.
10. Balance flow improvement with conversion improvement.
11. Benchmark.

Koskela states that, "only conversion activities add value…to a product." It is therefore beneficial to make the conversion activities more efficient. The flow aspects of production, inspection, moving, and waiting, must therefore be either reduced or eliminated altogether. Many of these many of these can be effectively approached through a Short Interval Production (SIP) schedule. A SIP schedule is a means in which to simplify the control aspect of construction scheduling. Increasing output value through systematic consideration of customer requirements (1), a 24-month schedule, is addressed through the implementation of the area-based production schedule. Also, production principles 2,5,7,8 and 11 become much easier to define and control within a SIP schedule. A SIP schedule is inherently systematic (2) and transparent (7) through its simplicity (5). Control also becomes much more focused (8) through the use of area designations for subcontractor work. Finally, benchmarks (11) are clearly visible and strictly enforced by the area "lock-downs." Output flexibility (6) and continuous improvement (9) are addressed by completing "space ready" sheets; these note any changes that must be made from the original plan. Balancing flow (10) is done through crew and material balance at a very quantifiable level.

By modularization and prefabrication of certain areas of the construction, for instance bathroom units, time saving steps can be reduced in the process (5). Prefabrication also reduces variability (3) because units are produced in a factory where quality is easier to control. Cycle time is also reduced (4) because assembly of these units reduced the number of steps that must be done onsite.

To sum it up, a SIP schedule and prefabricated units effectively address each of the eleven principles in a clear, concise, and executable fashion.

What is a SIP Schedule?

An important component of lean construction, and more specifically lean project delivery, is that of "production control." The LCI says, "Production control consists of work flow control and production unit control." A Short Interval Production schedule is a tool in which to establish and guide this control in a systematic and transparent way. The LCI says, "control first of all means causing a desired future rather than identifying variances between plan and actual." This is exactly what a SIP schedule does.

The first step in creating a SIP schedule is to determine the amount of time *given* to complete the task at hand. The schedule allows for MEP rough in starting at the beginning of April 2003 and final building completion by the end of July 2004. This gives exactly 70 weeks to complete all interior work. The building must then be divided into work areas and labeled. These areas provide a clear distinction as to where a particular subcontractor's work must take place during any given time period. The exact amount of time needed for each activity is then discussed within the whole context of time allowed. Subcontractors must be willing to size crews and material demand according to the work done in a given area and time period.

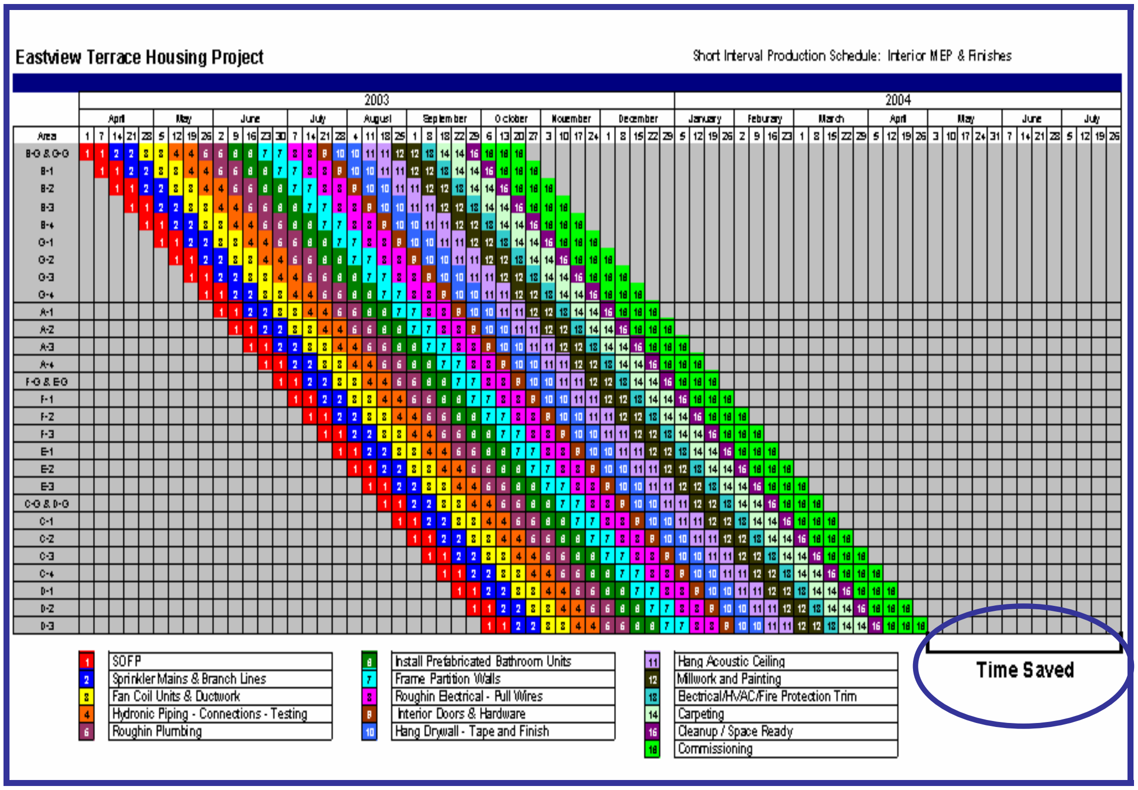
It is most beneficial to create these areas in the most typical fashion possible. This will take better advantage of the learning curve and more efficiently balance activity time. When work begins, subcontractors then "follow" their predecessor through the areas towards completion. As subcontractors move through and complete any given area, inspections by the owner, architect, and engineers can assure quality requirements have been met prior to the area's "lock-down."

Production Schedule in Practice

I found the use of a SIP schedule during a visit to the Pentagon Renovation Project in Washington D.C. Hensel Phelps Construction Company was accommodating in providing some practical insight in how these ideas are implemented in practice. They stressed the most important thing is to get everyone on your construction team to by into the idea and understand how it works. This is especially important when dealing with subcontractors. They suggest that as the project is bid out, the CM should sit down with all bidders and thoroughly explain the expectations of using a SIP schedule.

Hensel Phelps also suggested that even after the subcontracts are awarded, the CM sit down with the subs again to formulate a plan to complete the tasks on time. They stressed that it is important for a sub to thoroughly think through the process. Inefficiencies caused by lack of materials or manpower can create burdens on space being completed on time. Balancing crews, equipment, and materials is essential for this schedule to work smoothly.

After all this has been communicated, a SIP schedule is given to every sub and superintendent. It is also beneficial if the individual crewmembers have a schedule in their pocket so there is no confusion about who is where and when. There should be no confusion about the work that must take place and where. Areas should be closed off after work is completed and no crew should enter another space before their time. This eliminates any confusion surrounding responsibility or work. Spaces are closed down with a formal walkthrough with a superintendent, necessary code officials, applicable engineers, and the crew's Forman. Everyone will sign a "space ready" sheet with notes that concern any deviation in the original plan. The Contractor should place area designations throughout the buildings for reference respect to the building plan.



Eastview Terrace SIP Schedule – Time Saved

The production schedule I produced for Eastview Terrace looks specifically at the interior work. This includes all work within the shell of the building; including: all MEP work, partitions, ceiling, flooring, fixtures, interior doors, millwork, painting, and cleanup. The seven buildings were divided into areas based on size requirements and building erection logic. Most activities have two weeks to complete their work in a given area. Some have only one week when the activity has considerably less labor involved.

As you can see from the figure above, the initial “float” for this revised schedule is 13 weeks. This schedule will then be taken to all the subcontractors after bidding to determine the actual feasibility of the time constraints. If material and crew demands are too high, adjustments can then be made within the 13 weeks of float. After the necessary revisions have been made, a final schedule will be issued and subs must adhere. If the current SIP schedule is used, 3 months of General Conditions costs can be saved. At $81,240 per month, this will represent a saving of $264,030 from the original $1,868,500.

A set of drawings for area designations is included in the appendixes of this document.

MEP Design Studies

Chiller Alternative

Introduction

"Value engineering is a creative, organized approach the objective of which is to optimize the cost or performance of a project."

Frederick E. Gould
Managing the Construction Process

Value engineering has the objective to maximize the value based engineering decisions with respect to total, or life cycle, costs, quality, and material availability. These decisions should be made early in the designing/building process before changes become too costly or even unfeasible. Penn State spent a great deal of time determining life-cycle costs for the mechanical systems in the Eastview Terrace project. The "HVAC System Life Cycle Study" was performed early in the project to determine the optimal system to use. The results of this analysis concluded the use of fan coil units supplied by hydronic steam heat and chilled water. The low operation and maintenance costs associated with this system made it the most desirable and negated the high installation costs. My study here focuses on a specific component of that system, the centrifugal chiller, and how it might be better integrated with the central utility services at the University.

Existing Chiller

The existing chillers used for Eastview Terrace are centrifugal water chillers. This means the chillers are driven by an electric powered centrifugal compressor to drive the vapor/compression refrigeration cycle. They use R-134a refrigerant to chill the water that is distributed to all the buildings in Eastview. There are three 400-ton chillers specified for Eastview that deliver chilled water at 43°F. These chillers require a 480volt 3-phase electrical connection.

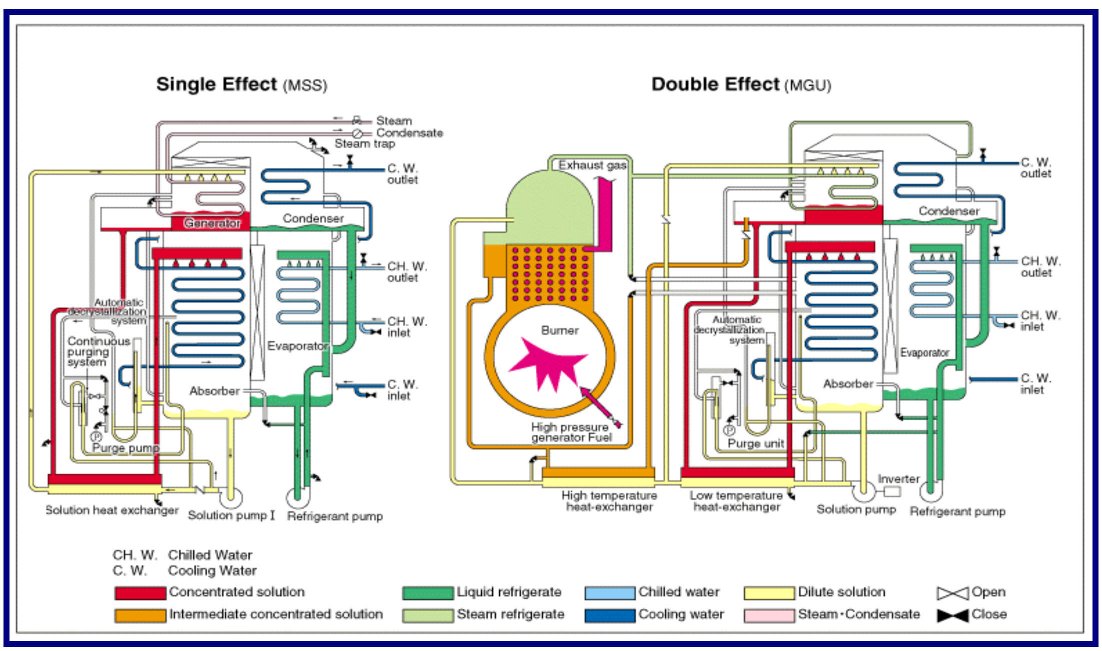
McQuay International Distinction Series WSC Centrifugal Chiller
www.mquay.com

Alternative Chillers

The natural thought progression in value engineering for a facility, such as Penn State that centrally generates its own steam, is to look at using an a**b**sorption or a**d**sorption chiller. They sound similar but have unique differences which I will discuss as I look at the possibility of using these at Eastview Terrace. Both the absorption and adsorption chillers use heat as opposed to electricity to operate. Glenn Lelko, an engineer with OPP, said a few absorption chillers are used on campus; mainly to dispose excess steam during the summer months that is produced from electric generators. This takes advantage of what is know as cogeneration, in which waste steam from the production of power is used. This 13-psig steam is the byproduct of the electric generators used at the west campus steam plant. The plant is on the corner of College Avenue and Boroughs Street and currently there are no 13-psig-steam lines running in the vicinity of Eastview Terrace. I will look at other benefits and concerns of being able to integrating these units within a cogeneration facility such as Penn State University Park.

Absorption Chiller Principles

An absorption chiller uses heat, as oppose to electricity, as the energy to drive the refrigeration cycle. Absorption chillers work on the same refrigeration cycle principles as a vapor compression chiller but do not have a compressor. Instead these units use a combination of a generator and absorber to replace the compressor. The "refrigerant" used in these is a solution of lithium bromide and water. The lithium bromide is actually the absorbent in the absorption cycle. There are indirect and direct-fired absorption chillers. Indirect use either hot water or steam and direct fired use natural gas for sources of heat. For applications, such as at Penn State campus, where waste steam is readily available, indirect units can make both economical and environmental sense.



Typical Absorption Chiller Cycles - http://www.mhi.co.jp/aircon/english/index.htm

Absorption Benefits

Since the primary source of energy for an absorption chiller comes from steam or hot water, these units require very little electric power. Typically, absorption chillers require only 0.02 kWh per ton of cooling, compared to conventional electric chillers that need 0.6 to 0.88 kWh per ton of cooling. This can represent a significant amount of energy cost over the life of a unit.

By using water as a refrigerant and not a refrigerant containing chlorofluorocarbons (CFCs) or hydro chlorofluorocarbons (HCFCs), they are environmentally friendly. The regulation of these contaminates continues to evolve and with a chiller being long-term investment, it is important to consider rising maintenance costs of recharging the system.

There are also less moving parts associated with absorption chiller then with centrifugal chillers, so maintenance is sometimes less costly. However, Penn State OPP has not seen these savings. These units are usually considerably quieter due to a reduction in size and number of pumps needed.

Trane Single-Stage Steam-Fired Absorption Liquid Chiller
www.trane.com

Absorption Concerns

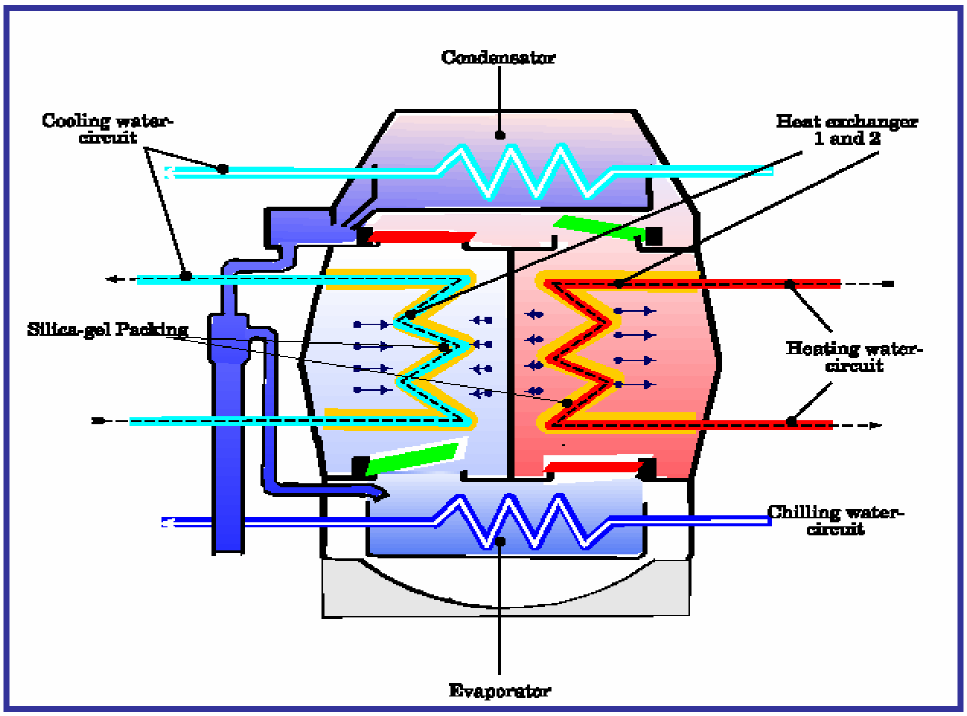
Some facilities maintenance managers have seen the down falls of using these units within a cogeneration setup. Hot water flow rates and temperatures can fluctuate with heat recovery applications. These chillers become less efficient as heat input drops below 185°F and prefer a stable input condition to operate.

The lithium bromide is highly corrosive and can cause hassles with crystallization within the machines. Lower temperature condenser water causes the Li-Br to crystallize clogging valves and increasing pressure. Li-Br is also hard to dispose of and costs around $1,200 per 30-gallon drum to replace. Its life expectancy is around 3-5 years.

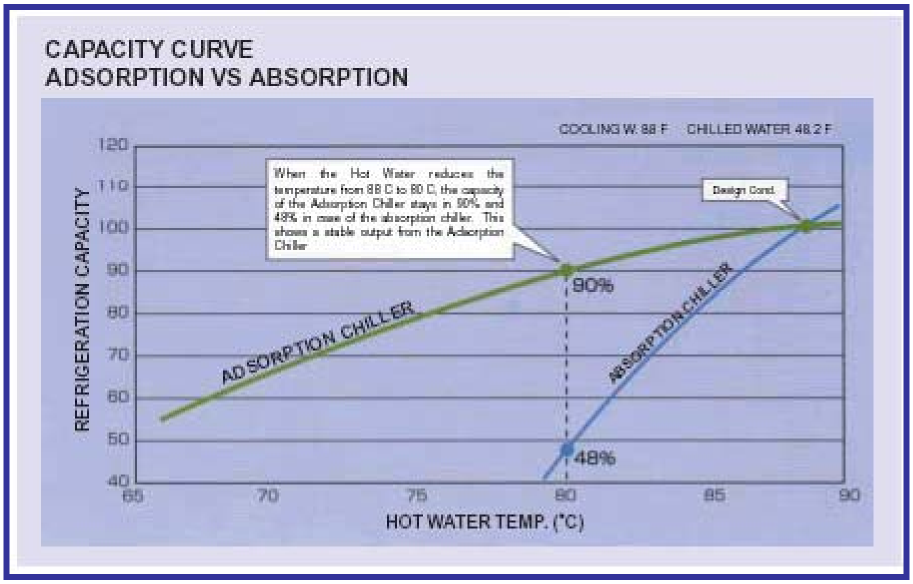
Finally, absorption chillers must reject more heat than a centrifugal chiller. They must not only reject the heat from the building but also the heat used in the absorption process. This requires the system to have a larger cooling tower. With the concerns over where to put the cooling towers on Eastview, adding extra size would not be a good alternative to suggest. I sized cooling towers for each of the units considered in my thesis and they are listed in the appendix.

Adsorption Chiller Principles

As my research into absorption chillers progressed, I found an innovative solution to the shortcomings of these units. There are now chillers that take advantage of the principles of adsorption, as opposed to absorption, to produce chilled water. Adsorption is defined as, "The accumulation of gases, liquids, or solutes on the surface of a solid or liquid." In refrigeration engineering, the principle of adsorption is, "the collection of water vapor in the air by a hydroscopic material." This is commonly used to dehumidify air. Within an adsorption chiller, the hydroscopic material is a silica gel and the only refrigerant is the water itself. After the water vapor has been adsorbed by the silica gel, the inlet hot water is used to then condense the water again, in what is called regeneration. The silica gel can easily adsorb and release the water vapor an unlimited amount of times. The water must be in a vacuum to evaporate at a low enough temperature. Unlike an absorption chiller, which uses lithium bromide and water, adsorption chillers use only water as the refrigerant. Below is a schematic of how an adsorption chiller works.



Typical Adsorption Chiller Cycle Schematic

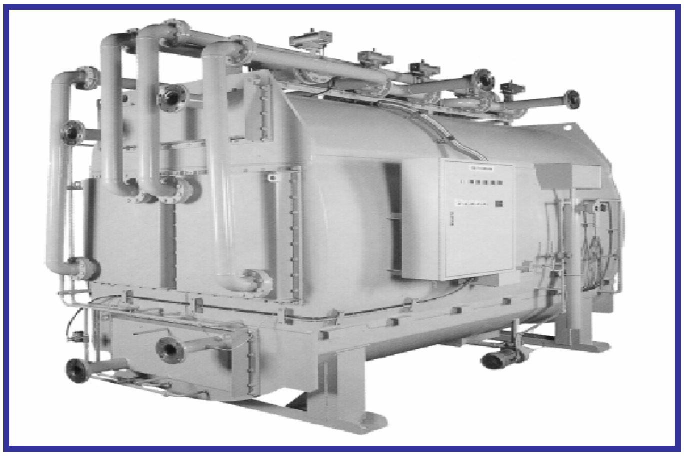


www.adsorptionchiller.com

Adsorption Benefits

The adsorption chillers include the same ability to use under a cogeneration setup as with an absorption chiller. However the main benefit is that these units can perform well over a broad range of hot water input temperatures. The recommended hot water range is from 122°F to 194°F. Thus, the capacity output remains stable even as input temperatures drop. The graph above show the efficiencies of both absorption and adsorption chillers as the hot water input temperature drops. Hot water flow rates can fluctuate as well with heat recovery applications. An adsorption chiller can maintain capacity even when flow rate varieties +/- 50%.

Water and silica gel are used within the machine - no lithium bromide solution and no corrosion and crystallization problems. The silica gel is expected to last upwards of 30 years. A high efficiency evaporator allows chilled water supply temperatures to reach as low as 37°F, supply for Eastview is 42°F. There are even fewer mechanical parts then that of absorption chiller, which means lower maintenance costs. They are also much smaller in size and thus use less space in already cramped mechanical rooms.



Absorption Chiller – www.adsorption.de

Adsorption Concerns

The biggest drawback of using an adsorption chiller is availability. Nishiyodo Kuchouki, Co., LTD. in Japan first invented these in 1986. I only found one other manufacturer producing these in Germany. They are now available here in the United States through HIJC USA in Houston, Texas. Carl Moeller, of HIJC USA, informed me they would soon be manufactured in the United States to lower the cost and make them more available to customers.

The unit I chose for Eastview is a 600-ton model. This will require the use of only two chillers. Since the units run only on hot water, they require using a steam to water converter. This is simply a plate type heat exchanger. The hot water input flow rate for a 600-ton chiller is 2,400 GPM. I used two 1200 GPM units.

Life Cycle Comparison

Chiller Type		Centrifugal	Absorption	Adsorption
Chillers				
	Size	(3) 400T	(3) 400T	(2) 600T
	Cost	$143,000	$187,000	$250,000
	Volts	480V - 3phase	460V - 3phase	200V - 3phase
	kWhr/ton	0.7	0.02	0.004
	kWhr	240	24	4.8
	Yearly kWhr	403200	40320	8064
	Price per kWhr (¢)	3.763	3.763	3.763
	Electric Cost (per year)	$15,172.42	$1,517.24	$303.45
Cooling Tower				
	Cost	$59,400	$103,950	$69,500
	Flow Rate (GPM)	3,600	4,800	4,224
	Motor Size (h.p.)	20	30	30

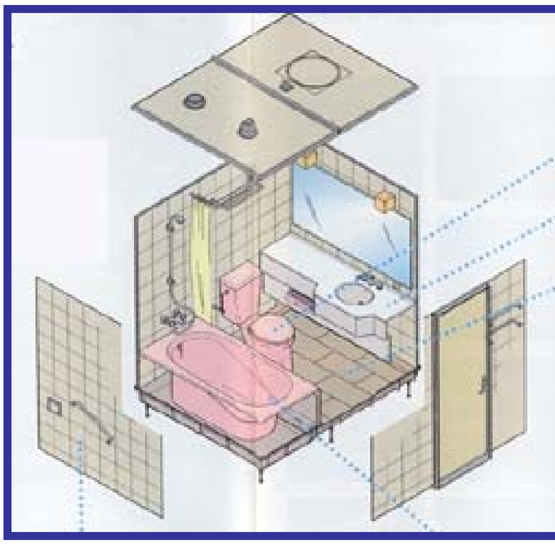
	Full Load Amps	27	40	40
	Volts	460	460	460
Heat Exchanger (Steam to HW)				
	Quantity/Size	n/a	n/a	(2) 1200 GPM
	Cost	n/a	n/a	$133,000
Condenser Water Pumps				
	Quantity/Size	(6) 600 GPM	(6) 800 GPM	(7) 600 GPM
	Cost	$14,100	$15,000	$16,400
	Intital Costs	**$216,500**	**$305,950**	**$468,900**
	1st Year Costs	$231,672	$307,467	$469,203
	2nd Year Costs	$246,845	$308,984	$469,507
	3rd Year Costs	$262,017	$310,502	$469,810
	4th Year Costs	$277,190	$312,019	$470,114
	5th Year Costs	$292,362	$313,536	$470,417
	6th Year Costs	$307,534	$315,053	$470,721
	8th Year Costs	$322,707	$316,571	$471,024
	9th Year Costs	$337,879	$318,088	$471,328
	3rd Year Costs	$353,052	$319,605	$471,631
	10th Year Costs	$368,224	$321,122	$471,934
	11th Year Costs	$383,397	$322,640	$472,238
	12th Year Costs	$398,569	$324,157	$472,541
	13th Year Costs	$413,741	$325,674	$472,845
	14th Year Costs	$428,914	$327,191	$473,148
	15th Year Costs	$444,086	$328,709	$473,452
	16th Year Costs	$459,259	$330,226	$473,755
	17th Year Costs	$474,431	$331,743	$474,059
	18th Year Costs	$489,603	$333,260	$474,362
	19th Year Costs	$504,776	$334,778	$474,666
	20th Year Costs	**$519,948**	**$336,295**	**$474,969**

The centrifugal chiller is the obvious choice based on initial capital costs. However, it can be easily seen that the absorption and adsorption chillers will pay back this difference by the amount of electric power required for these units. The electric use per year, in this life cycle study, assumes each unit will run 12 hours a day, 7 days a week, and 20 weeks out of the year. The electric rate is from Allegheny Power Company. The absorption chiller actually pays for itself in the 8^{th} year and the adsorption chiller pays for itself in the 17^{th} year. To simplify this investigation, I assumed that maintenance costs actually remain even for all the chillers compared.

Prefabricated Bathroom Units

Introduction

To prefabricate means to "manufacture a building or section of a building in advance, especially in standard sections that can be easily shipped and assembled." Prefabrication within the construction industry is not a new concept by any means. To some extent or the other, prefabrication, has always been used within building construction for centuries. Also, the housing industry has seen large gains in market share from manufactured housing in recent years. Architects such as Walter Gropius and Buckminster Fuller were significantly involved in the development of prefabrication of urban housing starting almost a century ago. Overseas is where most headway has been made within commercial construction in this regard. The idea to use a prefabricated system came from my research within construction production. The elimination of steps or procedures in a production schedule creates more efficiency in the process. Done right, it can also raise quality of the end product. There are over 800 bathrooms in Eastview Terrace, so I decided to look at the ability to use these in a dorm building.



Expanded View of Prefabricated Bath - http://www.tsigm.com/

Finished Bathroom - http://www.horkew.com.sg

Types of Systems

There are four basic construction methods used to modularize these bathrooms. These include: concrete, fiber reinforced plastic, a combination of galvanized steel wall panels and concrete floor panel, or a combination of cement board wall panels and either concrete or fiber reinforced plastic floor panel. They can either come as a panelized unit (walls, ceiling, and floor) or as a completed unit. The fully completed units come to site with all sanitary fixtures, fittings, accessories, and all electrical, heating, air-conditioning and ventilation connections in place. They can be installed in conjunction with the structure, where units are dropped in each floor prior to the erection of the successive floor. Or they can be brought in laterally after the complete structural shell is in place.

Benefits

There are numerous benefits of using any prefabrication on a building project. Saving construction time is one of the more visible. Completed bathroom units can be assembled and ready for delivery as soon as concrete floors are poured. With all the fixtures and finishes in place, there is no need for these activities later in the schedule. Once the unit is in place and hooked to all service systems, it is complete. Fabrication at a factory ensures theses units have higher quality control and uniform finishes. Also, there is one source responsible for the entire systems' functionality and quality. Streamlined material deliveries make for a more efficient jobsite. Units can be delivered just in time for placement meaning less materials staging area. These units also work well within a production schedule by reducing the amount of non-value adding activities. Hard costs for these units can be readily determined earlier on in design development then with traditional onsite construction. Finally, a big reason these are used over seas has to do with the amount of skilled labor in the workforce. There are only a simple connects that must be made to have the completed bathroom running and ready for occupancy.

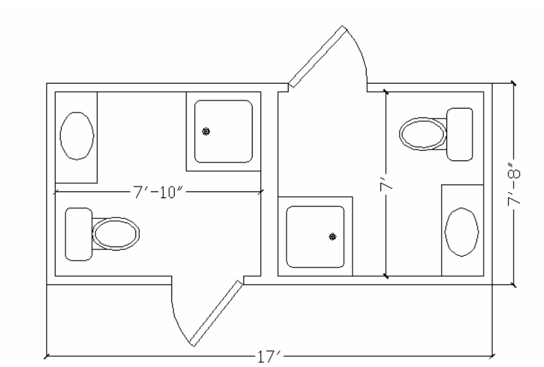
Prefabricated Bathroom Unit - http://www.parmametals.fi

Unit Lifted into Place - http://www.modularuk.com

Concerns

Local codes and standards must be addressed to each specific location for which these are built. Some code officials will require third party inspections on factory-build construction components. Shipping requirements must be considered when they are designed so that they will be able to fit on a standard flatbed tractor-trailer. I have a floor plan with dimensions showing the size and layout of a typical unit that will fit on a 53' trailer. A 53' trailer can accommodate three 17' units containing two bathrooms each. This means with over 270 of these units need, it will require using 90 truckloads to ship all the bathrooms to site.

Through all the research I did over the semester, I did not find one domestic manufacture for these units; thus they are not very practical. I spoke with Lee Shu Hao from the Housing & Development Board in Singapore about cost concerns for these systems. Lee said costs for these were about 30% higher when they first started using them in 1996, but as more units were built and demand rose, costs are now comparable to that of traditionally build bathrooms.



Manufactures

Many of the manufactures of these bathroom units have a history with the ship building industry. Ships are built extensively in modular form and this includes bathroom and cabin configurations. Most of these manufactures have adapted their expertise to demands from the building industry for a more efficient building method through modularization. As I researched suppliers of these units, it was apparent that the United States is years behind in adapting these practices to building construction.

Below is a list I compiled during my research - note the country of origin:

BIP Corporation – Korea
http://www.bip-korea.com/eng/products/bu_feat.asp
Compomatic – Italy
http://www.compomatic.it/Inglese/
Hor Kew Corporation Limited – Singapore
http://www.horkew.com.sg/bathroom.html
Parma Metals – Finland
http://www.parmametals.fi/BATH.HTM
Pyramid Building Systems – United Kingdom
http://www.modularuk.com/products.htm#bathroom
Sico Bagni & Bagni – Italy
http://www.telemar.it/sico/Home_en.html
TSI Group – Malaysia
http://www.tsigm.com/product/others_unitbath.htm

Conclusions

The project management research done suggests that owners are addressing ways to educate managers on alternative project delivery. Alternative project delivery is not something that any organization can attempt just because it is an available option. If not done correctly alternative project delivery can sometimes be more harm than good. Therefore it is important for an owner to educate those managing projects about the different methods available, what decisions must be made when decidingover another, and using

The case study into Georgia State Investment and Financing Commission is an excellent example of how to educate these ideas to their managers. It may not be a

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