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Executive Summary

Enclosed is my yearlong senior thesis project on the University of Pennsylvania Pre K-8th Grade School. The general approach applied to all the analyses and research is that of a mechanical design build contractor. This approach allows me to not only analyze the first cost of the mechanical system, but the building performance after design. Mechanical design build contractors have distinct advantages over traditional mechanical designers and mechanical contractors. The integrated design build concept provides an owner with efficient and optimized design with verification of the design and operating strategy at the end of the project.

Extensive energy modeling was conducted in Carrier's Hourly Analysis Program (HAP). This program encouraged me to look at the monthly utility bills, which currently is $183,716 or $2.08 a sqft annually. Alternate mechanical systems were analyzed to lower this cost. In total four different options were investigated, and one recommended. The recommended solution lowered my first cost by $87,966, and the annual energy cost from $2.08 a sqft. to $1.17 a sqft or $103,027 annually. The total energy savings is $80,689 annually.

These cost reductions were realized by switching the heating plant from a dual fuel boiler (No. 2 Heating Oil and Natural Gas) to an all natural gas boiler. Taking credits for all the fuel oil equipment paid for the more expensive, but less expensive to operate ice storage plant. The ice storage plant allowed me to shift the steep electric demand loads that were occurring in the summer time to off peak hours. Enthalpy wheels were also added to reduce my overall loads, and to save energy. Analyzing and combining these different systems lowered the annual energy costs, while improving first cost without having a negative impact on schedule.

The recommended redesign is more complex than the current system. Mechanical design build contractors have used 3D CAD to better understand the construction issues with such complex system. My research is on mechanical design build contractors and their use of 3D CAD. I interviewed five leading mechanical design build contractors and contractors to discuss the issues and current difficulties with implementing 3D CAD in five major categories marketing, design development, coordination, prefabrication, foreman planning, and operation & maintenance.

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Jim Meacham
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April 21, 2003

University of Pennsylvania
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Dear Ms. Alexandra Handago:

I appreciate this opportunity to submit these proposed redesigns of the mechanical systems for the University of Pennsylvania Pre K-8TH Grade School. This proposal is in response to the request for proposal dated 9/5/02.

Careful consideration was taken when analyzing the schools current systems. The analysis began with a specific approach to lower annual energy costs through integrated design. As the mechanical design build contractor different energy resources and source equipment were examined to lower these energy costs. While investigating different systems I found that not only could annual energy costs be reduced, but first cost as well. The recommended redesign was not allowed to have a negative impact on schedule, cost, architecture, or function of the building. There were four total design options considered and one recommended that is a combination of parts of the other four. The analyses include:

1. An Energy analysis switching the two existing electric screw chillers and two fuel oil boilers to natural gas engine driven chillers and natural gas boilers.
2. A redesign of the four air handlers to include energy recovery wheels
3. Redesign of the existing chiller plant to downsize the chillers and include thermal energy storage
4. A combination of the energy recovery wheels and the thermal energy storage systems

All of these analyses were estimated and compared on a first cost, annual operating cost, simple payback, and a life cycle cost analysis basis. The detailed calculations and cut sheets for the equipment selected are included in the Appendices. The final recommendation is an integration of different heating and cooling systems.

I hope that you will be pleased with the thoroughness of this report, and become more interested in mechanical design build contracting as a result for consideration in future projects. A current paper written about mechanical design build contractors and the utilization of 3D CAD is included. It focuses on different aspects of integrated design and construction including marketing, design development, coordination, prefabrication, foreman planning, and operation & maintenance. I will be presenting this research at the Partnership for Achieving Construction

Excellence (PACE) national conference in Washington DC on April 23rd & 24th, and I hope you will be able to attend.

If you have any questions please do not hesitate to call at (814)-867-9493. I look forward to working with you and the University of Pennsylvania. I want to thank you again for considering these redesigns, and I hope that I will hear from you soon.

Sincerely,

Jim Meacham

Thesis Approach

Most new buildings are designed with a primary mechanical designer and then a different mechanical contractor. My approach to this thesis is one of an integrated process between designers and contractors called mechanical design build. This approach encouraged the redesigns of the current mechanical systems to not only conclude with the best design, but also the best system for the owner in terms of cost, schedule, function, and controls. This delivery system has many advantages and can be very valuable to an owner or a general contractor. Mechanical design build contractors are usually brought on early in the project program to offer value engineering and feasible design and construction solutions. This integrated design and construction approach was used throughout this thesis.

Mechanical design build contractors have advantages over traditional mechanical consulting firms, and hard bid mechanical contractors. Design build contractors don't have a strict time table to have a set of 100% design drawings as in a typical design-bid-build delivery method. Mechanical contractors can optimize a design that a mechanical consultant might not have been allotted enough time due to a rushed design development process. The results of an integrated design and construction process with the owner and its facility staff in mind leads to better design with properly sized equipment. The true optimization of a system will result in decreased first cost and increase system efficiency. Accurate system cost comparisons can be done during the design phase instead of waiting until the design drawings are almost complete before a price can be determined.

The design build contractor can also design to its strengths, whether that is prefabrication in a shop, or designing a specific system which their field personnel are familiar and efficient in. All of these advantages potentially allow for more innovative designs, better engineering, more energy efficient systems, and cheaper first or operating costs.

When analyzing the current systems in the grade school, a close look was taken at how a mechanical design build contractor could have value engineered the building to make the mechanical systems cheaper in first cost and/or operating costs. The focus was on annual energy cost reduction, but the environment was a consideration and the green aspects of the various technologies were included as much as possible.

Introduction

University of Pennsylvania Pre K-8th Grade School occupies a five acre lot in West Philadelphia on 4243 Spruce Street. The school is a very unique project with social ramifications beyond the kids and the community it serves. The school is being held as a national standard for universities partnering with their communities to bring in the most effective, researched proven educational practices into the classroom. In the ever harder economic times of education University of Pennsylvania is leading the way in true cooperative education between community leaders, teacher's unions, school districts, local governments, and universities. The social aspect of this school is discussed in the unique aspects section of this paper.

The analyses undertaken were all mechanical system designs and redesigns of the central heating plants, central cooling plants, and the air system. The proposed redesigns were looked at individually. These redesigns were done to see the individual effects on the building as a whole. The final recommendation for the redesign will pick the most cost effective and appropriate combination of both the heating and cooling plant redesigns. Special consideration was taken in the design process to consider both the design and construction aspects of the systems.

The construction aspect of my thesis is important because it led me to workable designs that could be used without negatively affecting the schedule or cost impact. Simple paybacks and life cycle cost analyses were performed to measure the different systems economics. The final recommendation was evaluated on many different aspects of construction including: first cost, annual cost, maintenance cost, workable design, controls, constructability, and schedule impact.

This thesis was conducted using many design assumptions that the original mechanical design build firm may or may not have used. The engineer of record might not have been able to investigate different systems due to restraints during design development. The current system in place is a workable system, and this thesis investigates alternative options that could have been considered. All of these redesigns theoretically take place during the design development stage before construction began. It is not recommended to incorporate these designs after the design development stage.

This thesis is broken up into four major Chapters (3-6) containing the different redesigns, and then the final recommended design is in Chapter 7. The research portion is located in Chapter 8. The Appendices are ordered according to chapter starting with Chapter 3 which corresponds to Appendix A.