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Thesis Proposal

Preliminary Proposal for Spring 2010 Project

WESTINGHOUSE ELECTRIC CO. NUCLEAR ENGINEERING HEADQUARTERS CAMPUS

Pittsburgh, PA

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Executive Summary

Westinghouse Nuclear Engineering Headquarters is comprised of three buildings. The central building, Building 1, is the topic of this report. Building 1 is largely open office with conference rooms, computation laboratories, a Data Center, Fitness Center and cafeteria. The concentration of computer equipment is relatively high compared to a typical low-rise office building.

Of primary importance to the client are adequate thermal comfort and air quality. Both of these variables will allow the occupants to be more productive in the workplace. Also of importance is the cost of operation for the facility in the long-term.

The primary system for Building 1 is a Variable Air Volume (VAV) system supplemented by Computer Room Cooling Units (CRAC Units) where the sensible load is too great for the VAV to handle—specifically in the Data Center. A VAV system was chosen because of its low maintenance costs, easy manageability, and efficiency. The system is supplied by chiller water from three centrifugal chillers and electric re-heat/gas-fired burners from the VAV boxes and AHUs.

In an effort to optimize the systems of Building 1, analyses will be performed involving an office space conditioning strategy, the use of Chiller & Boiler plants, and the implementation of a Ground-source Heat Pump.

The best step to making a building efficient is to reduce the loads. In general, this is the most cost-effective method to gain overall efficiency. Since the building is largely office space, a major proportion of this analysis will focus on reducing the loads to these spaces. A Dedicated Outdoor Air System, or DOAS, system will be explored to reduce the loads of this space with the use of DOAS Fan Powered Terminal Units. Other major steps will be taken to reduce external gains to these spaces including solar shading, façade re-design, and building orientation optimization.

Once the loads have been reduced or adjusted, the existing VAV system will be compared to a Chiller/Boiler system as well as the Ground-source Heat Pump system. Applying these reduced loads to these three systems allows for the determination of overall system efficiency.

The system's analyses will be performed using the load data provided through the building energy model. These analyses will include an investigation of initial cost, long-term costs, payback period, reliability and emissions.

These analyses will require the use of multiple programs and resources including Trane Trace energy modeling, ASHRAE façade load modeling, soils reports, and manufacturer's data.

System Description

Introduction

Westinghouse Nuclear Engineering Headquarters is a complex of three buildings of approximately 845,000 square feet, and is being delivered is a Design-Bid-Build project. The complex contains office space with conference rooms as well as a data center, cafeteria and fitness center for employees. With the higher density of computing loads, the receptacle load of the complex will be higher than a typical office building.

For the purpose of this analysis, only Building 1 has been investigated because it contains the largest variety of occupancy types including the cafeteria, atrium/lobby, data center and fitness center along with a largest amount of office space and conference rooms.

Design Objectives and Requirements

The purpose for any HVAC system is to properly ventilate the building for the specified occupancy while maintaining a comfortable temperature and humidity level for the occupants. The mechanical system for Building 1 is designed to do exactly this. However, since every building is unique, every mechanical system is unique and is designed accordingly to accommodate these unique characteristics.

In the case of Westinghouse's Building 1 of their Nuclear Engineering Complex, the program is largely open office space with conference rooms and computer laboratories. The building also houses a data center, fitness center and cafeteria. This particular program consequently has a relative high concentration of computing equipment. This increase in internal heat load actually benefits the mechanical system because of need for heating for this particular building.

Several similar buildings have had problems maintaining a healthy indoor environment from low relative humidity and poor air filtration. Thus, the owners of the building gave higher priority to a healthier and more productive indoor environment for the workers.

The existing mechanical system was designed with low maintenance as a major influence. A system was designed that provided low maintenance costs, easy manageability, and efficiency. For the owner, this means lower energy bills and less operational costs over the lifetime of the mechanical system.

Equipment Summary

The primary system for Building 1 is a Variable Air Volume system. The system is supported by CRAC (Computer Room Cooling) Units in spaces with higher thermal loads that the VAV system cannot accommodate—specifically the Data Center, and a few computing laboratories. The VAV system was implemented because of it is practicality and lower first costs. VAV systems are widely used in similar buildings and have proven to be adequate systems.

The VAV and CRAC systems are supplied chilled water from the chiller plant located in the Basement of Building 1. The chiller plant includes three chillers with three cooling towers located in the mechanical penthouse. The four main Air Handling Units provide pre-heating through Gas-fired Burners. These main AHU's provide the building with about 40% OA. The VAV Terminal Units have Electric Resistance Re-Heating to provide the heating for the zones. Fan Powered Boxes are used to condition the perimeter spaces.

Building 1's Chiller Plant consists of three 450 Ton Chillers and three Cooling Towers. The building's heating needs are met with Gas-fired pre-heat in the AHU's with Electric Resistance Re-heat in the VAV terminal boxes.

All of the mechanical equipment is controlled using a complex-wide BACnet Building Automation System. This will allow the operation and maintenance employees to monitor the building(s) to ensure that the systems continue to run at maximum efficiency.

Power is provided to the site through an electric grid connection and a Natural Gas line. The 500kW back-up generator is used only in the event of a power failure.

Discussion of System

For detailed analysis of the system, Building 1 was closely investigated. The VAV System chosen for Building is typical choice for an office building of this nature.

Information on the first cost for the mechanical system of Building 1 has not been available for this report. However, with the VAV system specified and no special equipment, i.e. enthalpy wheel, the cost of the mechanical system should be relatively normal for a building of this type. This building is tenant-occupied and the owners were primarily concerned with low initial costs to return their investments as quickly as possible—thus a typical VAV system was the obvious HVAC solution.

The system should also have a relatively low operational cost. According to the Trane Trace model from Technical Report 2, the operational cost for the HVAC system is estimated to be $1.30/SF ($0.73/SF for energy bills and ~$0.60/SF for maintenance). This is quite similar to a similar to the $1.40/SF listed in the Energy Information Agency's (EIA) 2003 Commercial Buildings Energy Consumption Survey. The lower cost might be accounted for with the VAV system being relatively low maintenance and relatively efficient. Another major influence is the low utility cost for the Pittsburgh area.

Another cost of a system of this type is that a considerable amount of space is required for routing of ducts. The owner of the Building, Wells REIT II, is leasing the building out to Westinghouse, this lost square footage effects the payback period for the owner significantly—less rentable square footage, less revenue. By downsizing certain components through alternative strategies, the overall building cost could be decreased. Since air has a relatively small heat capacity, by conditioning the spaces through other means, i.e. chilled beams or radiant floors, the ductwork can be significantly downsized. This idea was implemented in the Data Center with the CRAC Units. These units were configured to connect to the Chilled Water loop and would condition the space by re-circulating the air instead of using return air.

With a VAV system, Indoor Air Quality can become an issue. This problem comes from the very nature of the system; that the air delivered to the rooms is a combination of ventilation and return air. If designed or installed incorrectly, modulations of supply airflow by the VAV Boxes can occur with no change in the outdoor air fraction-- resulting in a ventilation air deficiency. Also, if filters are not placed in the correct location and maintained, contaminants from inside the building can be re-circulated to all of the spaces in the building.

When designed, each of the Westinghouse Complex buildings was given chiller plants to more easily separate the leasing space into the three buildings. However, from an overall maintenance perspective, this is harder to maintain as the personnel must go from building to building. Also, each building has N+1 redundancy for its chillers, the cost of which could be reduced through a plant strategy.

Overall, the VAV system was the best choice for a variety of reasons. The VAV system will exhibit a low first cost, high ease of construction and maintenance, and can be designed to adequately meet the needs of the building. Other systems may have been ruled out due to higher first costs. However, better economic performance may be achieved from another system. A system with a lower operational cost, more energy savings and low emissions might be a better solution for the owners.

Proposed Alternate Systems

While a VAV system is effective to meet the needs of the client, other alternatives may be better in the long-term. To determine the best solution for Building 1, the loads within the building will be analyzed and options will be studied to determine load reduction relative to a VAV System. Then these loads and the initial loads will be applied to two different options: a Ground-Source Heat Pump (GSHP) System and a Chiller/Boiler System. Both of these systems will be implemented into a Dedicated Outdoor Air System (DOAS). The results from these studies will be compared with the design case of the VAV system with a Chiller and Electric Re-heat.

Reducing the Loads

The best step to making a building efficient is to reduce the loads. In general, this is the most cost-effective method to gain overall efficiency. For example, selecting a very high efficiency chiller might not be the best choice if the loads have not been addressed. In that case, the chiller does not need to be as large as it is to meet loads that are dealt with more efficiently. By meeting the loads with less input energy required, the chiller can be downsized, increasing savings.

Since the building is largely office space, a major proportion of this analysis will focus on reducing the loads to these spaces. A Dedicated Outdoor Air System, or DOAS, system will be explored to reduce the loads of this space with the use of Chilled Beams and/or DOAS Fan Powered Terminal Units. One study will explore the usage of only the DOAS FPBs while another study will use both systems in tandem—DOAS FPBs for the perimeter and Chilled Beams for core office spaces. Other major steps will be taken to reduce external gains to these spaces including solar shading, façade re-design, and building orientation optimization.

Dedicated Outdoor Air Systems can be a very effective method to not only reduce a building's overall energy efficiency but can dramatically increase the Indoor Air Quality. A DOAS system needs to supply much less air than a typical air system (rule of thumb is about 20% of a conventional system). This reduction in supply air means a downsizing of ductwork and fans. Additionally, the downsizing of ductwork results in lower floor-to-floor height requirements—saving additional construction costs. With the use of DOAS, the heating and cooling is decoupled from the ventilation air. Since water has a much better heat capacity than air, the energy requirements for the mechanical system will be much less.

With ventilation and space conditioning decoupled, DOAS can accommodate 100% of the space latent loads, 100% of the outdoor air loads, and near 30% of the space sensible loads. With all of these loads handled the a Dedicated OA System, only about 40% of the design chiller load must be handled by the parallel sensible only cooling system.

According to Stanley Mumma, compared to a conventional VAV system, which can have issues with properly ventilating all the spaces with enough outdoor air, a Dedicated OA System can place the proper ventilation air quantities into every space. Also, a VAV system generally uses 20-70% more outdoor air than is required in an effort to assure proper ventilation air distribution in all air systems than is required with DOAS. Cooling and dehumidifying the high OA quantities in the summer and humidifying and heating the air in the winter is an energy intensive proposition.

Additionally, VAV systems always use more terminal reheat than DOAS at the same air temperature because VAV requires more air.

Chilled Beams are a cutting-edge application of an old technology; the induction unit. They are more sophisticated, but operate on the same premise of buoyancy of air at differing temperatures. By using this property, fan energy can be reduced for the movement of air across the cooling coil. Active chilled beams have a connection for airflow from a DOAS unit and the chilled beam unit induces room air to re-circulate after mixing with the ventilation air. Passive chilled beams only induce room air to cool it, ventilation air must be provided by other means. The problems that could exist with chilled beams are condensing water in dangerous location and that most contractors and commissioners have little experience with them.

DOAS Fan Powered Boxes (DOAS FPBs) have not had the wide spread popularity as Chilled Beam but still provide several advantages that even Chilled Beams cannot match. DOAS FPBs have a non-condensing cooling coil (and heating coil if needed) in the induction inlet of the box. Because Fan Powered Boxes are already common, the installing contractor and maintenance staff will be dealing with known technology. Similarly, this technology results in significantly lower zone cost.

DOAS FPBs can be very useful for spaces that may need heating as well as cooling i.e. perimeter spaces. Thus a single DOAS FPB unit can both heat and cool, and provide required ventilation air. The FPBs can be ducted to several spaces, unlike a Chilled Beam, as a result one unit can service several enclosed spaces.

By investigating these methods further a comparison can be made with the VAV system as designed with respect to initial cost, energy efficiency gain, payback, construction impact, thermal comfort and indoor air quality.

Ground-Source Heat Pumps

Once the loads have been reduced or adjusted, the design case of current chiller plant and electric re-heat can be compared to the Ground-Source Heat Pump option. Applying the loads from each of the systems allows the determination of overall system efficiency.

With the Westinghouse complex located in the middle of a large piece of property, there is a considerable amount of open land that would be suitable for a ground-source heat pump system. Also, with most of property being covered by asphalt parking, a ground-source heat pump will add no marginal site disturbance. The GSHP system could provide a considerable amount of energy savings because of the near constant temperature of the earth (52°F in the Pittsburgh region). The GSHP System will be explored in two different fashions—with and without a supplemental Cooling Tower or Boiler. The two cases will be compared in both the existing VAV Air System and the Dedicated OA System.

A ground-source heat pump system has a significant initial cost however maintenance costs are generally low and the life of the system will outlast almost any other system. A GSHP system will also have an impact on the construction schedule depending on the depth and number of bores needed to meet the building's load. The GSHP system will be implemented into the reduced load design as well as the current unreduced load design. The two results will be compared to indicate the savings resulting for load reduction and GSHP.

Chiller and Boiler Plants in Hydronic System

Another option for providing heating and cooling to the building is the use of a Chiller and Boiler Plant. The existing mechanical system already has a Chiller Plant, but the heating is done with Gas-fired pre-heat in the main AHUs with electric resistance in the terminal units. However, with the addition of a Boiler Plant and a Hydronic System, the spaces will be able to be conditioned much more efficiently with less prime fuel usage. Many commercial boilers and chillers are 80%-95% efficient which may lead to it being a better choice of a system than the Ground-source Heat Pump.

This system will be implemented in the existing VAV system as well as the Dedicated OA System to compare and determine the most economically and energy efficient design.

Architectural Breadth

To reduce the external thermal load on the Building, an architectural breadth will be explored. A study of the building's façade will be done to determine how to lower summer solar gains as well as reducing winter thermal losses. Coloration of the façade and roof will be explored to optimize solar loads of the building. Also, other façade treatments like double skin, phase-changing wall material and thermal massing will be researched.

In addition, building orientation will be examined to determine the optimal orientation for effective solar gain as well as effective daylighting.

Lighting Breadth

In addition to an architectural breadth, a lighting breadth will be done with an overall goal to reduce the lighting requirements for the open office spaces. Light shelves will be explored to possibly reduce the need for as much artificial lighting. These light shelves can be projected from the building's façade to also act as a solar shade. The implementation of solar shades has an architectural aspect to them as they will be a prominent feature on the building's façade.

Overall, the addition of light shelves may be an inexpensive addition with major impacts to the design of the building's mechanical system.

Integration of Studies

All of the above depth and breadth topics will be integrated in such a way that the overall combination of efforts will be toward a more efficient system. In this manner the office system load mitigation systems can be combined with the DOAS and GSHP analyses to determine the best overall configuration for the building.

The building has been design architecturally to be relatively efficient. The windows are large, but meet the Comprehensive Plan for the 90.1 requirements for insulation. Through a preliminary load reduction analysis, both the Chiller/Boiler and GHSP studies can be evaluated at their most efficient.

The analysis of a Dedicated OA System will allow for a complete comparison against the existing VAV System. The decoupling the ventilation and conditioning of the spaces will result in a significant amount of energy savings, however all aspects will be researched including first cost, emissions, maintainability and payback period.

The Table below represents how all the comparisons of this project will be accounted for. Every combination of systems will be compared for first cost, construction impact, energy usage, efficiency, emissions, maintainability and payback period.

Table 1. Proposal Spreadsheet

	Existing VAV System	Dedicated OA System	Existing VAV System	Dedicated OA System
	No Load Reduction		Load Reduction	
Existing Chiller with Electric Re-heat	Existing System			
Chiller with Boiler Hydronic System				
Ground-Source Heat Pump Only				
GSHP with Supplemental Cooling Tower				Anticipated Best System

Tools for Analysis

For a comprehensive analysis of the systems mentioned above, many different analysis methods and tools will be required. Some preliminary research can be found in Appendix A and a draft work plan is available in Appendix B.

Load Reduction

First, for the system efficiency requirements for the office space thermal load reduction, a building energy modeling simulation program will be used. The program used will depend upon interface and data available within the program. Problems in this area could arise from insufficient modeling capabilities of cutting edge systems. The systems proposed above are all relatively recent technology (at least within the U.S.) with the exception of the hydronic boiler system. If the modeling software is incapable of offering a simulation including those technologies, then it will not provide meaningful results. Additionally these results will be checked against actual building energy use data found on the Energy Information Agency's (EIA's) Commercial Building Energy Consumption Survey (CBECS) to determine the validity of the findings.

It may also be beneficial to run Computational Fluid Dynamics (CFD) simulations. CFD analysis of the Dedicated OA System could be used to make sure that the system meets the requirements for ASHRAE Standard 55 for thermal comfort. With higher internal loads near the core of the building, the system might not perform as it would in a typical office space. It is important to consider occupant thermal comfort in the office space to ensure that the employees are productive and undistracted.

Ground-Source Heat Pump

Energy modeling software may be available to simulate a GSHP system. Trane Trace and Carrier's HAP will both be explored for GSHP simulations. If both programs can model GSHP systems then a comparison and average of the two programs can be made to culminate precise results. Also, research on the property soil make up will have to occur. The efficiency and construction impact of GSHP relies quite a bit on what lies within the ground. Additionally, information from EIA's CBECS will be used to determine the validity of the simulation.

Chiller Plant and Boiler Plant with Hydronic System

Since Chiller plants and Boiler plants are rather common in commercial buildings, modeling them should be quite simple. A Trane Trace simulation can be run with a Boiler plant introduced to replace the existing Electric resistance re-heat. The energy simulation will be able to give estimations of emissions, energy cost and energy usage.

Architectural and Lighting Breadths

The architectural breadth will focus on façade treatment and building orientation. The façade study will be done using an Excel Macro program published by ASHRAE. This program simulates building thermal loading for any possible façade. If Phase-changing material is pursued, a secondary program will have to be developed to take into account the changing Heat Capacity values.

The orientation optimization study will be done in Trane Trace. The Trace program allows the simulated building to be rotated 360 degrees. This will allow for an easy determination of an optimized orientation.

The Lighting Breadth encompasses a study of how the use of light shelves can reduce the lighting energy usage. Therefore a lighting simulation program will be run on a typical office space to determine the effectiveness of the shelves. Additionally, the solar shade aspect of this addition will be modeled into the existing Trane Trace model to determine its overall effect in reducing the cooling load.

Appendix A: Preliminary Research

1. Int-Hout, Chief Engineer, Dan. "A Reasonable Alternative to Chilled Beams- The DOAS Fan Powered Terminal Unit."May 2009. Krueger HVAC. 8 Dec. 2009

   <http://doas.psu.edu>

This article discusses the benefits of a DOAS Fan Powered Box over the popular Chilled Beam. The article explains the uses of each terminal unit and how they can work in tandem.

2. Kavanaugh, PhD, Steve. “Ground Source Heat Pumps.” ASHRAE Journal 40.10 (1998): 31-36.

This article discusses in some detail the cost of a GSHP system for different construction methods and tubing used. It also includes design suggestions, potential outputs for various GSHP systems. The article illustrates its point with a thorough example of a GSHP in a small commercial building.

3. Kavanaugh, PhD, Steve. “Ground Source Heat Pumps for Commercial Buildings.” September 2008. HPAC Engineering. 8 Dec. 2009

<http:///hpac.com>

This web article discusses some of the key points of how a Ground Source Heat Pump System operates. It compares a GSHP system to other standard commercial systems. Additionally, it lists the benefits and disadvantages of three different types of GSHP.

4. Minea, PhD, Vasile. “Ground Source Heat Pumps.” ASHRAE Journal 48 (2006): 28-35.

This article discusses a comparison of a vertical to a horizontal Ground Source Heat Pump System in Canadian Schools. The article includes discussions on system descriptions, construction costs, soil temperatures, energy consumption and operating experiences.

5. Mumma, PhD, PE, Stanley. “Dedicated Outdoor Air Systems.”February 2001. The Pennsylvania State University DOAS. 14 Dec. 2009

<http://doas.psu.edu>

This webpage discusses the advantages of a Dedicated OA System over a conventional system—namely VAV. It also explains the basic concept of how DOAS is implemented into a building.

6. Mumma, PhD, PE, Stanley. "Designing Dedicated Outdoor Air Systems."ASHRAE Journal 43.5 (2001): 28-31.

This article discusses in some detail the working parameters of DOAS. The article includes a comparison of a VAV system to three different configurations of DOAS.

Appendix B: Work Plan

For this analysis there is a significant amount of work that needs to be completed but it should be attainable using the schedule below.

<table>
<tr><th>Week #</th><th>Start Date</th><th>End Date</th><th>Academic</th><th>DOAS Analysis</th><th>GSHP Analysis</th><th>Boiler Analysis</th><th>Breadth Analyses</th></tr>
<tr><td>1</td><td>11-Jan</td><td>15-Jan</td><td>Schedule,Brdth Prop Corrections</td><td colspan="4">Locate and Learn All Programs Needed for Analyses</td></tr>
<tr><td>2</td><td>18-Jan</td><td>22-Jan</td><td>Prop Revised and posted</td><td colspan="4" rowspan="2">Correct, Add and Develop Existing Energy Model(s)</td></tr>
<tr><td>3</td><td>25-Jan</td><td>29-Jan</td><td>Submit Progress Schedule</td></tr>
<tr><td>4</td><td>1-Feb</td><td>5-Feb</td><td>Post Discussion Board Qs</td><td rowspan="3">DOAS Research</td><td rowspan="3">GSHP Research</td><td rowspan="3">Boiler Research</td><td rowspan="3">Façade and Shelf Research</td></tr>
<tr><td>5</td><td>8-Feb</td><td>12-Feb</td><td>Submit Progress Schedule</td></tr>
<tr><td>6</td><td>15-Feb</td><td>19-Feb</td><td>Meet with Consultant</td></tr>
<tr><td>7</td><td>22-Feb</td><td>26-Feb</td><td></td><td colspan="4" rowspan="2">Model Different Systems</td></tr>
<tr><td>8</td><td>1-Mar</td><td>5-Mar</td><td></td></tr>
<tr><td>9</td><td>8-Mar</td><td>12-Mar</td><td>Spring Break</td><td colspan="4" rowspan="2">Compare the Different System Combinations</td></tr>
<tr><td>10</td><td>15-Mar</td><td>19-Mar</td><td>Submit Progress Schedule</td></tr>
<tr><td>11</td><td>22-Mar</td><td>26-Mar</td><td>One Page Presentation due</td><td colspan="4" rowspan="2">Write report on findings in all areas and create a presentation of the results of the analyses.</td></tr>
<tr><td>12</td><td>29-Mar</td><td>2-Apr</td><td>Presentation Outline w/ Slides</td></tr>
<tr><td>13</td><td>5-Apr</td><td>9-Apr</td><td>FINAL REPORT DUE AND POST</td><td colspan="4">Check and Revise Report and Presentation</td></tr>
<tr><td>14</td><td>12-Apr</td><td>16-Apr</td><td>PRESENTATION WEEK</td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td>19-Apr</td><td>23-Apr</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>16</td><td>26-Apr</td><td>30-Apr</td><td>Finalize CPEP, Reflection, Updates</td><td></td><td></td><td></td><td></td></tr>
<tr><td>17</td><td>3-May</td><td>7-May</td><td>Final Exams</td><td></td><td></td><td></td><td></td></tr>
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