Bentworth Middle School

Bentleyville, PA

Revised Mechanical Thesis Proposal

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Date January 21, 2011

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Executive Summary

The purpose of this proposal is to outline the Bentworth Middle School studies that will be conducted next semester as part of the Architectural Engineering Capstone Project. This proposal includes a summary of the current building design and all proposed mechanical redesigns and breadth alternatives, which have also been outlined below.

Summary of Proposed Mechanical System Alternatives

- Reduce the loop field size and overall costs to the school through the design of a geothermal hybrid system
- Decentralize the loop field pumps to improve the systems efficiency and reduce the overall costs
- Ensure that proper ventilation is provided to all spaces through the use of occupancy sensors or counters
- Recover energy from all air exhausted from the building
- Provide ventilation air directly to the heat pump through the wall to eliminate ductwork and large rooftop heat pump units
- Use natural ventilation to improve air quality and reduce mechanical operation costs

Summary of Proposed Breadth Alternatives

Architectural

- A new façade design will be developed due to changes required by the mechanical and natural ventilation systems
- A new roof design will be required to incorporate the photovoltaic array

Electrical

- A study will be conducted to test the feasibility of using a photovoltaic array to improve the electric consumption efficiency of the school's computers and/or fluorescent lighting

The proposal concludes with a summary of the tools and methods that are to be used to complete these studies. A proposed semester schedule for all proposed work is also included. This schedule outlines that all depth studies shall be completed by the third milestone such that all depth work is completed before spring break. By the fourth milestone, all breadth study work is to be completed so that the remainder of the time can be used for finalizing the report and presentation portions of the project.

Building Design Summary

When the Bentworth School District began the building design process for their new middle school, one of their primary considerations was to create an advanced facility capable of meeting their needs for years to come. However, in doing so they wanted to avoid unnecessary costs and maintain environmental conscientiousness. Completed in January 2009, the new 83,800 square foot Bentworth Middle School did in fact come to be considered a state-of-the-art facility capable of providing a comfortable learning and working environment for both its students and staff. While this accolade was achieved through inter-discipline comprehensive design practices, it is obvious that the sustainable mechanical design for the building was at the forefront of the effort.

Existing Mechanical System

Bentworth Middle School is heated and cooled by a distributed two-pipe ground source heat pump system which is driven by two variable speed central pumps that are in parallel. The extensive loop field for this system covers almost three quarters of an acre and consists of 96, six inch diameter wells, each of which are 350 feet deep. This system is designed to supply the building's heat pumps with 72℉ water while in cooling mode and 42℉ water while in heating mode.

Supply air is distributed to the different building spaces by two different methods. The first method, which is how most of the spaces including the administration and classroom areas are supplied, is done by bringing 100% outdoor air into one of two rooftop heat pump units. These units then condition the outdoor air to a temperature of 68℉ and a relative humidity less than 60% by means of an enthalpy wheel, DX coil, and reheat coil. This outdoor air is then distributed throughout the building to terminal heat pumps where it is mixed with returned air from the space and then supplied to the space. The air exhausted from the terminal heat pumps is returned to rooftop heat pump where it is run through the enthalpy wheel and before it is finally exhausted.

Large, single assembly spaces are also provided supply air by a rooftop heat pump. Similar to the first method, outside air is brought into the unit and then run through an enthalpy wheel. It is then mixed with a fraction of the air returned to the unit before it is passed through the DX and reheat coils. The unit provides 55℉ supply air to the space when in cooling mode and 100℉ supply air when in heating mode. The fraction of the returned air not mixed with the outdoor air is then diverted through the enthalpy wheel before it is exhausted. Space temperature and humidity is regulated by the rooftop heat pump unit by sensors placed within the assembly space.

Advantages of Designed System

Geothermal systems are significantly more efficient than a comparable electric heating and cooling system. Likewise they also have few moving parts and have a longer lifetime than comparable equipment which greatly reduces maintenance and replacement costs of an owner. The environmental impact of a geothermal system is also significantly less as electric demand of the system is less than that of a typical system.

Another advantage of geothermal heating and cooling is its use of water for thermal transport as opposed to air. Water has a much greater thermal capacitance compared to air which allows for the same amount of energy to be transported by a much smaller volume. For instance, water from the loop field is distributed throughout the Bentworth Middle School via a piping system that takes up little mechanical space. If an air system had been used instead the amount of mechanical space required by the ductwork would have been significantly greater. In the end, a water system is of greater value for the building owner.

Proposed Mechanical System Alternatives

Although the mechanical design of Bentworth Middle has been found to be more than adequate, the system redesigns proposed below are to only further increase the efficiency of the building as well as reduce the overall costs to the building owner.

Terminal Unit Redesign

Although each space may be provided with the proper amount of supply and outdoor ventilation air, it is believed that under the current design the building as a whole does not. The primary reason for this is that there is no make-up air provided for the exhaust fans in the bathroom. These exhaust fans instead consume air from the hallway by means of either the door undercut or door grate. This in turn under supplies the hallways and creates negatively pressurized spaces within the building allowing for infiltration, wasting energy.

In order to alleviate this problem several things will be considered. First, the terminal heat pumps within the classroom and administration spaces will no longer receive their outdoor air supply from the rooftop units currently providing outdoor air to them. Instead the terminal heat pumps will be placed in a mechanical tower on the exterior of the building's classroom and above the ceilings of the administration spaces. Outdoor air will then be drawn directly into the room through the wall of the classroom or from the outdoor air plenum box for the administration spaces. Placing the terminal heat pumps in this location will also eliminate the mechanical mezzanine which will allow for a reduction in building height and construction costs. The rate at which the outdoor air will be brought into the space will be determined by a CO_2 or occupant counter sensor which will control the outdoor air damper. This sensor will help in reducing the fan energy used to bring in the outdoor air as well as the energy used to condition it.

Before entering the terminal heat pump the outdoor air will be preconditioned by an energy recovery device. This will be done to reduce the load on the heat pump as much as possible and to prevent humid air from entering the space. Energy wall will be the basis of the design for three reasons. First, it was found to be the most efficient product on the market when compared with products from other companies such as Dpoint Technologies and Dais Analytic. Second, the membrane of the Energy Wall component kills 98% of bacteria and therefore the air quality of the room will be improved unlike what happens with the use of energy wheels produced by companies such as Air-X-Change. Energy wheels actually induce cross contamination between the exhausted and ventilation air. Finally, Energy Wall contains no moving parts which means the use of this product uses no extra energy (except for fan energy) to operate and will require less maintenance than what an energy wheel would.

A final benefit of this system is that most of the vertical duct shafts that were used to supply air and return air to the space will be eliminated. This will free up a small amount of usable space as well as reduce ductwork and construction costs.

Natural Ventilation

Bentworth Middle School currently has operable windows, but lacks any sort of organized ventilation plan. A study will be conducted to determine if Bentworth Middle School would benefit from a natural ventilation system and if the current windows are adequate for this system or if they would need to be replaced. A natural ventilation system will at times reduce the load on the mechanical system and thus result in energy savings. Both a system that is operated by hand and system that electronically controls window actuators will be considered in this investigation. The drawback to this system occurs during times when natural ventilation is not appropriate. A façade that is designed for natural ventilation will undoubtedly have a higher infiltration and exfiltration rate. This will result in wasted energy use. Therefore, the conclusion of this study may instead reveal that the most efficient design would consist of fixed windows and ventilation air that is solely provided by the mechanical system.

Reducing the Loop Field Size (Hybrid System)

Often times the loop field is the most expensive component of a geothermal system as the drilling and piping are both very expensive. Currently the loop field of Bentworth Middle School is sized to meet the peak cooling and heating loads of school. A feasibility study will be conducted to see if downsizing the loop field to a size consistent with the typical load of the building will offset the purchasing and maintenance costs of a cooling tower and boiler which will be used to meet the peak loads of the building. This should in turn reduce the pumping costs by reducing the feet of heat of the system and which will reduce the overall building operation costs for the owner.

Decentralizing the Loop Field Pumps

In theory, placing a variable speed pump before each heat pump will minimize pumping energy by allowing for greater control of the loads. Therefore a study will be conducted to see if this is true and if it is worth the additional cost of maintaining many more pumps. The distributed pumps will also require more room and may cause unwanted noise in classroom areas. As such, it may be found that a central pumping system was indeed the best decision for Bentworth Middle School.

Proposed Breadth Alternatives

The proposed mechanical alternatives will innately have an effect on several of the other systems in the building. The overall efficiency of the building can also be improved by examining other construction disciplines. For these reasons, breadth design alternatives are presented below.

Electrical Breadth

Fluorescent lighting and computers both run on DC electric. The typical power supply to these components however is AC, which must then be converted to DC for the component's use. During this conversion process, energy is lost. In order to try and reduce the electric consumption of these building components a feasibility study will be conducted to explore the possibility of being able to power either one or both of these components through the use of a photovoltaic array. This study will assume that the photovoltaic array, which inherently produces DC electric, will be located on the roof of Bentworth Middle School. Technologies such as solar tracking and battery back-up will also be considered. The payback period of installing such a system will be significant in deciding whether a photovoltaic array at the school would practical.

Architectural Breadth

Significant consideration will have to be given to the architectural changes necessary for the natural ventilation, the new outdoor air ventilation source location, and the photovoltaic studies. The natural ventilation study will most likely result in the current fenestrations needing to be changed which will result in a new façade appearance. Air intake grilles will also have to be placed into the walls for the proposed mechanical systems. This will change the façade as well. Lastly, in order to make the photovoltaic array practical, the roof will need to flatten. This will greatly change the roof lines of building and will most likely require an entirely new roofing system.

Tools and Methods

In order to complete the proposed studies outlined above, several software packages will be utilized including Carrier HAP, Revit Architecture, AutoCAD, and Microsoft Excel. Through the use of these programs both the energy consumption and cost feasibility of the studies will be able to determine. This information will then be able to be used in future reports and presentations.

Carrier HAP is a program used to calculate building loads and conduct annual energy analyses. This program will be used to compare the currently designed mechanical system of Bentworth Middle School to the redesigned system. Specifically it will be used to study the amount of energy saved by the proposed terminal heat pump redesign and energy recovery system.

AutoCAD and Revit Architecture are design software programs used to produce two and three dimensional images. This software will be used extensively for the architectural breadth as well as to produce images to assist in explaining the other redesigned systems.

Microsoft Excel is a useful tool for solving equations in a table format which can then be used to produce graphs and charts. Ventilation rate calculations, solar calculations for the photovoltaic study, hourly load profiles used for the natural ventilation and decentralized pump studies will be analyzed by Excel.

Annotated Bibliography

Durkin, Thomas H. "Geothermal Central System." ASHRAE Journal 49.Aug (2007): 42-48. Web. 10 Dec. 2010.

This article talks about different topics pertaining to geothermal systems including different water-flow arrangements, incremental Equipment efficiencies, payback period calculation, well field design, and hybrid systems.

MacMillan, Jim. "Ground Source Heat Pumps In Schools." ASHRAE Journal 49.Sept (2007): 34-38. Web. 10 Dec. 2010.

This article addresses the appeal of geothermal systems to school boards, how to conduct calculations for a geothermal system, proper loop field location, geothermal pumping and piping arrangements, the use of geothermal heating and cooling in high occupancy spaces, and appropriate construction coordination methods.

Marriott, Carol. "3 Simple Approaches to Energy Efficiency." ASHRAE Journal 48.July (2006): 44-50. Web. 10 Dec. 2010.

The article outlines three different engineering techniques that can be used to improve a buildings energy efficiency including, optimal air systems, energy recovery systems, and geothermal heating and cooling.

Sirard, Stephane. "Geothermal for Grain Research Center." ASHRAE Journal 51.Aug (2009): 52-56. Web. 10 Dec. 2010.

This article pertains to the design and use of a geothermal system that was used on a research facility in Montreal and is composed of discussions on the heating and cooling, fresh air, refrigeration, control system, and cost effectiveness of the design.

Proposed Semester Thesis Schedule