2009

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Thesis Proposal

Manoa Elementary School

[THESIS PROPOSAL]

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Executive Summary

The current design of the Manoa Elementary School's systems was based on the various detailed design objectives described in this report. These design objectives, in conjunction with ASHRAE standards and the funding available, dictated the complexity of the designed mechanical systems. An energy model of the designed system was used to approximate the systems performance.

Various alternative systems were considered for the building analysis. These systems included air-source heat pumps, combined heat and power, water cooled units, natural ventilation and geothermal heat pumps. After comparing the costs and benefits of these systems as applied to Manoa Elementary School, air-source heat pumps, geothermal heat pumps and an automated natural ventilation system were chosen for further analysis. A complete façade study will be completed to cover both breadth studies. This study will include

Ground source heat pumps were considered as a design alternative due to their efficient use of energy. Two different types of ground source heat pumps will be considered for this analysis. These systems are a direct exchange heat pump system and a well system. Factors such as initial cost and operating cost will be a focus of evaluating the benefit of using this system instead of the designed system.

Air-side heat pumps were also considered as an alternative system for design. The high COP of this system for mild climates makes this system seem beneficial for this application. Comparison of this system to the performance of the ground source and designed system will be the focus of the analysis.

Natural ventilation is already implemented into the design of the building, but as a passive system. An active design system which uses the appropriate design methods as well as automated controls above the space occupants will be considered. Detailed calculations of the benefits of this system will be done to determine if the benefits of this system are worth the cost in design.

An in-depth study of the impact of altering façade components such will be performed in order to design a more efficient system for the building. Improvements to the thermal mass, daylighting, solar heat gain and façade materials will be investigated. Alterations to these systems will be evaluated based on the reduction of cost and the increased efficiency of the overall mechanical system.

System Design

Design Objectives

Architecture

The design of Manoa Elementary School had very specific architectural and system design objectives. The building site was 3.1 acres of a 10 acre community sports complex located in a Philadelphia streetcar suburb. The design of the school required four classrooms for each grade level, kindergarten through fifth grade. This requirement along with the objective to maximize the amount of usable athletic field space resulted in a three story classroom wing constructed at a height which did not exceed local zoning ordinances. The utilization of the cafeteria as both a stage area and a sub divisible large group instructional area created a spatially efficient building footprint. To further minimize the building's impact on the neighborhood the building envelope utilizes a mixture of reflective zinc colored metal panels which decrease the apparent mass of the building by allowing it to assume the color of the surrounding environment.

Structural

Structural design objectives utilized were to minimize cost and construction duration. A reinforced masonry bearing and pre-cast concrete plank structural system were utilized for the classroom wing which also limited the overall height of the building to meet the zoning requirement of 30 feet.

Sustainability

Cost effective and environmentally protective sustainability strategies were incorporated into the architectural and systems design. Sustainable materials and finishes were used, such as bamboo wainscot and acid etched and sealed concrete floors in circulation spaces. To reduce the load on the mechanical systems, sustainable design features such as insulated glass windows and doors, DDC Building Automation System, energy recovery systems, lighting control system which includes occupancy sensors, high efficiency indirect/direct lighting and daylighting were utilized.

Mechanical

The mechanical design objectives for Manoa Elementary School were relatively straight forward. The primary design objective for the HVAC system was to provide adequate heating and cooling to conditioned spaces while complying with ASHRAE Standards 55, 62.1 and 90.1. Another design objective was to control the humidity of spaces in order to minimize mold and mildew growth and improve the indoor air quality of the space.

Design Factors

Site

The location of the building in the heart of a residential community and within the center of a community sports complex provided many issues for the design. One of the main design concerns was maximizing the amount of athletic field space available for the community. This was achieved by utilizing a subsurface storm water detention system, hard surface playground that doubles as event parking and the efficient building layout described in the architectural objectives above. Noise generated by the mechanical systems was another issue of concern. Great effort was made in the design process to minimize the impact of noise generated by the mechanical systems to the surrounding community.

Cost

Manoa Elementary School is one of five elementary schools in the Haverford Township School District. As a public school, all funds for the construction of the new building were obtained through tax dollars or donations. As such, the total cost of the building was limited to the amount allotted by the Pennsylvania Department of Education though taxes and donations.

Major Equipment

Manoa Elementary School was designed to utilize several different mechanical system types. This was done because it houses several different types of spaces. These systems include four rooftop air handling units with energy recovery systems, one indoor air handling unit, a make-up air unit, 5 split system packaged rooftop air handling units and two dual fuel boilers. Two of the rooftop air handling units are variable volume outdoor air units and serve Wing A as shown in Figure 1. The other two rooftop air handling units in conjunction with the indoor air handling unit are constant volume systems that condition the classroom, office, gymnasium and kitchen spaces of Wing B which can be seen in Figure 2. The make-up air unit serves the kitchen and is a constant volume system that serves to replace the air exhausted from the space. The five air-cooled ductless split system units are two speed constant volume units that serve to condition the electrical and data distribution rooms in the Classroom Wing A.

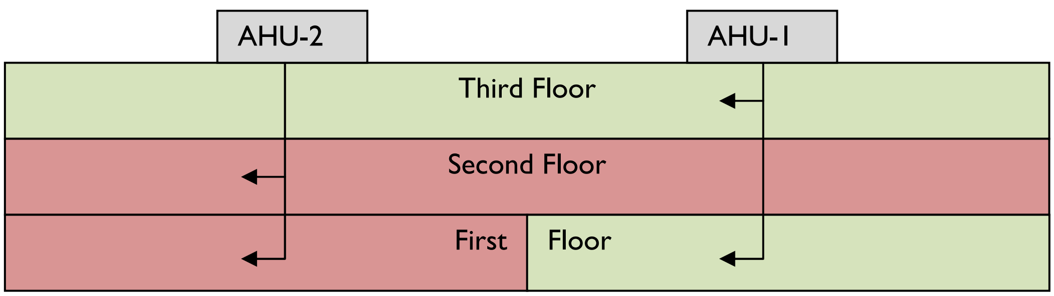


Figure 1: Wing A AHU Distribution Schematic

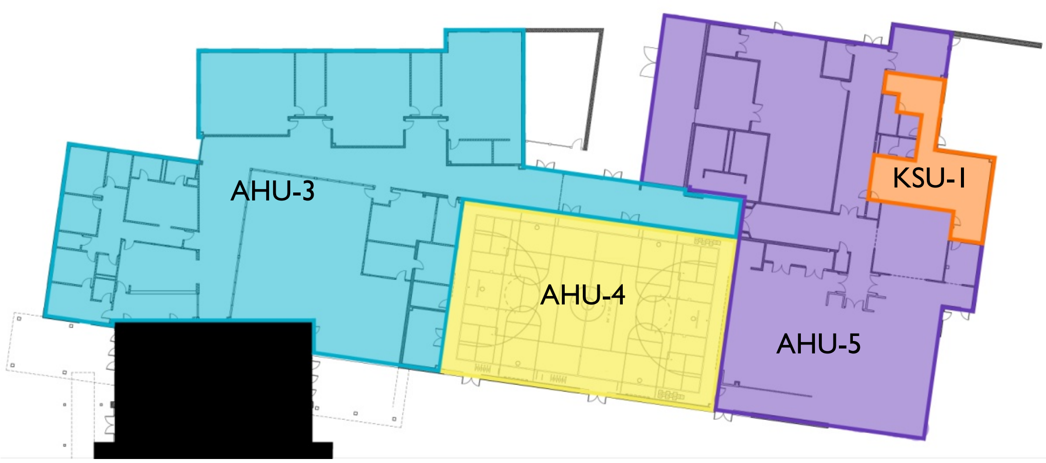


Figure 2: Wing B AHU Distribution

System Evaluation

Construction Cost

The construction cost of the mechanical system was 16.4% of the overall project budget. However, the utilization of energy recovery ventilators raises the complexity of the mechanical system. The increase in complexity to save energy does not substantially increase the cost of the mechanical system.

Operating Cost

The operating cost of the system was determined in Technical Report II to be $1.23 per square foot. This value is comparable to the value listed for schools in ASHRAE Handbook of Applications 2007. Table 4 in Chapter 35 of this handbook gives a reference value of $1.09 for the 50th percentile. The data used by the authors of the handbook are from 2003 and are obviously outdated.

Space Requirements

Because of the design objective to minimize the building footprint, interior spaces needed to be used for educational purposes, not mechanical spaces. To minimize the impact of the mechanical equipment on the building rooftop air handling units and a mechanical penthouse were utilized. Implementation of other mechanical systems would take up far more floor space than the designed system.

Maintainability

The systems require a relatively knowledgeable maintenance staff in order to keep them running. The system includes pumps, chillers, boilers and energy recovery units which all need supervision by a qualified staff. Since the air handling units are either on the roof or in the mechanical penthouse, components such as the coils, filters and fans requiring maintenance are easily accessible by the maintenance staff.

Indoor Air Quality Issues

A variable air volume system can create indoor air quality problems. Air delivered to the conditioned spaces is a mixture of the ventilation air and return air. The mixing with the return air can produce issues with the quality of the air distributed to the space. Ironically, another source for a reduction in the quality of air supplied to spaces can occur by the air filtration system. Leakage around the filters due to the inherent nature of filter construction or incorrect installation of the filters significantly reduces the performance of the filter and also reduces the air quality.

Proposed System Alternatives

The mechanical system described above was designed to be as efficient as possible while complying with the budget requirements. A further investigation of systems that reduce initial cost, operating cost, mechanical space or payback period will be researched further. An in depth analysis of modifications in these areas will be evaluated in the system redesign. These alternatives include

Several system alternatives were considered as possible system alternatives. These alternatives included:

- Air-source Heat Pumps
- Combined Heat and Power
- Water Cooled Systems

- Ground Source Heat Pumps
- Automated Natural Ventilation

Air-source heat pumps, ground source heat pumps and an automated natural ventilation system were chosen for further investigation based on their applicability to the building size and type. These alternatives will be analyzed to determine their impact on the initial cost, operating cost, mechanical space and payback period of these systems.

Ground Source Heat Pumps

An investigation of the effects of a ground source heat pump system will be conducted. Both a direct exchange and a well type system will be compared to determine the different effects on the building systems. The main focus for the comparison of systems will be their impact on the initial cost, operating cost and impact on the square footage of the building. Another benefit of this system is it reduces the noise impact of the system to the environment by eliminating the need for compressors outside. Environmental noise reduction was a primary concern for the design team because the school is located in the center of a residential community. The basic components of both ground source heat pumps can be seen in the schematic below.

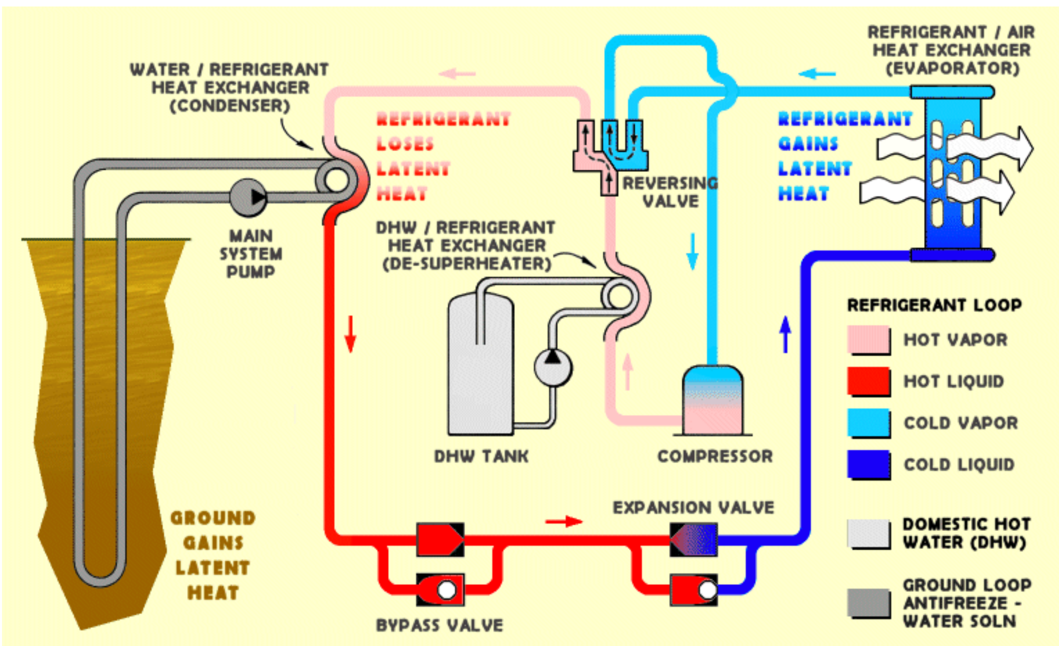


Figure 3: Geothermal Heat Pump Schematic

The direct exchange heat pump system has several benefits as well as drawbacks that will be investigated. The primary benefits of the system is that it is significantly more efficient as well as a lower installation cost compared to a closed loop system. However, the system utilizes copper pipes as the underground heat transfer device which has a long life but the cost is of major concern as well as the greater use of refrigerant. The comparison of system costs and potential energy savings is of primary concern of analysis.

The vertical well system will be used to determine the increase in performance when compared to the direct exchange system. The main drawback of this system is the cost of boring holes 75-500 feet deep, however this system is beneficial for sites where space is a concern. The comparison of this system to the direct exchange and designed system is a concern of study.

Air Source Heat Pumps

The consideration of using this system for analysis is based on the interest in comparing the system performance to that of the ground source heat pump systems. Estimated system performance in mild weather can be approximated to have a COP of 4 where the designed system has a COP of 2.7. The savings in energy efficiency makes this system a viable research option for an alternative design. Also, this system does not require the extensive excavation or underground piping requirements that the ground source heat pumps utilize therefore initial cost of the system would appear to be less that ground source heat pumps. The total cost comparison of this system to the ground source systems and the designed system is a definite area of interest for analysis. The major components of this system for both heating and cooling cycles can be seen in the schematic below.

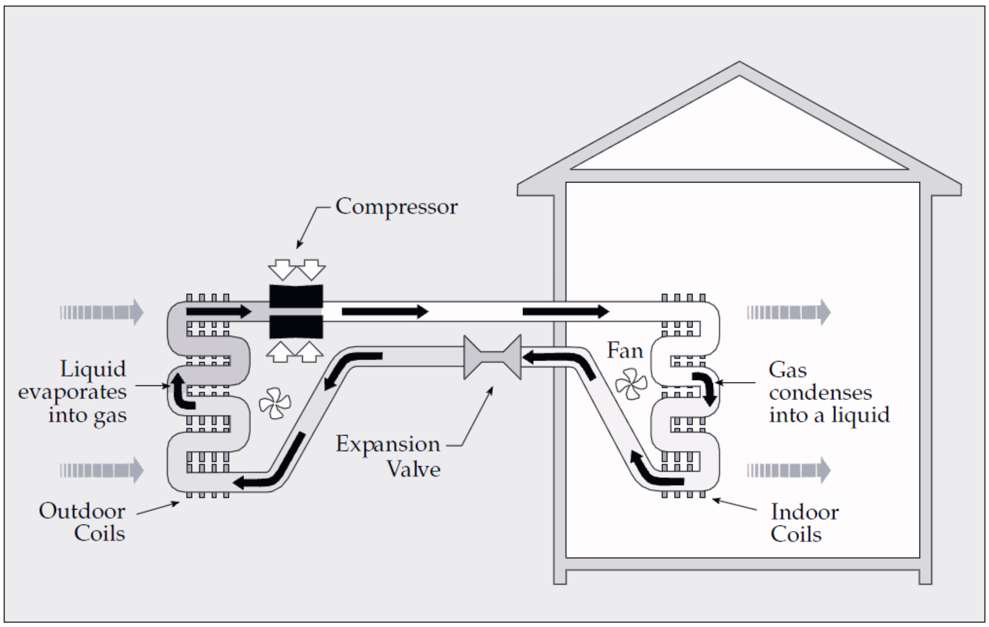


Figure 4: Air Source Heat Pump Heating Schematic

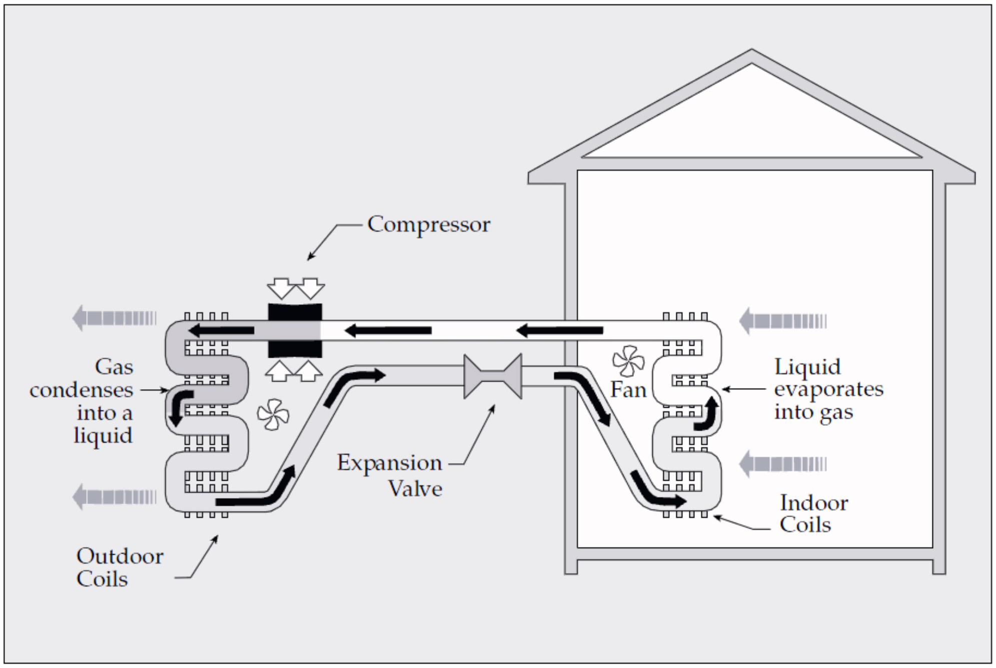


Figure 5: Air Source Heat Pump Cooling Schematic

Automated Natural Ventilation

Manoa Elementary School is already designed to utilize the benefits of natural ventilation; however it is only used as a backup to the mechanical ventilation system. Research and design for a primary natural ventilation system will be used to determine its impact on the energy use of the building. An analysis of the required glazing for each space will be done to ensure compliance with ASHRAE Standard 62.1 and study of the system controls will be detailed in the analysis.

Breadth Topic

Building Facade Redesign

An in-depth study of the impact of altering façade components such will be performed in order to design a more efficient system for the building. Improvements to the thermal mass, daylighting, solar heat gain and façade materials will be investigated.

Improvements to the thermal mass of the building will greatly affect the operational cost of the mechanical system. By designing a building that will absorb heat during the hours that the school is occupied and releasing the heat when the building is unoccupied will not only reduce the amount of electricity used to remove the heat from the space but can also reduce the size of the mechanical equipment needed to condition the space.

Research into the reduction of electricity use by taking advantage of daylighting will be beneficial to the mechanical system design. An analysis of the building orientation and solar angles as well as the performance of the glazing will be used in conjunction with the lighting controls to determine the energy savings of the system. The use of light shelves and light wells will also be investigated to provide light to the space. The study will take into account the increased amount of glazing that is required for natural ventilation.

A solar heat gain study will be performed in conjunction with the daylighting study. Exterior solar shades will be used to reduce the amount of direct radiation entering the building adding heat to the space. Effectively designed solar shades will prevent excessive amounts of radiation entering the space when the solar angles are high and allow the radiation into the space during the winter when the solar angles are low and heat is required for the space.

Masters Applications

Knowledge gained from AE 557 Central Cooling and AE 558 Central Heating will be used when evaluating the systems described above. Central Cooling will aid in the analysis of the heat pumps when in cooling mode and compare the system to the variable air volume system currently designed. Central Heating will evaluate the heat pump heating performance and compare it to that of the two fossil fuel boilers proposed. AE 552 Indoor Air Quality will also be used to determine the effect on the interior air quality of each system as well as the effect the geothermal heating system has compared to the fossil fuel boilers designed.

Tools and Methods

Several different standards and computer programs will be used to determine the benefits of the alternative systems described above. ASHRAE standards describing methods of designing those systems as well as Trane Trace for modeling will be used to determine the performance as well as the energy savings for each different system as well as a combination of those systems with the breadth proposals.

Trane Trace will be the primary program used to determine the performance of the alternatives. This program is capable of modeling any kind of equipment configuration and an energy model can be used to compare the alternatives to the current system design. From this model a detailed report of the energy savings can be constructed and the benefits as well as the drawbacks of the different systems can be directly compared.

Microsoft Excel will be used to perform necessary calculations as well as create graphical comparisons of the different system performances. Any complex engineering calculations above the capabilities of Excel will be performed in Engineering Equation Solver which is programmed specifically

AGI or other lighting analysis programs in conjunction with ASHRAE Standard 90.1 will be used to evaluate the adequacy of the daylighting system for lighting interior spaces.

Preliminary Research

Clearinghouse, E. E. (2001). *Air-Source Heat Pumps.* Department of Energy.

This article by the U.S. Department of Energy details the operation, the system types, method of selection and installation, performance improvements, operation and maintenance measures for an air-source heat pump system. All major design points and considerations are detailed here as well as a detailed list of resources that can be utilized for further research.

Durkin, T. H., & Cecil, K. E. (2007). Geothermal Central System. *ASHRAE* , 42-48.

ASHRAE Journal published this article in order to outline the benefits of using a central geothermal heat pump system as well as its applications to schools. The article includes configuration schematics as well as graphs and tables detailing the

application of this system to the design process. This article also discusses the energy savings and benefits for utilizing this system.

Honlness, G. (n.d.). *Energy Efficiency in Existing Buildings- Our Greatest Opportunity for a Sustainable Future.* Retrieved December 10, 2009, from www.ashrae.org: http://www.ashrae.org/aboutus/page/2372

This article written by the current president of ASHRAE discusses the effects of a sustainable design and the impact it has on our future. This article also discusses the design standards and techniques that can be used when attempting to design sustainable systems for new buildings.

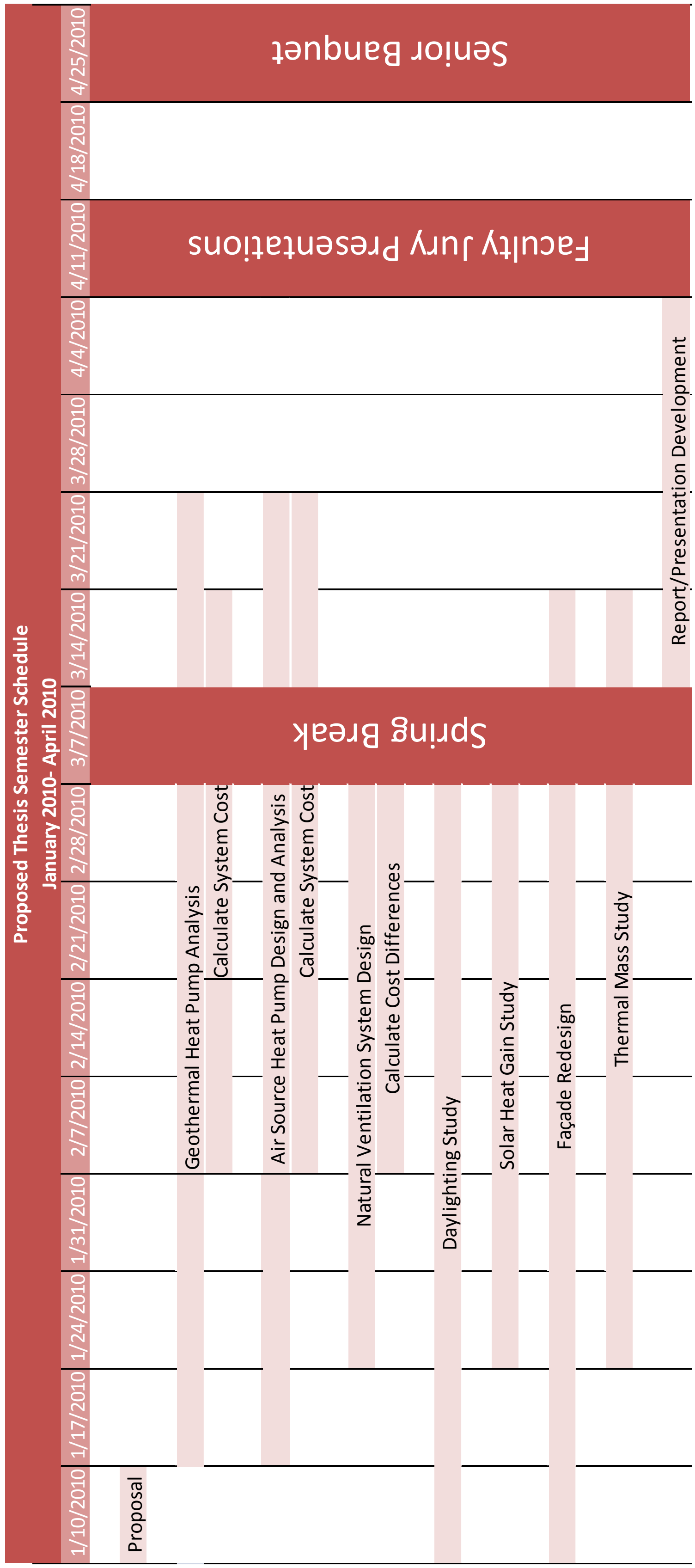
MacMillan, J. (2007). Ground Source Heat Pumps in Schools. *ASHRAE* , 34-38.

This article details design considerations that can be used when designing ground source heat pumps and their applications to schools. Although this article specifically discusses the application of a closed loop system, it also states that the concepts detailed in this article are also applicable for other types of ground source heat pump systems.

Walker, A. (2008, June 3). *Natural Ventilation.* Retrieved December 10, 2009, from National Institute of Building Sciences Whole Building Design Guide: http://www.wbdg.org/resources/naturalventilation.php

The article on this website details the method of design for a natural ventilation system. A calculation procedure, design recommendations, materials and methods and analysis and designed tools are all specified in this article. All the information included in this article will be helpful when analyzing the performance of the proposed natural ventilation system.

Proposed Semester Schedule


Proposed Thesis Semester Schedule
January 2010- April 2010
1/10/2010
1/17/2010
1/24/2010
1/31/2010
2/7/2010
2/14/2010
2/21/2010
2/28/2010
3/7/2010
3/14/2010
3/21/2010
3/28/2010
4/4/2010
4/11/2010
4/18/2010
4/25/2010
Proposal
Geothermal Heat Pump Analysis
Calculate System Cost
Air Source Heat Pump Design and Analysis
Calculate System Cost
Natural Ventilation System Design
Calculate Cost Differences
Daylighting Study
Solar Heat Gain Study
Façade Redesign
Thermal Mass Study
Report/Presentation Development
Spring Break
Faculty Jury Presentations
Senior Banquet

References

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ASHRAE. 2004, ANSI/ASHRAE, Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA

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