Bentworth Middle School

Bentleyville, PA

Final Report

Alternative Systems Analysis

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Mechanical Option
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Bentworth Middle School

Bentleyville, PA

Kyle Courtney | Mechanical Option

Statistics

Building Size:
- 83,800 Square Feet

Number of Stories:
- 3 Stories Above Grade

Project Competition Date:
- January 2009

Overall Project Cost:
- $18 Million

Project Delivery Method:
- Design-Bid-Build

Project Team

Owner:
- Bentworth School District

Architect:
- Hayes Large Architects

Construction Manager:
- Oxford Development Co.

MEP Engineer:
- Hayes Large Architects

Structural Engineer:
- Atlantic Engineering Services

Civil Engineer:
- The EADS Group

Geotech Consultant:
- CMT Laboratories, Inc.

Food Service Consultant:
- McFarlnd Kistler & Associates, Inc.

Architecture

The entrance of the building is focused around a central octagonal lobby which acts as a node separating the academic wing from the rest of the building. Areas such as office spaces, the music and physical education rooms, cafeteria, and gymnasium are located in a separate, single story wing where the noise associated with these spaces will not disturb the learning process. The academic wing consists of three floors, all of which are arranged in an "L-shape". This design allows the classrooms located to either side of a central corridor to be provided with natural light and excellent views of the surrounding suburban area.

Mechanical

A geothermal system consisting of 96 six inch diameter wells, each of which are 350 feet deep, allows for the building to either gain or reject heat to the ground depending on the building's heating and cooling needs. The loopfield then feeds the building's heat pumps which provide heated or cooled air to the building spaces. Two rooftop heat pump units provide ventilation air to the terminal heat pumps located in the classroom, library, and administration areas while the four additional rooftop units condition the air of large single zones such as the cafeteria, stage, gymnasium, and kitchen.

Electrical/Lighting

The main switchboard in the building is a three sectioned 2000A, 277/480V, 3 phase, 4 wire board and the second switchboard, which stems off of the first, is a 1600A 120/208V, 3 phase, 4 wire board. Emergency power is provided by an 85KW generator which provides power to two separate automatic transfer switches. Classrooms spaces are primarily lit by T5 luminaires whiles hallways makes use of T8's and compact fluorescence lamps. The luminaires in the gymnasium are metal halide .

Structural

The academic wing's foundation is a continuous concrete wall footing which supports a 4" slab on grade. This foundation supports load bearing, reinforced concrete masonry walls and floors made of precast planks with a 2" reinforced concrete topping. The second wing of the building has the same foundation and not only makes use of load bearing, reinforced concrete masonry walls, but also steel beams and K-joists. The prefinished standing seam metal roofing system is supported by light gauge metal trusses and walls.

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Acknowledgements

I would like to express my gratitude to all who assisted me throughout the year in completing this final Capstone Project. A special thanks to:

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My fellow classmates who have supported me over the last five years, especially the gentlemen and ladies of 612

My friends and family for all their love and encouragement

Executive Summary

This report contains the results of several studies that were conducted over the course of a year as required by The Pennsylvania State Architectural Engineering senior capstone project. These studies primarily revolve around the mechanical systems of Bentworth Middle School in Bentleyville, PA. The first half of the report contains a synopsis of the studies conducted last semester, including an analysis of compliance with ASHRAE Standards and LEED criteria, discussions on building load modeling and building energy modeling, summaries of the mechanical system design and operation sequences, and an overall as designed system evaluation.

The rest of the document contains information regarding several feasibility studies that were proposed in order to improve the efficiency and over quality of the building. These proposed system redesigns consist of:

- The design of a geothermal hybrid system in order to reduce initial system cost and overall energy consumption
- A redesign of the terminal heat pump units in order to eliminate ductwork and improve system efficiency
- The development of a natural ventilation system in order to decrease energy usage and improve the condition of the learning environment within the classroom
- A study pertaining to the possible energy savings that could be achieved through a decentralized pumping system
- An investigation of the practicality and usefulness of a photovoltaic array
- Development of a new façade and roofing system as deemed necessary due to the other proposed system changes

The results of these studies varied from practical and economical to expensive and wasteful and are summarized below.

- The additional upfront costs of the terminal unit redesign had a simple payback period of 12 years due to its more efficient system and energy savings
- The geothermal hybrid system is capable of reducing initial system costs by $94,150
- Natural ventilation was able to save a significant amount of energy and the system had a simple payback period of 15 years
- Do to the high amount of head created by the geothermal loop field a decentralized pump system was not deemed feasible
- The photovoltaic array is so costly that even government incentives did not make the investment reasonable

Existing Conditions

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.

Mechanical Design Objectives

The purpose of any mechanical system is to provide a comfortable interior environment for the building occupants. In order to achieve this it is most important that the interior temperature, relative humidity, and outdoor ventilation air rates within the building are regulated and monitored. It is easy enough to accomplish this through many conventional mechanical systems, but Bentworth Middle School wanted to also consider the costs affecting both themselves and the environment when selecting the mechanical system for their building. Therefore, in an effort to curb the negative environmental effects of the school and provide the students and faculty of school with a building that would be able to provide an excellent learning and teaching environment for several decades, a geothermal heat pump system was selected.

Mechanical System Overview

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 degree Fahrenheit water while in cooling mode and 45 degree Fahrenheit 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 pre-condition the outdoor air to a temperature of 68°F 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 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°F supply air to the space when in cooling mode and 100 degree Fahrenheit 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. Sensors placed within the assembly space regulate the space's temperature and humidity.

Mechanical Equipment Summary

Most of the mechanical equipment in the building is heat pumps. Table 1 outlines the rooftop heat pumps. The enthalpy wheels of these units are summarized in Table 2. Rooftop heat pumps A1 and B1 solely provide ventilation air to smaller terminal heat pumps distributed throughout the building. There are several different sizes of these heat pumps used throughout the building and several of the models are arranged in different configurations in order to most accurately meet the loads of individual spaces. Table 3 outlines the typical airside configurations for most of these units while Table 4 outlines the waterside configurations. Please note that the units in corresponding rows of Table 3 and Table 4 are the same unit. The last main piece of equipment utilized by Bentworth Middle School is two identical pumps, which are used to distribute the water from the loopfield to the rest of building. These pumps are summarized in Table 5.

Table 1: Summary of Rooftop Heat Pumps

Symbol	Serves	Total CMF	Outside Air CFM	Supply Air Temp (F)		Filter Data	HX-Cooling		HX-Heating		Flow Rate (GPM)
				Summer	Winter		EWT (F)	LWT (F)	LWT (F)	EWT (F)	
RTHP-A1	Classrooms	11,500	11,500	68	68	30% Pleated	75.0	81.9	42.0	40.8	102
RTHP-B1	Admin/Lib	3,500	3,500	68	68	30% Pleated	75.0	82.3	42.0	41.3	34
RTHP-B2	Cafeteria	4,110	4,110	55	100	30% Pleated	75.0	81.2	42.0	37.1	69
RTHP-B3	Stage	1,100	1,100	55	100	30% Pleated	75.0	81.7	42.0	38.4	26
RTHP-B4	Gym	8,000	8,000	55	100	30% Pleated	75.0	81.4	42.0	36.6	102

Table 2: Summary of RTHP Enthalpy Wheels

Symbol	Cooling Data				Heating Data	
	EAT ℉ (OA)		LAT ℉ (OA)		EAT ℉ (OA)	LAT ℉ (OA)
	DB	WB	DB	WB	DB	DB
RTHP-A1	90.0	72.0	82.3	66.0	0.0	52.6
RTHP-B1	90.0	72.0	82.2	66.0	0.0	52.7
RTHP-B2	90.0	72.0	81.0	64.8	0.0	61.2
RTHP-B3	90.0	72.0	81.1	65.0	0.0	60.3
RTHP-B4	90.0	72.0	81.7	65.5	0.0	56.4

Table 3: Summary of Distributed Heat Pumps (Air Side)

	Model	Air Flow CFM	OA CFM	Cooling				Heating		Configuration
				EAT		LAT		EAT	LAT	
				DB (°F)	WB (°F)	DB (°F)	WB (°F)	DB (°F)	DB (°F)	
1	EC009	250	65	75	62.5	58.2	52.9	68	96.0	Horizontal
2	EC012	320	130	75	62.5	55.5	51.9	68	97.9	Horizontal
3	EC012	330	20	75	62.5	55.6	52.1	68	97.1	Horizontal
4	EC015	400	200	75	62.5	55.2	51.8	68	96.2	Horizontal
5	EC018	520	375	75	62.5	54.6	51.4	68	95.9	Horizontal
6	ES025F	680	170	75	62.5	52.0	50.2	68	97.6	Counter Flow
7	ES025F	800	375	75	62.5	53.3	52.0	68	94.0	Counter Flow
8	ES025F	920	415	75	62.5	54.2	53.3	68	91.2	Counter Flow
9	ES035F	1020	375	75	62.5	53.8	51.2	68	97.0	Counter Flow
10	ES049F	1360	55	75	62.5	54.0	51.4	68	97.8	Horizontal
11	ES035F	1380	500	75	62.5	55.4	53.9	68	90.4	Counter Flow
12	ES049F	1600	500	75	62.5	55.1	53.0	68	93.4	Counter Flow
13	ES049F	1840	200	75	62.5	55.8	54.1	68	90.5	Horizontal
14	ES061F	2200	750	75	62.5	55.3	53.6	68	92.0	Horizontal

Table 4: Summary of Distributed Heat Pumps (Water Side)

	Model	Cooling		Heating		Flow Rate (GPM)
		EWT (°F)	LWT (°F)	EWT (°F)	LWT (°F)	
1	EC009	75	84.3	42	36.7	1.9
2	EC012	75	84.3	42	36.7	1.9
3	EC012	75	85.0	42	36.5	2.5
4	EC015	75	85.3	42	37.0	3.1
5	EC018	75	86.0	42	36.5	3.8
6	ES025F	75	86.3	42	35.5	5.0
7	ES025F	75	86.6	42	35.3	5.0
8	ES025F	75	86.9	42	35.1	5.0
9	ES035F	75	85.7	42	35.7	7.5
10	ES049F	75	85.7	42	35.8	10.0
11	ES035F	75	86.3	42	35.3	7.5
12	ES049F	75	86.0	42	35.5	10.0
13	ES049F	75	86.2	42	35.3	10.0
14	ES061F	75	86.3	42	35.2	12.5

Table 5: Pump Summary

Symbol	Capacity		Motor		Imp. Dia.	Suction	Discharge	Control
	GPM	HD	PRM	HP				
P-1 & P-2	405	130	1750	20	12.125"	4"	3"	VSD

Waterside System Operation

Waterside operation is driven by two variable frequency drive pumps in parallel. They provide the system with 75̊F water during the summer and 42̊F water in the winter. In general, these pumps run continuously and operate in a lead/lag fashion. As can be seen in Figure 1, each pump is equipped with a flow switch which indicates the speed at which the pump is operating. Upon proof of pump operation as provided by the flow switch, two differential pressure transducers (also seen in Figure 1) are used to vary pump speed in order to maintain a remote differential setpoint of 5 PSIG. If the temperature of the water provided by the geothermal loopfield ever falls below 42̊F the system will begin to shed heat pumps from the loop system in order to prevent freezing. These units will only be brought back onto the system after the loopfield temperature has reached 44̊F.

As Figure 1 shows, the primary piece of equipment served by the geothermal system is heat pumps. Due to the number of heat pumps used in Bentworth Middle School, the entire waterside flow diagram was not shown as the academic wing was left out of the flow diagram schematic. However, Figure 1 clearly shows that water is distributed to the heat pumps in the administration wing as well as to the single rooftop heat pumps serving the large assembly type spaces. Water demand for both the rooftop units and terminal units is managed in very much the same way. The water flow rate is regulated by monitoring the supply air temperature of the unit such that if the supply air is lower than what is required the the flow rate is decreased. When there is a call for heating, the units divert the refrigerant from the airside evaporator coil to the liquid chiller by means of a 3-way valve. This is how both heating and cooling is achieved by these units. Most of the terminal units also have a waterside economizer. This means that when conditions are right “free” cooling can be utilized by diverting the water to a multi-row type water coil with copper tubes and aluminum fins. The waterside piping configurations for all of the heat pump units within Bentworth Middle School can be seen in Figures 2, 3, and 4.

Airside System Operation

Outdoor air is brought into Bentworth Middle School in two different ways. The first way it is brought in is through rooftop heat pump units which distribute 100% outdoor ventilation air to the terminal heat pump units serving the classrooms and administration areas. These rooftop units are primarily controlled by a discharge air sensor, humidity sensor, space temperature sensor, and humidity sensor. They are equipped with a variable frequency drive fan which allows them to match the demand of the terminal heat pumps. The speed of the fan is modulated by a static pressure sensor mounted in the ductwork. An increase in static pressure causes the supply and exhaust fans to slow down while a decrease in static pressure causes them to increase in speed. This type of system can be seen in Figure 2.

The terminal units are controlled by room thermostat. When the room in is the occupied mode the unit fan runs continuously. The changeover valve transition point is halfway between the occupied heating setpoint and the occupied cooling setpoint such that when the space temperature is above the changeover valve transition point, the changeover valve shall be in the cooling position. Likewise, when the space temperature is below the changeover valve transition point, the changeover valve will be in the heating position. Figure 4 shows this.

The second way outdoor air is brought into the building is by the rooftop heat pumps serving a single, large assembly space. These units are primarily controlled by a discharge air sensor and space humidistat. When in the occupied mode, the outdoor air damper will open and both the supply and exhaust fans run while the enthalpy wheel is energized. While heating, if the discharge dew point temperature of the enthalpy wheel falls below 54℉ and the dry bulb discharge temperature of the enthalpy wheel falls below 68℉, the unit's compressors shall be index on, and the hot gas reheat valve shall be modulated to maintain the space temperature at 70℉. The opposite occurs when the heat pump is in cooling mode. Instead, when the discharge dew point temperature of the enthalpy wheel rises above 54℉, the unit's compressors index on and the hot gas reheat valve is modulated to maintain a space temperature of 75℉. And when the discharge dew point temperature of the enthalpy wheel is below 54℉ and the dry bulb discharge temperature of the enthalpy wheel rises above 68℉, the unit's compressors shall be index on and the hot gas reheat valve shall be modulated to maintain a space temperature of 68℉. This system is outlined in Figure 3.

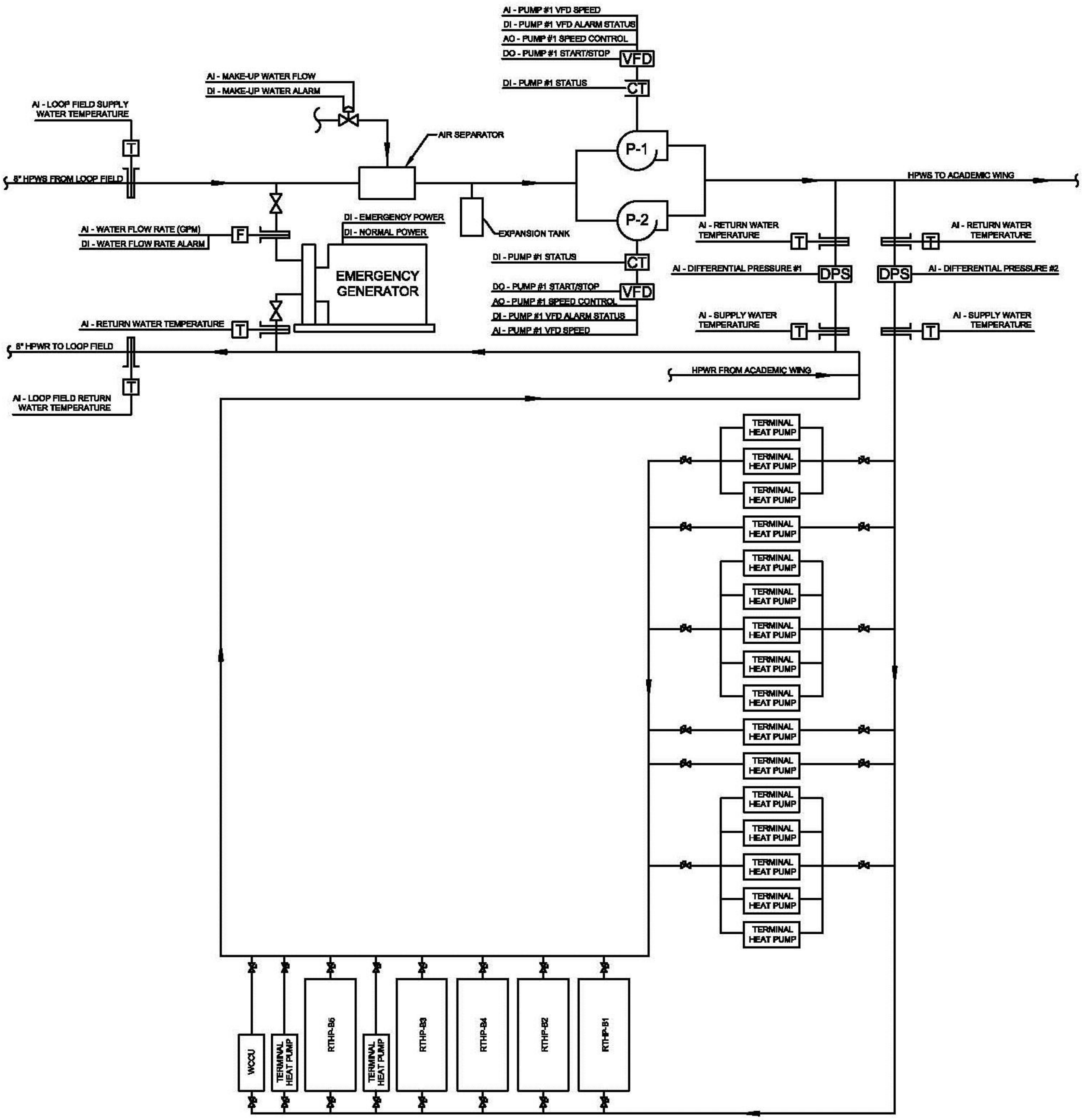


Figure 1: Waterside Flow Diagram

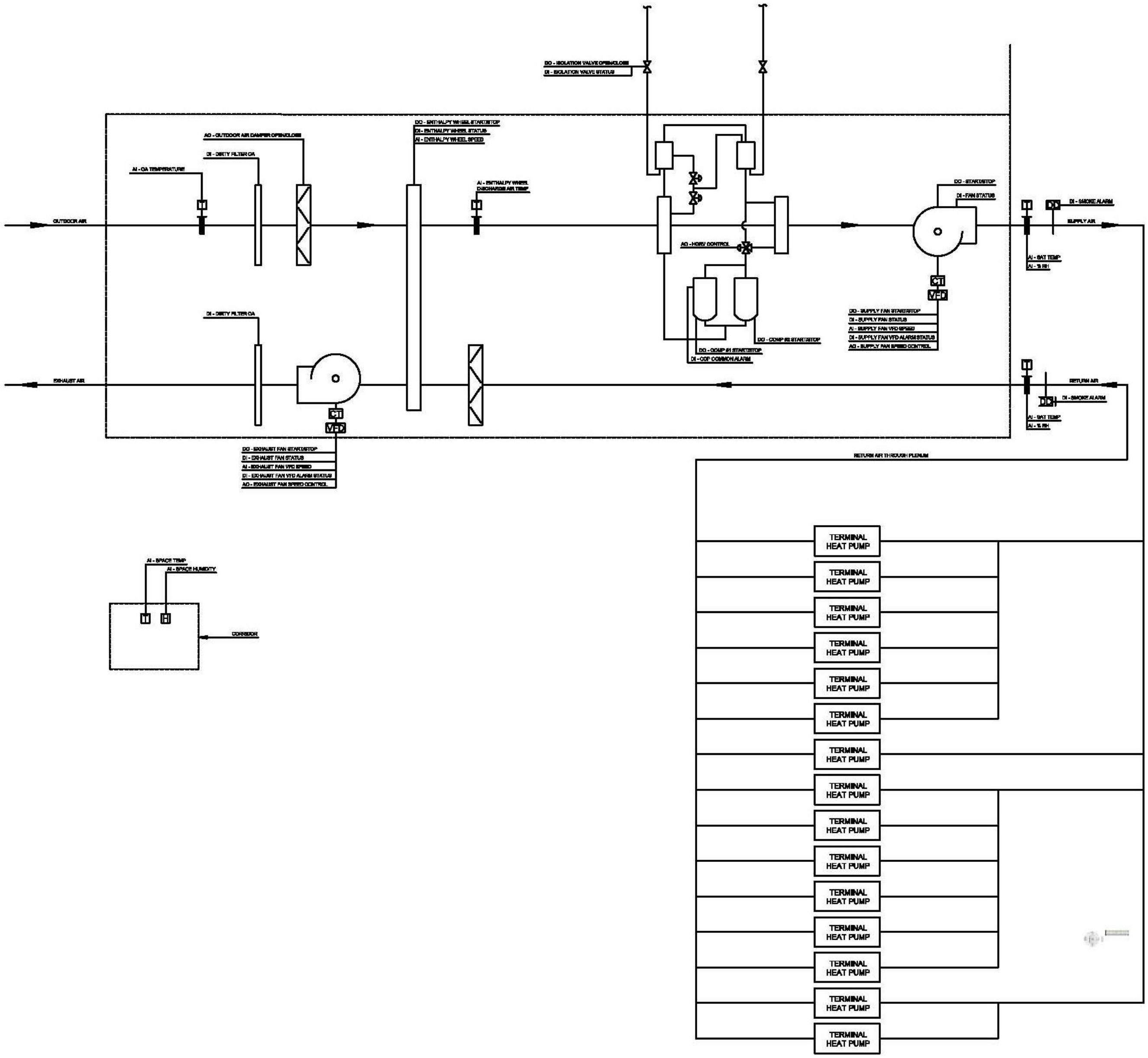


Figure 2: Airside Flow Diagram of a RTHP Serving Multiple Zones (Ex. RTHP-B1)

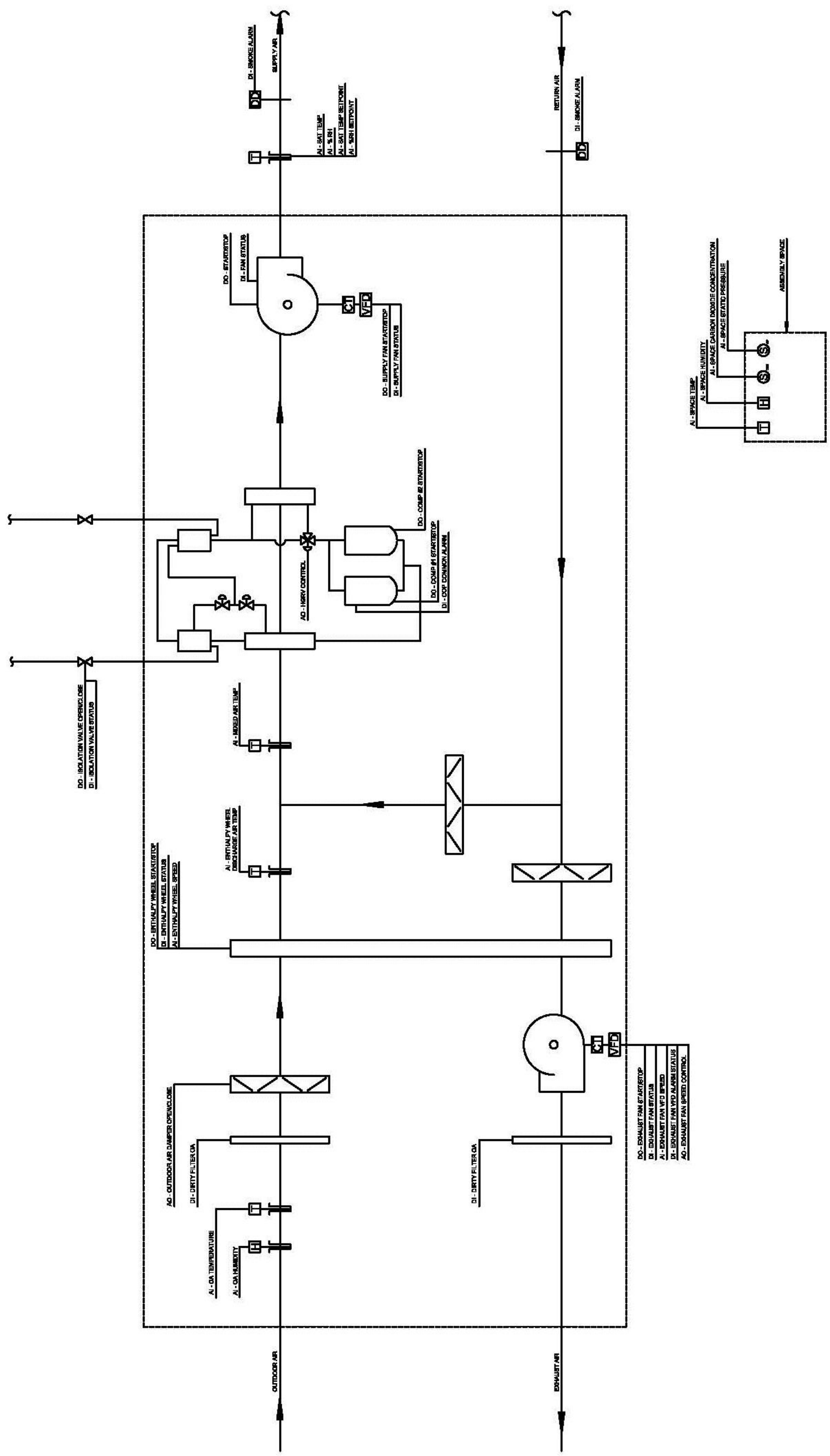


Figure 3: Airside Flow Diagram of a RTHP Serving a Single Zone

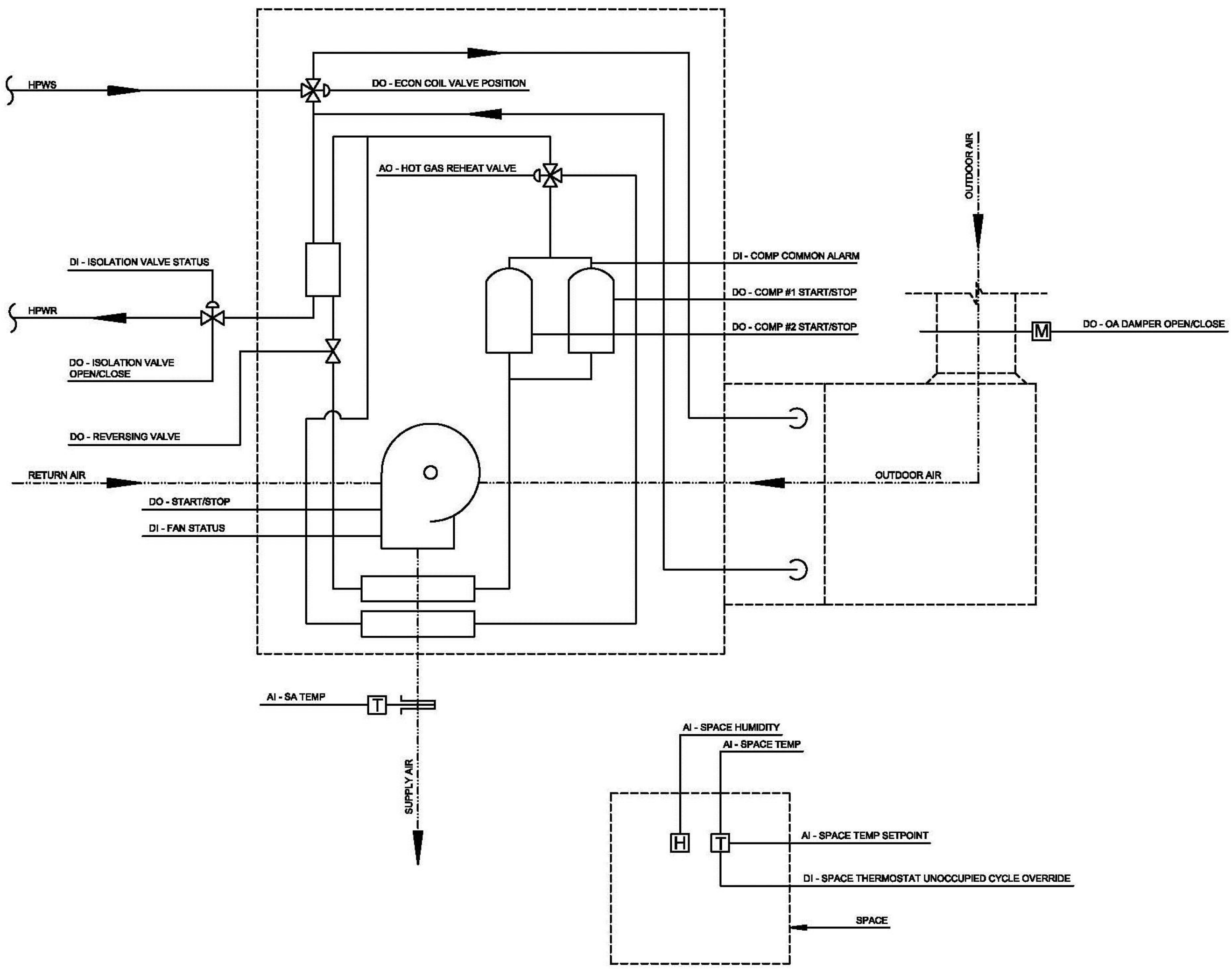


Figure 4: Flow Diagram of a Terminal Heat Pump

Energy Sources

The two energy sources available to Bentworth Middle School are electricity from Allegheny Power and natural gas. At this time, the actual energy rates that Bentworth Middle School pays are unavailable so for this analysis Pennsylvania's average rates of 11 cents per kilowatt hour for electricity and 1.17 dollars per therm for natural gas were used. Both of these rates were acquired from the U.S. Energy Information Administration website.

Design Conditions

The outdoor design conditions used by the design engineer to size the rooftop heat pump units were just slightly different from the outdoor design conditions that were used in this report when to performing load calculations with Carrier's Hourly Analysis Program (HAP). These two different sets of weather data can be seen outlined below in Table 6. The indoor design conditions for the building during its occupied and unoccupied states are located in Table 7.

Table 6: Outdoor Design Conditions

Summer Outdoor Conditions				Winter Outdoor Conditions			
RTHP		HAP		RTHP		HAP	
DB (F)	WB (F)	DB (F)	WB (F)	DB (F)	RH (%)	DB (F)	WB (F)
90	72	89	72	2	30	2	0.3

Table 7: Indoor Design Conditions

	Summer Indoor Conditions (F)	Winter Indoor Conditions (F)
Occupied	75	70
Unoccupied	85	60

Mechanical System Cost

The total cost of the mechanical construction, geothermal loop field drilling construction, and plumbing construction was $2,904,400. This cost does not include the cost of design, but is simply the total of the bids taken from the bid documents. This amount is equal to a cost of $34.66 per square foot.

Mechanical Space Requirements

For this calculation, only occupiable space taken up by mechanical equipment such as ductwork, heat pumps, and the loop field pumps were taken into consideration. Therefore, the mechanical room and vertical mechanical shafts containing ductwork were considered while the mechanical mezzanine and space taken up by mechanical equipment in the ceiling plenums was not. Table 8 summarizes this amount of space.

Table 8: Occupiable Space Used by Mechanical Equipment

Type	Area (ft^2)
Mechanical Room	395
Vertical Mechanical Shafts	330
Total	**725**

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. This 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.

Design Load and Annual Energy Usage Estimates

A Carrier HAP model was utilized to analyze to help determine the design heating and cooling loads of the building as well as estimate Bentworth Middle School's annual energy consumption. The model was created on room by room basis as opposed to the less accurate block load analysis technique. This was done so that more accurate results could be achieved. All assumptions and user inputs that were made to create the model can be found in Technical Report Two.

Results for Cooling and Heating Loads

Table 9 and Table 10, below, compare the cooling, heating, and ventilation check values of the HAP model and engineered design check values. Other than the cooling load, the HAP model's check values are higher than that of the design. One possible reason for this discrepancy could be that the design engineer considered safety factors which were not included in the HAP model. Additionally, despite creating the HAP model by the space by space method which is more accurate than a block load analysis, some of the assumptions made in the analysis may greatly differ from that of the design engineer who without a doubt had a better understanding of the client's desires.

Table 9: RTHP Check Value Comparison

	ft^2	HAP Cooling Load (tons)	Design Cooling Load (tons)	HAP Heating Load (tons)	Design Heating Load (tons)	HAP cfm	Design cfm
RTHP-A1	34201	80.26		29.58		31329	34820
RTHP-B1	10649	31.05		26.77		10776	9825
RTHP-B2	4059	17.2		26.2		4738	6000
RTHP-B3	1548	6.81		6.62		1641	2100
RTHP-B4	6920	39.87		49.12		10121	10000
Totals	57377	175.19	171.8	138.29	145.8	58605	62745

Table 10: Building Check Value Comparison

HAP Cooling (ft^2/ton)	Design Cooling (ft^2/ton)	HAP Heating (ft^2/ton)	Design Heating (ft^2/ton)	HAP (cfm/ft^2)	Design (cfm/ft^2)
327.5	334.0	414.9	393.5	1.02	1.09

Annual Energy Consumption Results

The mechanical system of Bentworth Middle School consumes approximately 822,000 kWh of electricity and 15,700 therms of natural gas each year. Unfortunately, there isn't much to compare this estimate to as the design engineer did not perform an energy consumption analysis of the building. The most likely reason for this is that there was simply no need to do this calculation. The building was not trying to achieve a LEED certification and the client did not ask for the analysis to be conducted. Bentworth Middle School was a new building replacing an old one so the owner knew they would be saving money on energy costs with or without the analysis. Information regarding the actual utility bills is also not available.

Break Down of Annual Energy Consumption and Cost

Figure 5 shows the percentage of electricity each subsystem of the building uses. Most of the electric consumed by Bentworth Middle School in this analysis is used for lighting. This makes sense as there were lighting loads for each space. However, electric equipment which includes the computer loads comes in at a close second. If additional receptacle loads other than just the computers are properly assumed for the building it very likely that this subsystem would make up the largest fraction of the electricity consumption.

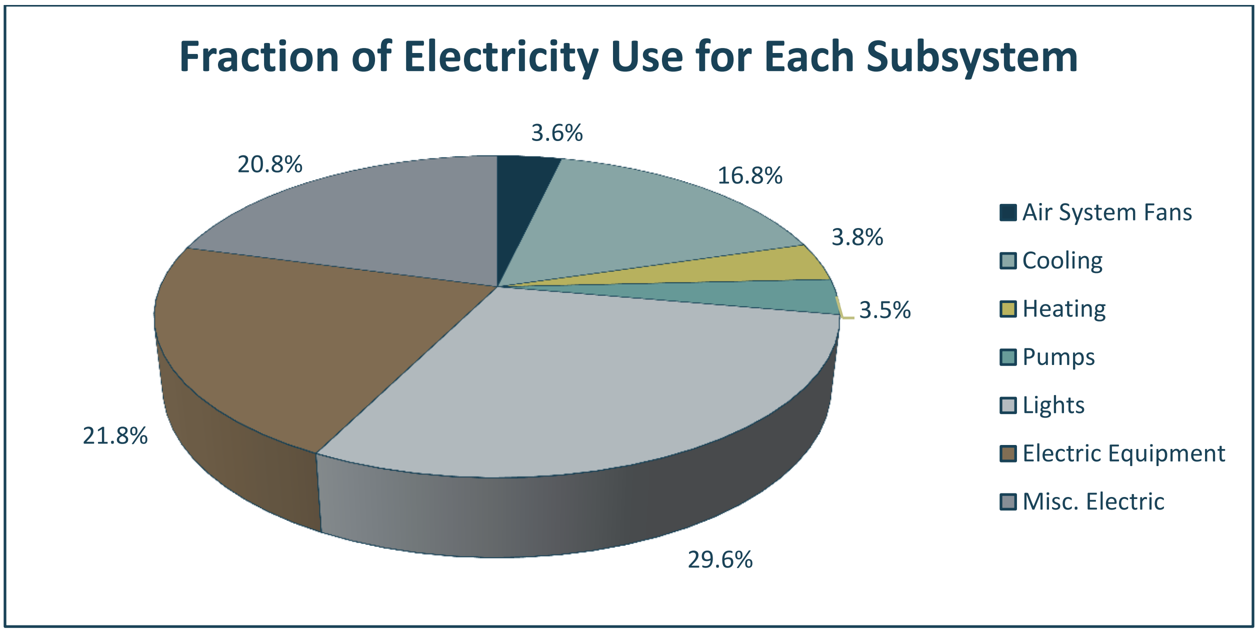


Figure 5

Table 11 provides a breakdown of the annual cost for each subsystem as well as the price per square foot of each subsystem and what percentage of the total cost each subsystem accounts for. It also estimates the total annual energy cost for Bentworth Middle School to operate at approximately $109,000. Lighting accounts for the highest percentage again. It is important to realize at this point how expensive lighting a building is and remember that the exterior lighting was not even accounted for in this analysis.

Table 11: Bentworth Middle School Annual Costs Breakdown

Component	Annual Cost ($)	($/ft²)	Percent of Total (%)
Air System Fans	3,274	0.057	3.0
Cooling	15,177	0.265	14.0
Heating	3,452	0.060	3.2
Pumps	3,199	0.056	2.9
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**25,102**	**0.438**	**23.1**
Lights	26,765	0.467	24.6
Electric Equipment	19,711	0.344	18.1
Misc. Electric	18,787	0.327	17.3
Misc. Fuel Use	18,313	0.319	16.9
Non-HVAC Sub-Total	**83,576**	**1.457**	**76.9**
Grand Total	**108,678**	**1.894**	**100.0**

Conclusion of Annual Energy Consumption Analysis

In order to compare Bentworth Middle School to some sort of baseline it can be compared to the 2006 data provided by the Commercial Buildings Energy Consumption Survey (CBECS). CBECS reports that the electricity energy intensity for an educational building between 10,001 ft² and 100,000 ft² is 10.2 kWh/ft². The electricity energy intensity for Bentworth Middle School is slightly higher than that and comes in at 14.3 kWh/ft². Likewise, the average price per square foot that Bentworth Middle School pays for natural gas is 32 cents. This is several cents higher higher than CBECS reported 27 cents. Both of Benthworth Middle School's values are close enough to the CBECS values that it displays that the model is relatively accurate. It is also believed that the main reason for this discrepancy is that Bentworth Middle School's values are averaged over only the conditioned spaces so spaces such as stairwells, storage closets, electrical closets, etc. are unaccounted for. The CBECS values however take the average over the entire building which will reduces the averaged values.

ASHRAE Standards and LEED Evaluation of Existing Building

ASHRAE Standard 62.1-2007 Analysis

In order to determine if Bentworth Middle School was providing adequate ventilation air to its occupants, the building was analyzed by ASHRAE Standard 62.1. A detailed report of this investigation can be found in Technical Report One. However, in summary, it was found that Bentworth Middle School for the most part compliant with Section 5 of ASHRAE 62.1 which outlines the required ventilation rates. The only concern that was found was that two of the five rooftop heat pumps did not appear to providing the amount of ventilation air required by them as can be seen in Table 12 below. It was later determined though that this discrepancy was due to the fact that average number of people that ASHRAE assumes to be the space was larger than what the building spaces were actually designed for.

Table 12: Summary of Ventilation Rate Calculations

RTHP	Design Max CFM	Design OA CFM	ASHRAE 62.1 Min OA	Compliance?
A1	11,500	11,500	18,487	No
B1	3,500	3,500	3,175	Yes
B2	6,000	4,110	3,538	Yes
B3	2,100	1,110	1,176	No
B4	10,000	8,000	4,791	Yes

ASHRAE Standard 90.1-2007 Analysis

Bentworth Middle School was largely compliant with ASHRAE Standard 90.1. The areas in which it did not meet the requirements of the standard were in fan power limitation and the overall U-value for the floors. Although it is obvious that the building designers were designing in an environmentally conscientious fashion, they were not trying to acquire any building accolades such as a LEED certification. Therefore, ASHRAE Standard 90.1 may have been overlooked during the design process, but with a few changes to the building's structural system and mechanical equipment, complete compliance should be easily attainable. Nonetheless, Bentworth Middle School's near compliance with ASHRAE Standard 90.1 further exemplifies the school as not only a great learning and working environment, but also as an energy efficient building.

LEED – NC Analysis

Realizing that there was a need to develop a method of rating buildings based on their sustainability, the U.S. Green Building Council created the Leadership in Energy and Environmental Design (LEED) system. This system allows buildings the opportunity to receive a rating from the USGBC which recognizes their effort to implement sustainable design.

This analysis studied how well the mechanical systems of Bentworth Middle School comply with the criteria set forth by LEED. Specifically, only two sections of LEED, Energy and Atmosphere and Indoor Environmental Quality, pertained to the mechanical systems of a building so only these two sections were analyzed.

Although it is believed that Bentworth Middle School provides a very safe and comfortable environment for learning and working the LEED analysis performed, which can be seen below, showed that there are many areas in which the building could be in improved. This was expected as Bentworth Middle School was known to not be pursuing any type of LEED certification.

EA Prerequisite 1: Fundamental Commissioning of Building Energy Systems - Yes

Intent: To validate that any energy-related systems are constructed as specified

It is specified that it is to be verified that all systems are complete and operable in accordance with all General Conditions, Supplementary Conditions, Division 1, and any other provided requirements before full operation of the system is commenced.

EA Prerequisite 2: Minimum Energy Performance – No

Intent: To reduce the environmental and economic impacts of the building's energy usage by instituting minimum energy efficiency levels

Bentworth Middle School does not meet the minimum 10% energy improvement over the ASHRAE 90.1-2007 baseline building. A summary of this comparison can be found in Appendix A. Bentworth Middle School is therefore not able to receive any LEED points under the Energy and Atmosphere section. However, for this study the rest of the sections under the Energy and Atmosphere section will be looked at to see which of the sections Bentworth Middle School does comply with.

EA Prerequisite 3: Fundamental Refrigerant Management - Yes

Intent: To decrease the amount of ozone depletion in the atmosphere

The only refrigerant used is R-410a which is a HFC refrigerant.

EA Credit 1: Optimize Energy Performance - No

Intent: To exceed the minimum energy performance requirements

Bentworth Middle School does not meet, let alone exceed, the minimum energy performance requirements set forth by LEED accreditation system.

EA Credit 2: On-site Renewable Energy – Yes

Intent: To support the usage of on-site renewable energy

Bentworth Middle School uses geothermal energy, which LEED considers a form of on-site renewable energy. The use of the geothermal system created a 2.1% saving in electrical energy when compared to the ASHRAE baseline system. This earns Bentworth Middle School one LEED accreditation point.

EA Credit 3: Enhanced Commissioning - No

Intent: To start the commissioning process early in the design phase and perform additional commissioning services after systems performance verification is completed

There is no evidence that Bentworth Middle School had any additional commissioning services performed.

EA Credit 4: Enhanced Refrigerant Management - No

Intent: To achieve early compliance with the Montreal Protocol and decrease ozone depletion.

The heat pumps of Bentworth Middle School use R-410a refrigerant, but no information pertaining to how much refrigerant is contained within the heat pumps themselves is available. So it is not currently possible to perform the necessary calculation for this section at this time.

EA Credit 5: Measurement and Verification - No

Intent: To be able to monitor the energy consumption of the building over time

Bentworth Middle School has the ability to monitor its systems through an online web based system. This system is capable of monitoring the efficiency of the building's mechanical systems, yet it is not set up in a fashion compliant with the protocols outlined in this section.

EA Credit 6: Green Power

Intent: To make use of renewable energy through an electrical grid source

Bentworth Middle School will not receive LEED points under this section as they are not contracted to purchase any electricity produced by renewable energies.

IEQ Prerequisite 1: Minimum Indoor Air Quality Performance - Questionable

Intent: To institute a minimum performance standard for indoor air quality

It was found in Technical Report One that the ventilation rate of one of the rooftop heat pumps was significantly undersized. However, it is believed that the ASHRAE Standard 62.1-2007 estimation was incorrect as it assumed that several more people were in many of the classroom spaces than what the system was actually designed for. So it is likely that the prerequisite is indeed met.

IEQ Prerequisite 2: Environmental Tobacco Smoke Control - Yes

Intent: To keep the exposure of building occupants, indoor surfaces, and ventilation air distribution system to environmental tobacco smoke at a minimum

The property on which Bentworth Middle School is located is designated a tobacco free zone. Therefore, this prerequisite is met.

IEQ Credit 1: Outdoor Air Delivery Monitoring - No

Intent: To ensure occupants are comfortable in ventilated spaces

Large assembly spaces within Bentworth Middle School are equipped with CO_2 sensors which are placed at appropriate locations within the space. However, there does not appear to be a flow sensor monitoring the air flow rate of the incoming outdoor air to the building. Since the outdoor air intake flow is not measured, Bentworth Middle School will not receive the point available under this section.

IEQ Credit 2: Increase Ventilation - No

Intent: To provide more outdoor air ventilation than required to enhance occupant comfort

In most of the spaces, the outdoor air ventilation rate is not exceeded by 30% or more of the minimum rate as required by ASHREA Standard 62.1-2007. Bentworth Middle School will therefore not receive the LEED point outlined by this section

IEQ Credit 3.1: Construction Indoor Air Quality Management Plan – During Construction - No

Intent: To improve the well-being of construction workers and building occupants while reducing indoor air quality problems related to construction

The ductwork for Bentworth Middle School was protected in the fashion outlined in this section, but the filters within the rooftop heat pumps are only equivalent to a MERV 6 or MERV 7 which is less than the minimum required MERV 8 filter of this section.

IEQ Credit 3.2: Construction Indoor Air Quality Management Plan – Before Occupancy - No

Intent: To improve the well-being of construction workers and building occupants while reducing indoor air quality problems related to construction

There is no evidence that any sort of flush out was performed at Bentworth Middle School before its occupancy.

IEQ Credit 4.1: Low-Emitting Materials - Adhesives and Sealants – Yes

Intent: To reduce the amount of air contaminants within the building that are bothersome to installers and occupants

It was specified that all materials were to abide by South Coast Air Quality Management District Rule #1168. As a result, Bentworth Middle School will receive one LEED point under this section.

IEQ Credit 4.2: Low-Emitting Materials – Paints and Coatings – No

Intent: To reduce the amount of air contaminants within the building that is bothersome to installers and occupants

It is specified that all paints and coatings used within Bentworth Middle School must meet the current VOC requirements set forth by federal, state, and local authorities, but it does not specify that it must also meet the requirements of Green Seal. No points will be awarded to Benthworth Middle School for this section.

IEQ Credit 4.3: Low-Emitting Materials – Floor Systems – No

Intent: To reduce the amount of air contaminants within the building that is bothersome to installers and occupants

The floor systems of Bentworth Middle School are not subject to the standard set forth by FloorScore and as such Bentworth Middle School will not receive a LEED accreditation point.

IEQ Credit 4.4: Low-Emitting Materials – Composite Wood and Agrifiber Products – No

Intent: To reduce the amount of air contaminants within the building that is bothersome to installers and occupants

Bentworth Middle School does not make use of any of these products and thus does not qualify for this LEED point.

IEQ Credit 5: Indoor Chemical and Pollutant Source Control – No

Intent: To minimize the exposure of building occupants to air pollutants

For several reasons Bentworth Middle School does not qualify for this LEED point as well as there are no significantly hazardous pollutants produced on the premises.

IEQ Credit 6.1: Controllability of Systems – Lighting - No

Intent: To provide building occupants with a significant amount of control over the lighting

Most of Bentworth Middle School's occupants are its students which will be subject to the lighting settings selected by their instructor as there is only a single set of lighting controls within each classroom. Therefore, the school does not qualify for this point.

IEQ Credit 6.2: Controllability of Systems – Thermal Comfort – Yes

Intent: To provide building occupants with a significant amount of control over the thermal comfort of a space

Each office and classroom of Bentworth Middle School has individual temperature controls to allow for individuals and groups to adjust the thermal environment of the school's spaces as desired. This earns the school one LEED accreditation point.

IEQ Credit 7.1: Thermal Comfort – Design - Yes

Intent: To create a thermal environment that promotes occupant productivity

Bentworth Middle School receives a point under this section as its heating ventilation and air conditioning system was designed to meet ASHRAE Standard 55-2004.

IEQ Credit 7.1: Thermal Comfort – Verification – No

Intent: To ensure adequate thermal comfort is provided over time

There is no plan for Bentworth Middle School to collect data from its occupants pertaining to their thermal comfort at this time so no LEED accreditation point will be awarded to the school under this section.

Overall System Evaluation

Bentworth Middle School wanted to establish a state of the art educational facility that they knew would be able to last for years while having minimal effects on the environment and minimizing costs to the school district. For this reason, a geothermal system was selected. This selection turned out well for them. The total cost of the mechanical construction, geothermal loop field drilling construction, and plumbing construction was $2,904,400 which is approximately 16% of the total cost and comparable to other school mechanical systems. The energy consumption of the building was 9.8 kWh/ft^2 for electricity and 22 cents per square foot for natural gas. Both of these values are considerably better than the CBECS average and offer the opportunity for a reasonable payback period after selecting a system that is typically more expensive upfront.

Less than one percent of occupiable floor is taken up by the mechanical systems as most of the mechanical equipment is located in ceiling plenums or the mechanical mezzanine. This is a significantly small amount of area and does not offer much of an opportunity for improvement.

Although it is believed that Bentworth Middle School provides a very safe and comfortable environment for learning and working the LEED analysis performed showed that there are many areas in which the building can be in improved. As shown above, Bentworth Middle School's energy consumption per square foot is quite low when compared to the Pennsylvania average, but according to LEED there is still a lot for this building to accomplish. This is certainly something that will be studied further.

There are no known indoor air quality issues with the school, except for the discrepancy on the amount of outdoor ventilation air provided by rooftop heat pump A1. This is certainly something that will be further investigated along with many opportunities suggested by LEED to ensure a high standard of air quality in Bentworth Middle School.

Overall, the Bentworth Middle School seems to have met the expectations of the school in both energy savings and in providing an appropriate learning and working environment. At the same time, the shortcomings of the building as seen in the LEED analysis also leave a lot of room for improvements to be made to the building. It will be interesting to investigate what can be done with a building that already has such a great base.

Systems Redesign Proposal

Although the mechanical design of Bentworth Middle has been found to be more than adequate, the system redesigns proposed below will be conducted a feasibility studies to see if alternative mechanical systems would be able to further increase the efficiency of the building as well as reduce the overall costs to the building owner. Innately, the proposed mechanical alternatives will affect several of the other building systems. Therefore, alternative breadth topics will also be explored.

Proposed Mechanical System Redesigns

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 Photovoltaic Design

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.

Proposed Architectural Redesign

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.

System Redesign Studies

Terminal Unit Redesign

Current System

The academic and administrative areas of building were provided outdoor air by a dedicated outdoor air system which consisted of a rooftop heat pump unit providing outdoor air to individual space units. A dedicated outdoor air system is typically considered to be a very efficient system. However, with the current design, one of the rooftop heat pump units required a large amount of ductwork in order to deliver air from the mechanical mezzanine located above the third floor of the academic wing to the spaces in the academic wing. So it was decided to explore the option of locating the terminal heat pumps in another location in an effort to reduce system costs by eliminating the mechanical mezzanine, two rooftop heat pumps, and a large amount of ductwork and mechanical chases.

The rooftop unit also provided the outdoor air to the spaces at a constant rate that was meant to meet ventilation requirements set forth by ASHRAE Standard 62.1. This standard allots a certain amount outdoor air per person in the space as well per square foot of floor space. This type of design is common practice in the industry, yet it can also be wasteful. Often times, a room is not occupied to its full capacity, yet there is enough outdoor air being introduced into the space as if it was. As a result, energy is wasted conditioning outdoor air that is not required for the space.

New System

There are two main areas of the school that utilized the dedicated outdoor air system, the academic area and the administrative area. Each of these areas was served by a separate rooftop heat pump unit. Although, the redesign for both of these areas consisted of using the same components, they were addressed in different ways. The considerations given to the academic area will be looked at first in this study.

The first step in designing the new system was deciding upon a new location for the terminal units. There was adequate plenum space above the drop ceilings of the classrooms and this was the first place considered for the new location of the terminal heat pumps. After taking a closer look at this option though, it was discovered that it was not as viable as originally thought. The compressors associated with the terminal heat pumps are known to be noisy. Being that they were to be placed above the drop ceilings in classrooms, there was worry that the noise might interfere with the students' instruction. The plenum space in the hallways was not a practical location either because it placed the units a great distance away from any outdoor air source which defeated the purpose to eliminating the duct shafts. So the obvious choice became placing the units on the exterior of the building and housing them within a mechanical tower.

This tower is very important to the redesign as it houses all of the terminal units of the school's classrooms. For this reason it is designed to be constructed out of the heavy material as rest of the building in order to ensure the units' protection from the elements. The CMU block walls would be backed with rigid insulation board to prevent freezing of the hydronic systems serving the heat pumps. In order to service the heat pumps the wall will also have some sort of removable panel. This will allow for units to be maintenance from the exterior of the building in order to prevent disruptions to the classroom areas. The tower should also be able to act as a reinforcing structural element to the building walls weakened by the ductwork penetrations.

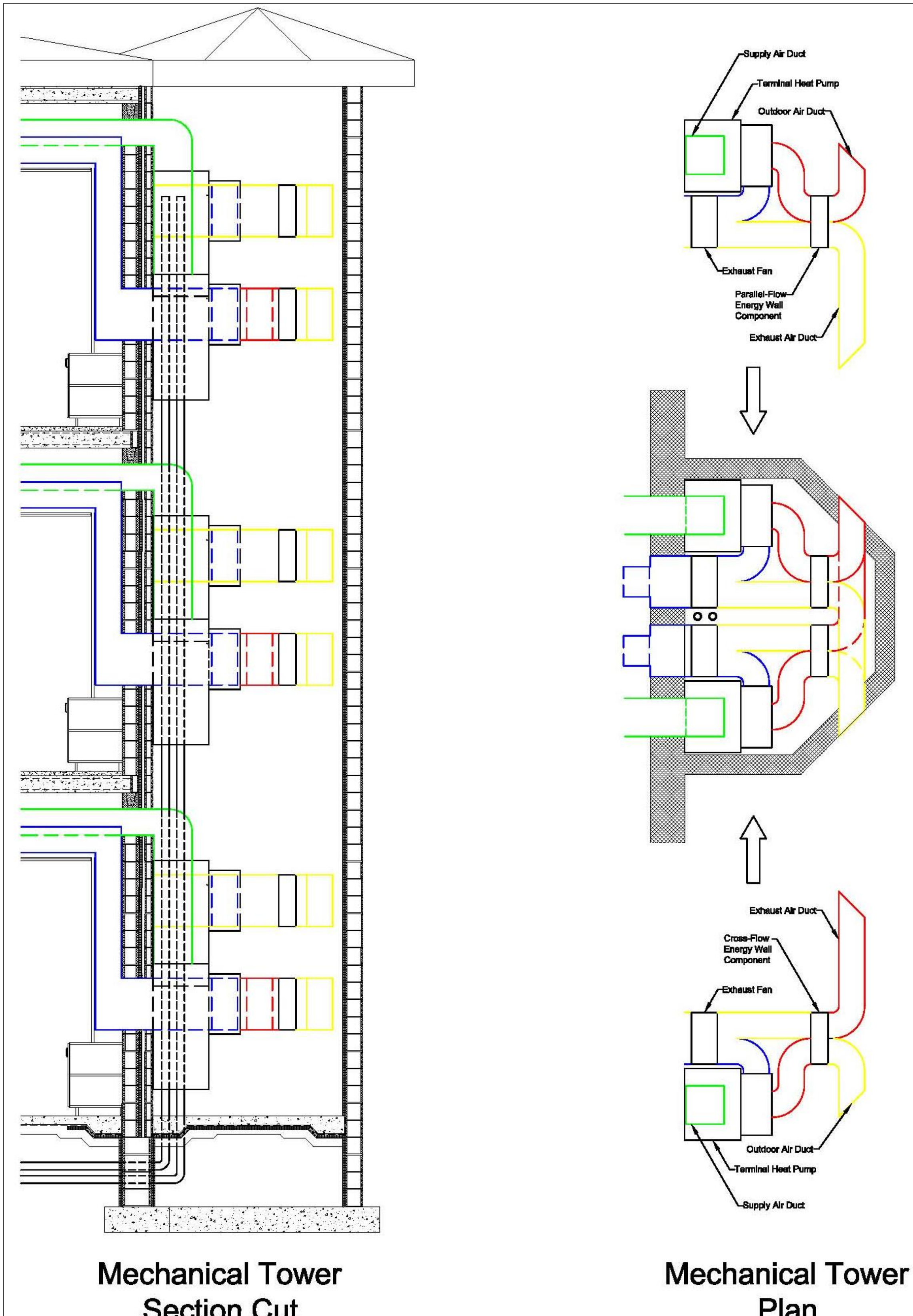
The system is to be configured in such a way that the outdoor air is brought in from one side of the tower while it is exhausted from the other side of the tower. This is to prevent cross contamination. The rate at which the outdoor air is brought into a space is to be determined by a CO_2 sensor from within the space. By introducing outdoor air into the space this way, as opposed to the constant volume method used in the original design, it is expected that energy will be saved.

The outdoor air is then to be passed through an energy recovery core manufactured by Energy Wall. This core was selected for the basis of the design for its ease of use, high efficiency of 80%, and the membrane's ability to kill up to 98% of bacteria which will ensure high air quality within the space. There is also no mechanical energy associated with use of Energy Wall like there is with an enthalpy wheel. The pressure drop associated with Energy Wall is a drawback to this system though. Due to this pressure drop, an exhaust duct fan will be a required system component as well. These fans are very inefficient, operating at an efficiency level of only about 50%. The industry is very focused on trying to improve the efficiencies of such fans, but for now, in an effort to combat the pressure drop, the duct system has been oversized and the airflow through the component itself is also less than 75% of the components capacity rating. For example, at max capacity the largest science classroom requires approximately 400 CFM of outside air. This amount of air is less than 75% of the rated capacity of the 600 CFM Energy Wall component utilized in the system. This allows the air passing through the Energy Wall component to experience a 0.63" wg pressure drop as opposed to the 0.85"wg pressure drop that would occur if the air was passed through an Energy Wall component rated at a smaller capacity. The oversized ducts also allowed for the overall efficiency of Energy Wall to bump up to 80%.

The preconditioned outdoor air is then mixed with the return air in a plenum box attached to the terminal heat pump unit. The heat pump then properly conditions this air and supplies it to the room. The air is then returned to the heat pump via the return air duct. In this redesigned system it was necessary to create a small bulkhead running down from the ceiling to the top of the casework in the corner of the room. It is understood that bulkheads are typically undesirable, but in order for the Energy Wall component to be used and fit into the space provided by the mechanical tower along with the terminal unit in a practical arrangement it was deemed necessary. Finally, a fraction of the return air is returned to the terminal heat pump while the remaining is passed through the Energy Wall component and exhausted through the wall of the mechanical tower.

Drawings of this system arrangement can be seen in Figure 6.

Figure 6: Mechanical Tower Drawing



The same system components are used to serve the administrative area as well but in a slightly different arrangement. Instead of providing each heat pump with its own energy wall component, the rooftop heat pump was just simply replaced by a larger Energy Wall component that could handle all of the outdoor air flow required for the administrative area. Outdoor air is ducted from the existing outdoor air plenum box to each of the terminal units after it passes through the Energy Wall component just as it was done before. In the same fashion, the exhausted air is collected and ducted through the Energy wall component and exits the building through the existing exhaust air plenum box.

Energy Analysis

Carrier HAP was used for the energy simulations conducted to compare the originally designed system with the proposed system. All of the building heat pumps were considered except for the rooftop heat pump unit that provides make-up air to the kitchen area as its loads are tough to predict and it would have the same loading profile in either situation as there were no proposed changes to this unit for this study. The school was also modeled as unoccupied during the summer months of June, July, and August. The results of the simulations are in Table 13 below.

Table 13: Terminal System Redesign Analysis

System	Cooling	Heating	Air System Fans	Pumps	Total Consumption
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Designed	59,538	27,048	71,872	17,992	183,585
New	64,339	1,282	40,900	15,648	122,171

As can be seen in Table 13, the simulation software predicted that the redesign would reduce the buildings mechanical energy consumption by 33%. Energy savings was an expected result, but the increase in the cooling load was a bit of a surprise as it was anticipated to decrease. This is because it was known that even during the winter months the terminal heat pumps in the school were more often cooling than heating. This is because of the assumed schedules that were used which reflect the requirements of LEED as published in ASHRAE Standard 90.1. These schedules, which an example can be seen of in Appendix B, are known to assume an internal load greater than the actual load during the school day. For example, these schedules simulate classrooms at full load throughout the entire day when this is not usually the case. So this wintertime cooling was cited as wasting energy in the designed system because it was assumed that often times the outdoor air brought into the building would first be heated to 68°F by the rooftop heat pump just to be cooled later by the terminal unit. Conditioning the air twice is obviously wasteful and thus it was anticipated that with the new system redesign that the air would only have to be conditioned once and thus save energy. So it was important to discover why the compressors were actually working harder in the redesign.

A psychrometic study, which can be found in Appendix C, was conducted to see if it could help offer an explanation. And indeed it did. It was found that on a cooling day in January when the outdoor temperature was 45.8°F that the Energy Wall component would actually bring the outdoor air temperature up to a temperature of 70.3°F. When mixed with the return air, the supply air temperature then increased to over 73°F. On its own, the terminal unit then had to cool the supply air down to a temperature of 66°F before it could be introduced into the space. This is a large amount of work for the smaller compressor of the terminal unit to do on its own as opposed to if the outdoor air supply temperature had been 68°F from the rooftop heat pump instead. It is assumed that the combination of the rooftop heat pump compressor operating to condition a large amount of air for all the units it supplies and the lower operation level of the terminal compressor is less than all of the terminal compressors cooling the entire load themselves. In fact, in this scenario the enthalpy wheel in the rooftop heat pump, which is of a lower efficiency than the Energy Wall component, would probably condition the outdoor air to right around 68°F so that the rooftop heat pump compressor wouldn't even have to operate.

Cost Analysis

Using RS Means 2011, a rough cost estimate has been developed for the system redesign and it can be found below in Table 14. As can be seen, it does not appear that it would be that much more expensive to install the redesigned system as $80,721 is a small amount compared to the $2,904,400 that the entire mechanical system cost. The redesigned system also would save the school roughly $6755 per year. Therefore the simple payback on the system would be approximately 12 years. It is assumed that the school district will be utilizing the building for more than 12 years so it would be worth their while to make the extra investment.

Table 14: Estimated Cost of Redesigned Terminal System

Material	Unit	Total Price/Unit	Total Price
	SF/LF/Unit	$	$
Ductwork	180	4.41	794
Split Face Masonry Wall	2785	7.87	21,918
CO_2 Sensor	39	800	31,200
Insulation	2785	0.63	1,755
Roofing	740	9.70	7,178
Energy Wall	5019	1.44	7,227
Piping	960	30.65	29,424
Exhaust Fans	30	1465	43,950
RTHP-A1	1	44,475	-44,475
RTHP-B1	1	18,250	-18,250
		Total Cost	80,721

Additional Notes

The model also would have performed better if an airside economizer could have been modeled. This would have greatly benefited the model as anytime the heat pumps were in cooling mode during the winter months they would be able to bring in outdoor air without preconditioning it with the Energy Wall component. After this air would mix with the returned air it would be at a temperature that should need little conditioning before being supplied to the space.

Natural Ventilation

Natural ventilation is an excellent way to reduce the energy consumption on a building. In this study, the feasibility of replacing the windows and installing a "green light" system will be explored as a means of creating a better environment within the classroom for natural ventilation.

New Windows

The installed windows within the school were 6 feet by 6 feet in dimension and were single hung. The size of the openings of these windows were large enough to provide natural ventilation by the requirements set forth by ASHRAE Standard 62.1, which state that the window opening area must be equal to 4% of the floor area being ventilated . However, the windows were lacking in design for natural ventilation to really be utilized in the building. For this reason it was decided to replace these windows with double hung windows from ECFO. Specifically, EFCO's XTherm HX45 was chosen for its high thermal performance which can be seen in Figure 7. Thermal performance was considered an important design criterion as façade's that are designed for natural ventilation are often critiqued for their poor thermal performance. And the double hung window configuration was selected in order to induce a natural current through the room by allowing fresh air to enter through the bottom opening of the window while the warmer can be exhausted through the upper window opening.

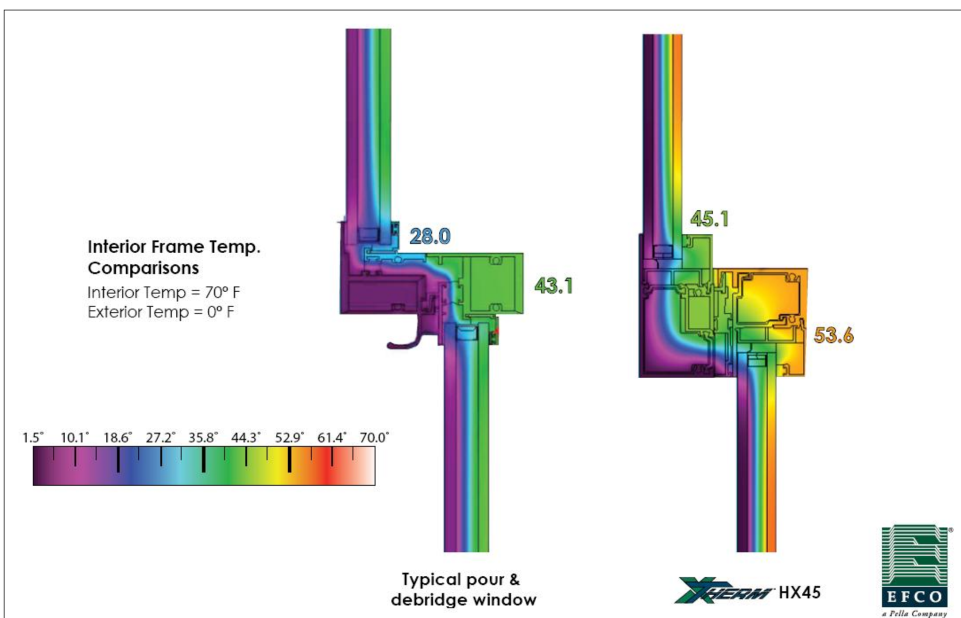


Figure 7: Thermal Image of ECFO HX45

System Operation

There are technologically advanced control systems capable of modulating the opening and closing of windows. These actuating systems themselves consume energy which may negate the energy saving effects of a natural ventilation system. The actuators also have a tendency to lose its precision over time, which requires them to be recalibrated often. A high maintenance cost is associated with this procedure. The advantage of this system, however, is that human participation is not required for the system to properly operate.

In order to try and maximize energy savings though, it was decided that this study would be conducted under the precedent that the windows would be manually operated by teachers within the rooms. In order for this plan to be successful a "green light" system which costs around $8000 dollars would have to be installed. This system consists of placing a green light within each of the classroom spaces and a sensor outside. When the sensor determines that the outdoor conditions are appropriate for natural ventilation, the green light in each room will turn on indicating to the teacher that the windows should be opened. At this point the terminal units will be signaled to be switched off.

System Analysis

In order to determine the energy savings that could be afforded by this "green light" system an hourly load profile for the classroom spaces was exported out of the HAP program and into Excel. For the analysis, if the outdoor temperature laid between 66°F and 80°F the terminal units were simulated as being off. This temperature range was select based upon the ASHRAE Handbook of Fundamentals suggestions that natural ventilation should be done when the outdoor temperature is within a few degrees of the desired indoor temperature. Based upon ASHRAE's thermal comfort, as seen below in Figure 8, 66°F to 80°F seemed like and appropriate temperature range.

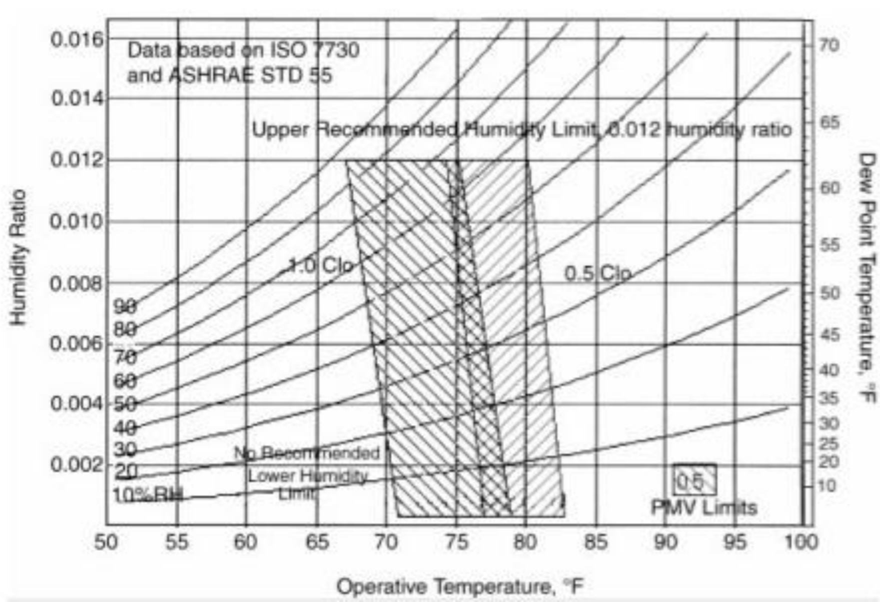


Figure 8: ASHRAE Thermal Comfort Chart

Operating under these conditions, Bentworth Middle School would be able to reduce its electrical costs by up to $1200 each year. Including the upgraded windows this gives the system a simple payback period of approximately 15 years.

Hybrid System

Geothermal hybrid systems can be beneficial in many ways. First of all, they can reduce the overall initial cost of the system. The bore holes that must be drilled for a geothermal system are very expensive so sizing the system for the smaller of either the annual heating or annual cooling load will reduce the well field size and save and owner money. This money can then be used to purchase a supplementary piece of equipment capable of meeting the unmet load. Often times this piece of equipment is cheaper than what the additional bore holes would have cost. Hybrid systems also alleviate another concern that is often associated with geothermal systems and that is creeping ground temperatures. If the geothermal loop field does not shed the same amount of heating and cooling loads to the ground on an annual basis the ground temperature will begin to either increase or decrease depending on which was the larger load for a particular year. When supplementary equipment covers the difference between the two loads the natural ground temperature is able to me maintained. In this study it will be determined whether or not a hybrid design would be feasible for Bentworth Middle School. Feasibility will be based upon the initials cost of the system as well as the expected operation and maintenance costs.

Analysis Method

A loop field sizing program is the best way to size a geothermal field. However, the software is expensive and was unavailable for this study. Instead, the spreadsheet utilized by the McClure for sizing their geothermal well fields was used in this study. This spreadsheet required inputs from the user including the peak heating and cooling loads, certain system parameters, and BIN weather data from the ASHRAE Handbook of Fundamentals. For this analysis, all of the units that condition occupiable spaces within the school were included except for the rooftop heat pump unit that provides make up to the kitchen area. For this reason, the hybrid system will be compared to a well field sized for the larger of the two loads and not the originally designed well field. It is also assumed in this analysis that when the academic and administrative areas of the school are fully occupied that the assembly areas served by the rooftop units are not. Therefore, the cooling well field size will be calculated by only considering the peak load of the academic and administrative areas as it is the larger of the two loads. A small safety factor will also be included in this to account for any of the remaining rooftop units that may be running at part load. The heating well field size will be determined by totaling the maximum heating load of all of the spaces that the maximum heating load will occurring during a time that the building is not occupied. Please see Appendix D for the calculated well field size for each load.

Analysis Results

It was originally expected that the school would be dominated by heating loads as schools typically are. However, as stated before, the schedules that are typically used in energy analysis programs have a tendency to cause the loads to be dominated by the cooling loads instead which is the case here. With that being said, a cooling tower will be needed to cover the 27 ton difference between the heating and cooling loads as the well field only needs to be 60 bores for heating, but 89 bores for cooling.

Cost Analysis

Based on an average price of $6350 per 350 foot bore hole (a value derived from cost data from the original design), the well field sized for the cooling load would be $565,150. If the well field is just sized for the heat load then it will cost around only $381,000. This is an $184,150 cost differential. The cooling tower that would be needed to go along with the smaller well field would only cost approximately $90,000. Already, the owner is saving around $94,150 in upfront costs. The smaller well field will also reduce the pump head by approximately 10 feet, which will result in pump savings. It is also estimated that the cooling tower will only be utilized 360 hours annually based upon the hourly loads. This is equivalent to 8% of the time the system is in operation per year. Therefore, the additional pumping pressure required to overcome the pressure drop of the cooling tower and the electricity required to run the tower should be comparatively minuscule.

Decentralized Pumping System

As stated in the proposal section of this paper, it is known that a decentralized pumping system is capable of saving pumping energy. Often times a main concern of such a system is space availability throughout a building for these distributed pumps as well as pump noise effecting adjacent spaces. In order to address these concerns, this study will be conducted under the precedent that the terminal unit redesign was used on Bentworth Middle School. This way some of the decentralized pumps can be place at the base of the mechanical tower where there is available space and protection from noise pollution. So it was determined that each tower would have a pump to serve its 6 terminal heat pumps as well as a pump to serve a few heat pumps in the attic space, another pump to serve the terminal units in the administration area, and finally a pump for each of the 3 remaining rooftop units.

System Analysis

In order to analyze the system the hourly loads were exported from Carrier HAP to Excel. Again, the make-up air rooftop heat pump unit was not considered. The required flow rates for each pump were then calculated based on the load profiles and assuming a 3 gpm/ton flow rate. The head was then calculated for each loop that the pump had to overcome. A pump was then selected with this calculated data. Using the affinity laws it was then possible to calculate the total head and flow rate of the pump as a lower speed. Using the pump characteristic curves (see Appendix E for curves) made it possible to associate an efficiency with each pump at each speed. Going back to the hourly load profiles, the number of annual hours the pumps would operate at a particular flow rate was able to be calculated. At this point, it was then possible to calculate the amount of energy consumed by each pump on an annual basis using the equation bhp = (GPM)(Head)(Annual Hours of Operation)/3960(Pump Efficiency). This process was used to analyze two different systems. First, the two original pumps in parallel were calculated so that there would be something to compare to. Then the decentralized pumps were analyzed. The Excel spreadsheets used to perform these calculations can be found in Appendix F.

Analysis Results

As can be seen in Appendix F, the current pumping system being used at Bentworth Middle School consumed a total of 25,235 kW while the proposed decentralized system was calculated to consume 61,138 kW. This is a great margin of difference and was a very unexpected result. It is quite possible that there was an error in the spreadsheet or in the way the analysis was conducted, but none could be detected.

A possible explanation for this large discrepancy could be the large pressure drop caused by the loop field. This large pressure drop made pump selection difficult because many of the pumps required a large amount of head for a fairly small flow rate resulting in a pump with a fairly low efficiency. In order to try and avoid this pressure drop a primary/secondary pumping configuration was also considered. This way a constant speed primary pump could pump the water through the loop field while smaller variable speed pumps operating at much less head than they previously were could pick up the water required by them. However, a quick calculation was done to see how much energy the primary pump consumed on an annual basis and this amount alone was close to double the energy the currently designed system is operating under.

Due to the results, no cost analysis was performed for the depth topic as the proposed alternative systems required more energy, the purchasing of additional pumps, and the increased maintenance fees associated with the additional pumps. It is recommended that Bentworth Middle School not reconfigure their pumping system.

Architectural Breadth

A few of the proposed system changes above have a major impact upon the architecture of Bentworth Middle School. Seeing as how a person's first impression of a building is based upon the appearance of the building it was important to maintain the architectural integrity of the building while designing the mechanical and electrical systems.

Please note that a Revit model was developed for this architectural study and therefore several renderings of the both the original and redesigned building are in Appendix G for comparative purposes.

Mechanical Towers

The proposed mechanical system changes would have the greatest effect on the current façade of Bentworth Middle School. In order to maintain a low level of noise in the classroom, yet draw outdoor air directly through the wall without excessive duct work, it was decided that best location for the terminal mechanical units would be on the exterior of the building. However, these units would need to be protected from the elements as well as accessible for maintenance. Therefore it became necessary to develop a new architectural system to support the proposed mechanical system.

The design of the system was driven not only by practicality but also by appreciation for architectural elements already incorporated in the design of the building. The school's library and the lobby are each located in one of two joined octagonal elements which act as the separation point between the academic and administrative wings of the building. Architecturally, this is the most interesting area of the building not only for its shape, but also because of its location and the amount of architectural detail integrated into that area of the building. Likewise, the same attention was desired for the proposed mechanical system, which would be meticulously designed. The octagonal shape will also help maintain the views from the classrooms so that students would continue to be able to look out over the surrounding rural area. The building as whole is very horizontal as most of it stretches out over a single story. This allows for the towers to be the dominating vertical elements of building and balance the design.

A structural study was not conducted on the mechanical towers, but they are envisioned to be constructed of the same split faced concrete block that the rest of the building is built out of. This material may prove useful for not only helping to tie the towers into the rest of the building, but also help the tower act as a structural element. Due to the terminal mechanical units being located on the exterior of the building, many wall penetrations will be required. This will have and obvious weakening affects to the load bearing walls of the school, but the towers should be able to help counteract the weakening forces.

Please see Appendix G for comparative images.

Windows

The designed windows were also affected by the proposed systems. Specifically, the natural ventilation system. The current windows were a single hung window, which were poor for helping induce natural convection currents. Therefore, it was proposed that they be replaced with a double hung window which would allow cooler fresh outdoor air in through the bottom opening of the window while exhausting the warmer air from the room out of the top of the window. The double hung windows that were selected for the proposed design were the same size as the designed windows in order to maintain the same amount of glazing on the façade as to not disrupt the current day lighting.

The previous windows also had a single mullion bisect the glazing in each direction giving the building a very institutionalized and heavy appearance. The proposed windows instead have three evenly spaced horizontal mullions. This gives the building a much lighter look and helps balance out the verticality of the mechanical towers. Please see Appendix G for comparative images.

Roof Redesign

With the addition of the mechanical towers the pitched roof, which housed the mechanical mezzanine over the academic wing was no longer necessary. This provided the opportunity to flatten out the roof and reduce the overall height of the academic wing and in turn construction costs. However, considering the rest of the roofing system had beautiful roof lines created by pitched and curved roofs, it would have been an architectural injustice to simply replace the current roof with a flat built-up type roofing system. It was also deemed architectural undesirable to pitch the roof at a lower pitch than what the rest of the building was pitched.

Instead, the curved roofing system of the gymnasium was borrowed and used for the new roof design. The curved roof was a practical option not only because it would help tie the two opposing wings of the building together, but also because it allowed the designer to control the roof height so that it could be easily matched with the adjoining roof height. The curved roof can also be constructed of the same standing seam metal roofing system that was used on the rest of the building.

Other considerations to the roof design were water drainage and the structural system. The average slope for proper water drainage is considered to be 5°. The proposed roof design exceeds this slope by maintaining an average slope of approximately 7°. The structural system would not have to change much from what it is now. A light gauge steel stud and truss system which was specified for the original roof design should be adequate for the roof redesign as well.

Please see Appendix G for comparative images.

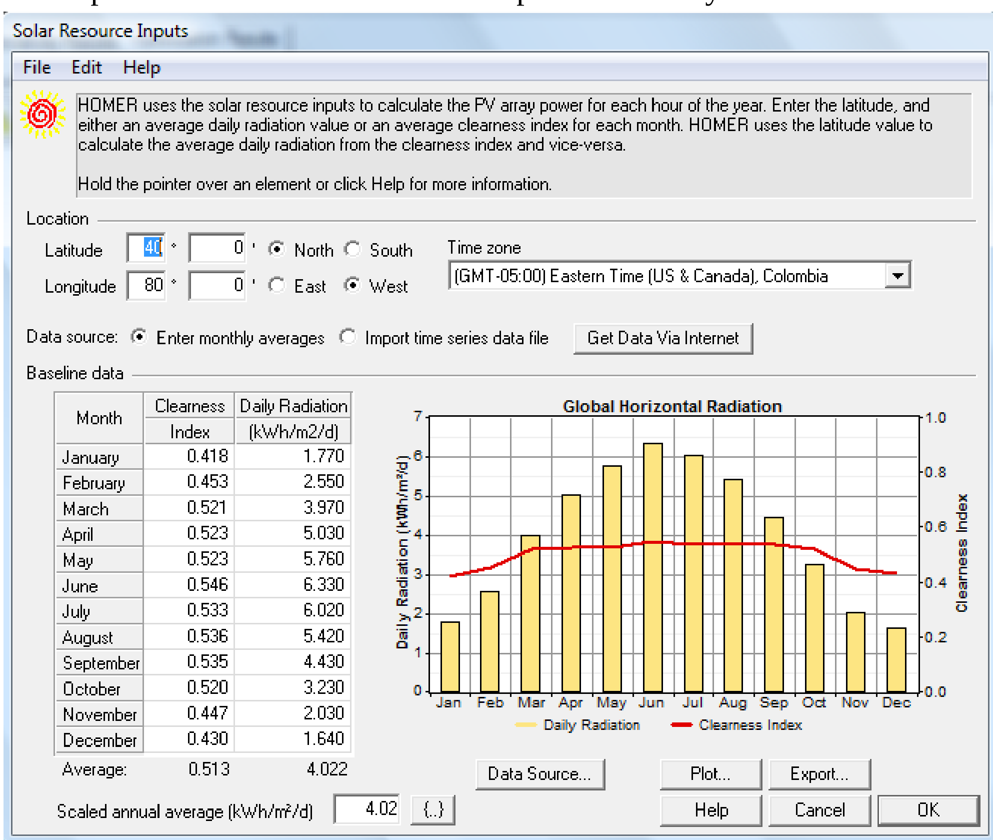
Electrical Breadth

After eliminating the mechanical mezzanine and designing the new roofing system it became feasible to investigate the possibility of placing a photovoltaic array on the roof of the academic wing as the faces of the roof face southwest and southeast. The eastward and westward orientation will allow for half of the array to peak in energy production in the morning, while the other half would be in the peak afternoon while the southward orientation would allow for the array to be productive throughout the entire day.

At first it was desired to place the panels on the most optimum angle in order to achieve greater energy production. This angle is determined by the Earth’s orientation in comparison to the sun and is equal to the latitude of the location of the array during the solar equinoxes. The optimum angle increases by approximately 15° during the winter and decreases by the same amount in the summer. For this reason, a solar tracking system was considered as the system would be able to control the orientation of the panels throughout the year in order to maximize energy production. However, this system would require additional upfront costs, electricity costs, and maintenance cost associated with the moving parts of the tracking system. Additionally, tracking systems are intended for array oriented due south. Therefore, solar tracking was not considered feasible for this design.

It was also a concern to place the panels on the optimum angle of 40° for year round energy production. Since panels are to be placed on the gradual sloping roof of the academic building a 40° angle would be too great of an angle in order to one panel from shading another. Placing the panels on such an angle would also detract from the redesigned roof profile so it was determined that the best design would be to just mount the panels directly to the roof using the SolarMount Rail System made by UNIRAC. This system will allow for a smooth connection between the panels as well as allow for airflow beneath the panels to maximize electrical output of the array. It will also maintain the integrity of the roof through the use of UNIRAC's FastFoot attachment system.

The solar panel that was chosen for the basis of this design was BP's 3230T. This panel was selected for several reasons. Most importantly, it is compatible with the UNIRAC mounting system. It is a panel recommended for roof mounting and it weighs less than 2.4 lbs per square foot. This means that either no change will have to be made to structural system for the new roof or very small changes to the stud spacing or gauge weight. The BP 3230T also has an efficiency of 13.9%. This efficiency is considered about average, but what is impressive about this panel is that under low irradiance levels (200 W/m^2) it is able to maintain an efficiency of 13.1%. This panel is also expected to produce 230W at Standard Test Conditions with 1000 W/m^2 irradiance. Based on Figure 9 below which shows the average amount of irradiance Bentworth Middle School will receive on an average day each month it is expected that the array will be able to produce its maximum amount of power most days.



Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.418	1.770
February	0.453	2.550
March	0.521	3.970
April	0.523	5.030
May	0.523	5.760
June	0.546	6.330
July	0.533	6.020
August	0.536	5.420
September	0.535	4.430
October	0.520	3.230
November	0.447	2.030
December	0.430	1.640
Average:	0.513	4.022

Figure 9: Solar Irradiance Information

The array will be comprised of 908 panels making it approximately a 210 kW DC array. It was originally desired to design this system to be able to directly power DC loads in order to bypass the energy losses associated with an inverter. The system was also intended to have a battery back-up system which could be charged by the array or by the grid. However, it was discovered that a DC-DC converter would be required in order to ensure the proper voltage supply to the DC loads. DC-DC converters have an approximate efficiency range from 70% to 95%. This is the same efficiency range of a typical inverter so the proposed system would not be averting any losses. Battery back-ups are also very expensive and can hazardous. The school would also not be able to take advantage of the solar array during its peak production time throughout the summer months as the school closes during that time. For these reasons it was decided to design the system instead as a typical grid tied system so that upfront costs of a DC system could be avoided and so the school could utilize the energy it produces during the summer months by selling it back to the power company.

The average cost for the purchase and installation of the BP 3203T can be assumed at $8 per watt DC. This comes out to approximately $1,680,000 for the entire system. There are several incentives offered by both local and federal government agencies that can help offset the costs of this expensive system. For example, the PA Sunshine PV Rebate offers up to $52,500 of the installed costs for a new system while the federal government offers a tax incentive. Assuming that the school qualifies and receives a grant of this type and benefits from the tax incentive, the costs of this system seem to become much more feasible. However, according to BP (see Appendix H) the simple payback period, even with these incentives, for this system is over 60 years. If the system is to be installed it would have to be under the precedent that eliminating 340,550 lbs of CO_2 is more important than the payback period.

Conclusion

It was interesting to take a building that was already considered to be a state-of–the-art facility and see if it could be further improved upon. It was disappointing that not all of the proposed systems resulted in energy savings and cost effectiveness. However, the systems that did produce a savings for the building were very pleasing.

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Appendices

Appendix A: MAE Course Work

As required by MAE student, this is a posting of the Masters level course work utilized in the analyses contained within this report.

AE 557 – Centralized Cooling Production and Distribution Systems

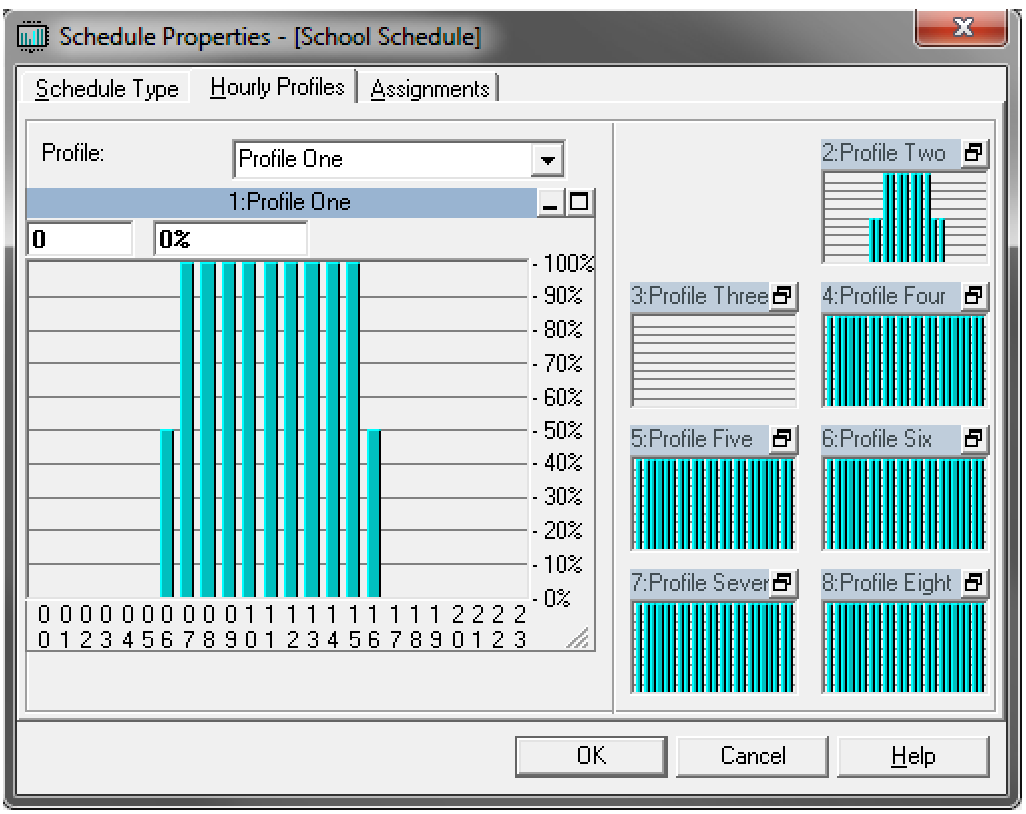
Information that was presented in this class was used to develop the pump redesign and conduct the associated analysis. Cooling towers were also discussed in this course.

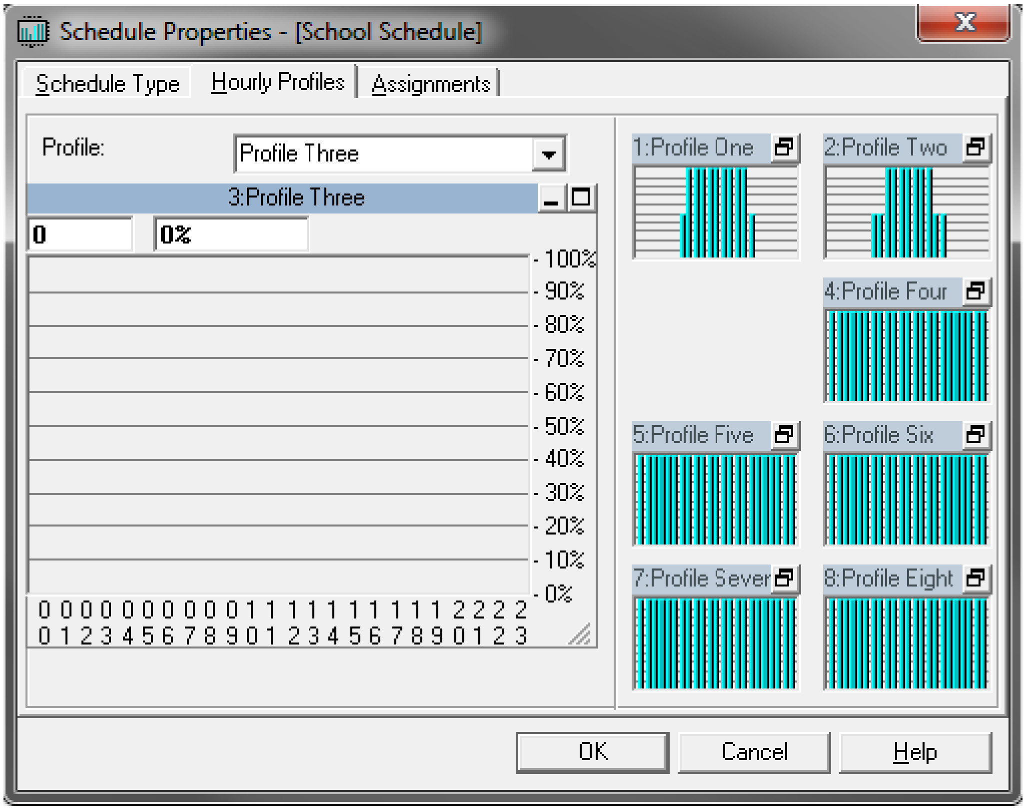
AE 558 – Centralized Heating Production and Distribution Systems

Life cycle cost analysis was taught in this course. Although, there is not a life cycle cost analysis contained within this report there is intent to develop one for the presentation.

Appendix B: Example Schedules

School Schedule

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Assignments
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4:Profile Four
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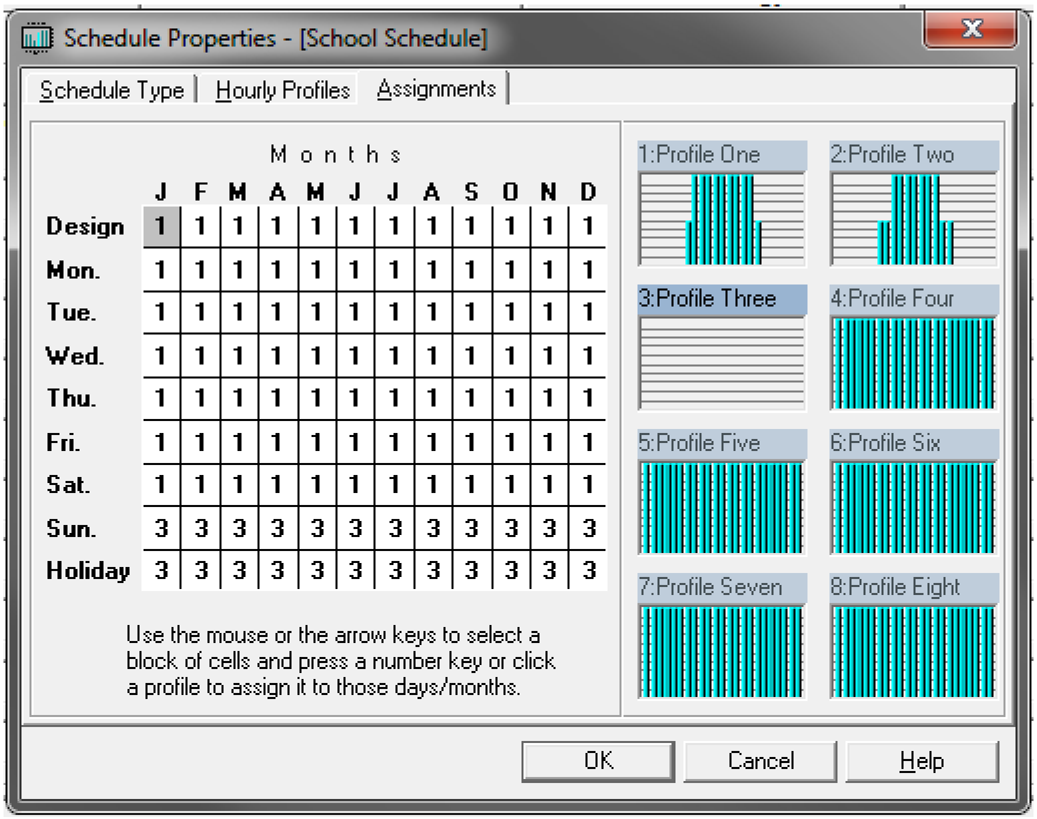
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Schedule Type
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Thu. 1 1 1 1 1 1 1 1 1 1 1 1
Fri. 1 1 1 1 1 1 1 1 1 1 1 1
Sat. 1 1 1 1 1 1 1 1 1 1 1 1
Sun. 3 3 3 3 3 3 3 3 3 3 3 3
Holiday 3 3 3 3 3 3 3 3 3 3 3 3
Use the mouse or the arrow keys to select a block of cells and press a number key or click a profile to assign it to those days/months.
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4:Profile Four
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7:Profile Seven
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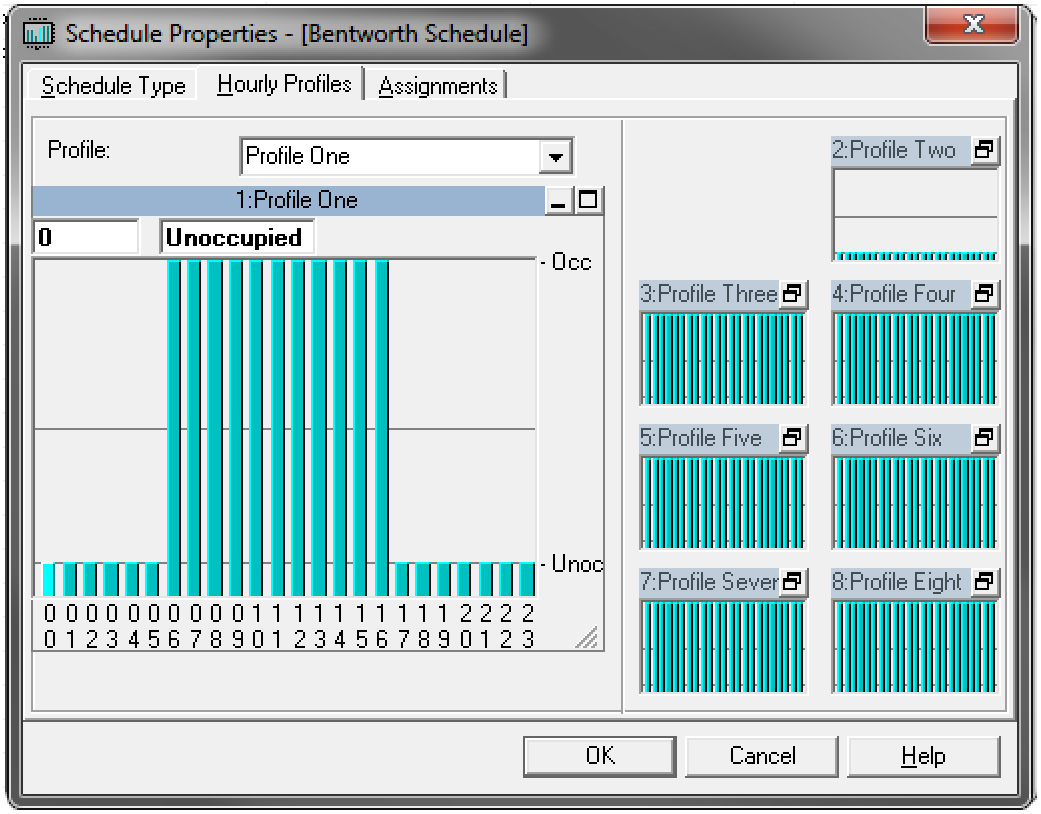
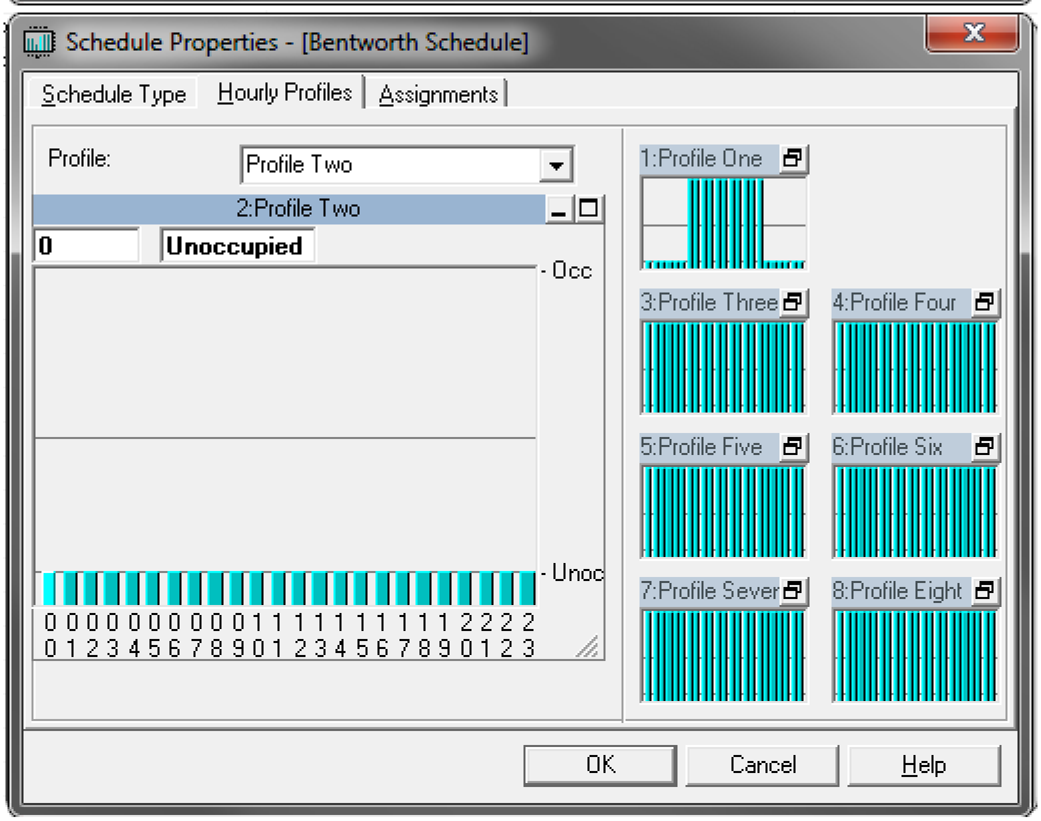
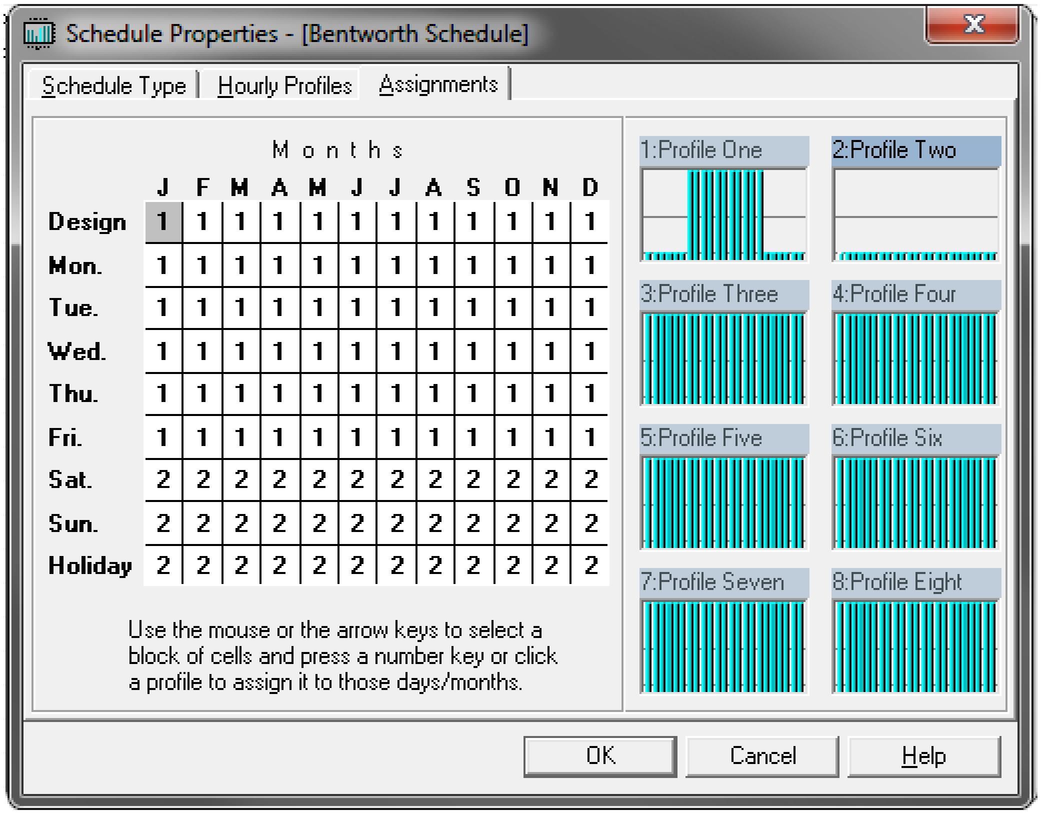
Thermostat Schedule



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Thu. 1 1 1 1 1 1 1 1 1 1 1 1
Fri. 1 1 1 1 1 1 1 1 1 1 1 1
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Use the mouse or the arrow keys to select a block of cells and press a number key or click a profile to assign it to those days/months.
1:Profile One
2:Profile Two
3:Profile Three
4:Profile Four
5:Profile Five
6:Profile Six
7:Profile Seven
8:Profile Eight
OK
Cancel
Help

Appendix C: Psychrometic Study

System Psychrometrics for Tower 1

Project Name: BMS New Windows and Air 04/06/2011
Prepared by: PSUAE 06:24PM

January DESIGN COOLING DAY, 1400

TABLE 1: SYSTEM DATA

Component	Location	Dry-Bulb Temp (°F)	Specific Humidity (lb/lb)	Airflow (CFM)	CO2 Level (ppm)	Sensible Heat (BTU/hr)	Latent Heat (BTU/hr)
Ventilation Air	Inlet	45.8	0.00605	2303	400	-14602	-19927
Ventilation Reclaim	Outlet	70.3	0.01377	2303	400	-58407	-80714
Vent - Return Mixing	Outlet	0.0	0.00000	0	0	-	-
Ventilation Fan	Outlet	70.3	0.01377	2303	400	0	-
Cold Supply Duct	Outlet	70.3	0.01377	2303	400	0	-
Zone Air	-	75.7	0.01567	2303	1223	45343	32390
Return Plenum	Outlet	75.7	0.01567	2303	1223	0	-
Exhaust Fan	Outlet	76.4	0.00000	2303	1223	1707	-

Air Density x Heat Capacity x Conversion Factor: At sea level = 1.080; At site altitude = 1.033 BTU/(hr-CFM-F)
Air Density x Heat of Vaporization x Conversion Factor: At sea level = 4746.6; At site altitude = 4540.4 BTU/(hr-CFM)
Site Altitude = 1224.0 ft

System Psychrometrics for Tower 1

Project Name: BMS New Windows and Air 04/06/2011
Prepared by: PSUAE 06:24PM

TABLE 2: ZONE DATA

Component	Location	Dry-Bulb Temp (°F)	Specific Humidity (lb/lb)	Airflow (CFM)	CO2 Level (ppm)	Sensible Heat (BTU/hr)	Latent Heat (BTU/hr)
Zone 1 (Cooling)							
Ventilation Air	-	-	-	392	-	-	-
Cooling Coil Inlet	-	73.9	0.01486	815	0	-	-
Cooling Coil Outlet	-	66.4	0.01418	815	0	6317	2556
Heating Coil Inlet	-	66.4	0.01418	815	0	-	-
Heating Coil Outlet	-	66.4	0.01418	815	0	0	-
Zone Air	-	75.7	0.01588	815	1195	7858	-
Zone 2 (Cooling)							
Ventilation Air	-	-	-	342	-	-	-
Cooling Coil Inlet	-	73.6	0.01418	634	0	-	-
Cooling Coil Outlet	-	64.3	0.01313	634	0	6056	3027
Heating Coil Inlet	-	64.3	0.01313	634	0	-	-
Heating Coil Outlet	-	64.3	0.01313	634	0	0	-
Zone Air	-	75.8	0.01466	634	1277	7476	-
Zone 3 (Cooling)							
Ventilation Air	-	-	-	483	-	-	-
Cooling Coil Inlet	-	73.2	0.01473	803	0	-	-
Cooling Coil Outlet	-	66.8	0.01438	803	0	5387	1300
Heating Coil Inlet	-	66.8	0.01438	803	0	-	-
Heating Coil Outlet	-	66.8	0.01438	803	0	0	-
Zone Air	-	75.7	0.01618	803	1145	7445	-
Zone 4 (Cooling)							
Ventilation Air	-	-	-	351	-	-	-
Cooling Coil Inlet	-	74.1	0.01377	784	0	-	-
Cooling Coil Outlet	-	63.2	0.01254	784	0	8878	4390
Heating Coil Inlet	-	63.2	0.01254	784	0	-	-
Heating Coil Outlet	-	63.2	0.01254	784	0	0	-
Zone Air	-	75.8	0.01376	784	1289	10255	-
Zone 5 (Cooling)							
Ventilation Air	-	-	-	392	-	-	-
Cooling Coil Inlet	-	74.0	0.01559	898	0	-	-
Cooling Coil Outlet	-	68.7	0.01547	898	0	4907	529
Heating Coil Inlet	-	68.7	0.01547	898	0	-	-
Heating Coil Outlet	-	68.7	0.01547	898	0	0	-
Zone Air	-	75.5	0.01702	898	1195	6304	-
Zone 6 (Cooling)							
Ventilation Air	-	-	-	342	-	-	-
Cooling Coil Inlet	-	73.9	0.01498	699	0	-	-
Cooling Coil Outlet	-	67.5	0.01477	699	0	4612	709
Heating Coil Inlet	-	67.5	0.01477	699	0	-	-
Heating Coil Outlet	-	67.5	0.01477	699	0	0	-
Zone Air	-	75.8	0.01615	699	1277	6005	-

Appendix D: Geothermal Loop Field Calculations

Cooling Load Calculations

GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: Bentworth Middle School
Job Number:
Date: 04/07/11
User: Kyle Courtney

INPUT DATA

Total Building Load (Ton)=	100	**Bldg Area**	60000	Sq Ft
Outdoor Design Temp. (°F)=	95	**Sq. Ft / Ton**	600	
Indoor Design Temp. (°F)=	75			
Balance Temp. (°F)=	65			
Total Heat Pump Capacity (Ton)=	202			
$COP_{COOLING}$=	3.5			
Pipe Resistance (Hr-Ft-°F/BTU)=	0.141			
Soil Resistance (Hr-Ft-°F/BTU)=	0.5			
Average Water Temp. (°F)=	75			
Mean Earth Temp.(°F)=	55			

BIN DATA

Design Month: July
Location: Bentlyville PA

BIN Range		Mean	Hours	WB(°F)
90	95	92.5	14	74.9
85	90	87.5	69	73.1
80	85	82.5	400	68.7
75	80	77.5	465	66.1
70	75	72.5	703	64.0
65	70	67.5	603	61.3
60	65	62.5	1060	57.0
55	60	57.5	708	50.9
			4022	

CALCULATIONS

BIN Range	Bldg Load Tons	Heat Pump Hours
95/100	137.50	9.53
90/95	112.50	38.43
85/90	87.50	173.27
80/85	62.50	143.87
75/80	37.50	130.51
70/75	12.50	37.31
65/70	-12.50	-65.59
		467.33

Run Fraction= 0.63
Ground Loop Heat Exchanger Length(Ft/Ton)= 310.60
Total Ground Loop Length= 31060.00

Bores Required: Depth (Ft)	Number
400	78
375	83
350	89
325	96
300	104
250	124
200	155
600	52

Heating Load Calculations

GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: Bentworth Middle School
Job Number:
Date: 04/11/11
User: Kyle Courtney

INPUT DATA

Total Building Load (MBH)= 876
Outdoor Design Temp. (°F)= 0
Indoor Design Temp. (°F)= 70
Balance Temp. (°F)= 55
Total Heat Pump Capacity (MBH)= 2160
$COP_{HEATING}$= 3.3
Pipe Resistance (Hr-Ft-°F/BTU)= 0.141
Soil Resistance (Hr-Ft-°F/BTU)= 0.5
Average Water Temp. (°F)= 42
Mean Earth Temp.(°F)= 55

Bldg Area 60000 Sq Ft
BTUH / SF 15

BIN DATA

Design Month: January
Location: Bentleyville

BIN Range		Mean	Hours	WB(°F)
60	65	62.5	1060	57.0
55	60	57.5	708	50.9
50	55	52.5	693	46.8
45	50	47.5	595	42.5
40	45	42.5	540	38.3
35	40	37.5	853	33.8
30	35	32.5	705	29.4
25	30	27.5	523	24.9
20	25	22.5	334	20.5
15	20	17.5	298	16.1
10	15	12.5	112	10.9
5	10	7.5	50	5.3
0	5	2.5	29	-0.1
-5	0	-2.5	6	-2.7
			6506	

CALCULATIONS

BIN Range	Bldg Load	Heat Pump Hours
62.5	-93.86	0.00
57.5	-31.29	0.00
52.5	31.29	10.04
47.5	93.86	25.85
42.5	156.43	39.11
37.5	219.00	86.48
32.5	281.57	91.90
27.5	344.14	83.33
22.5	406.71	62.89
17.5	469.29	64.74
12.5	531.86	27.58
7.5	594.43	13.76
2.5	657.00	8.82
-2.5	719.57	2.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
		516.50

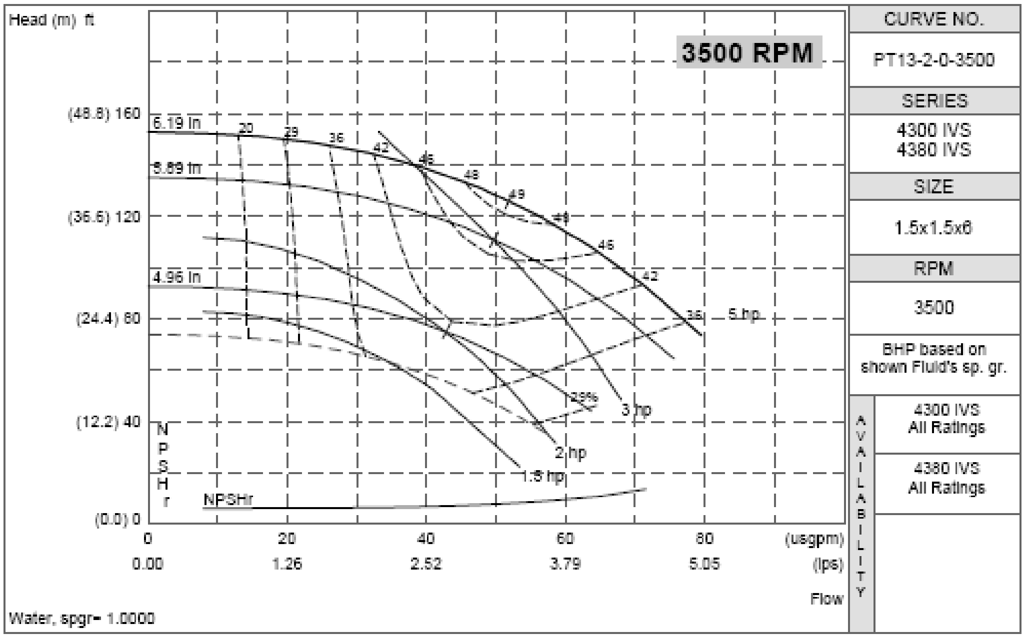
Run Fraction= 0.69
Ground Loop Heat Exchanger Length(Ft/MBH)= 23.86
Total Ground Loop Length= 20899.38

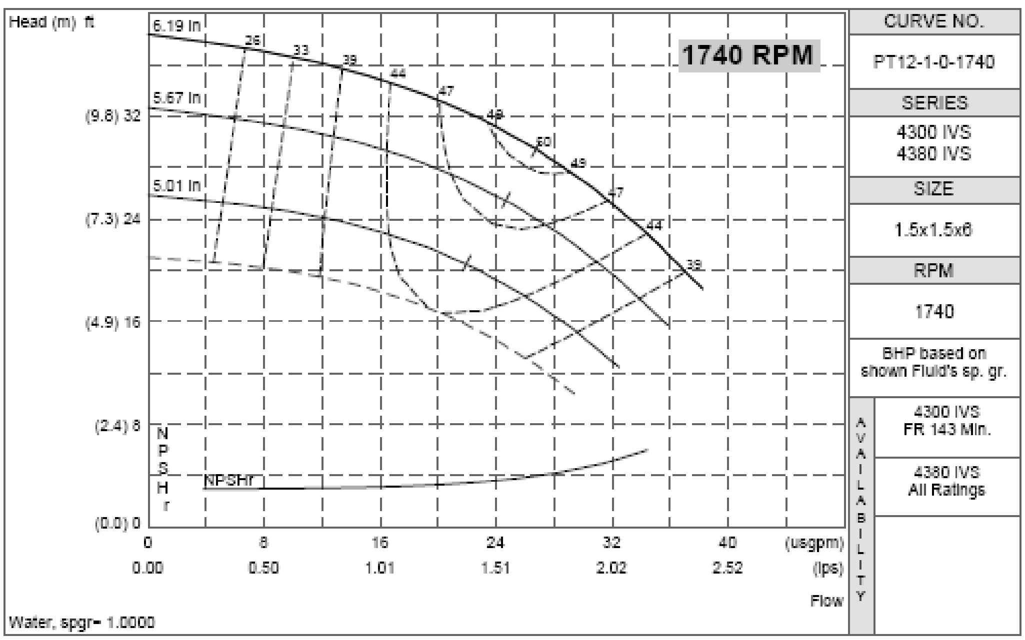
Bores Required:

Depth (Ft)	Number
400	52
375	56
350	60
325	64
300	70
250	84
200	104
600	35

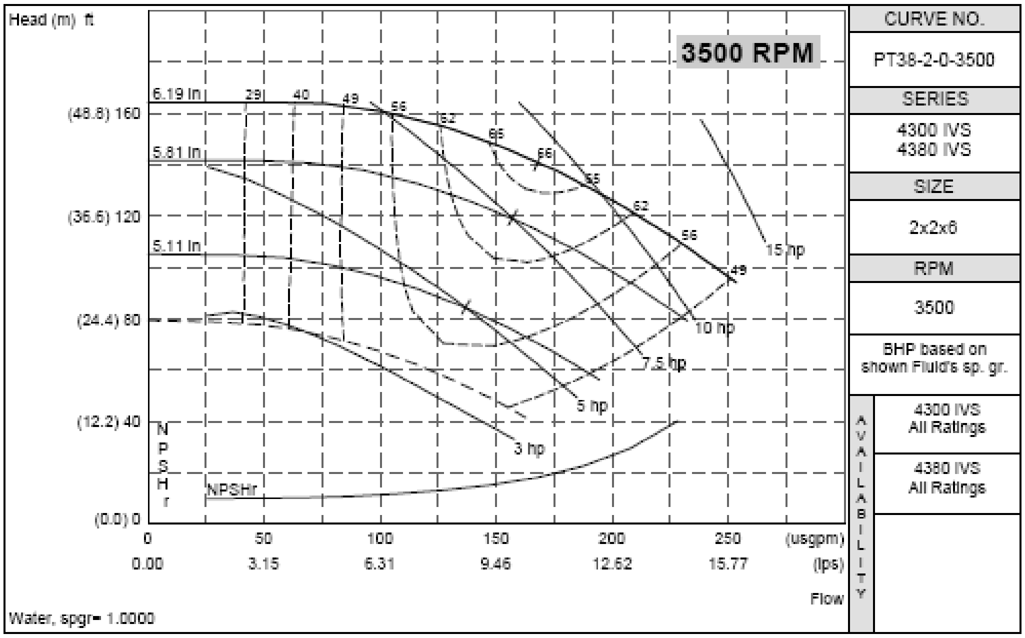
Appendix E: Pump Curves

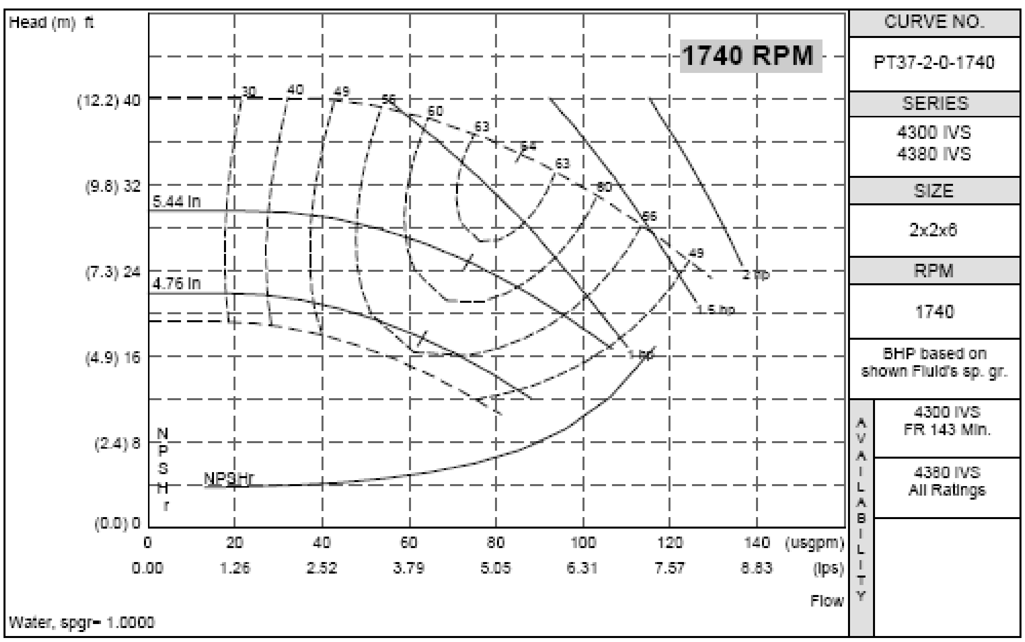
ARMSTRONG

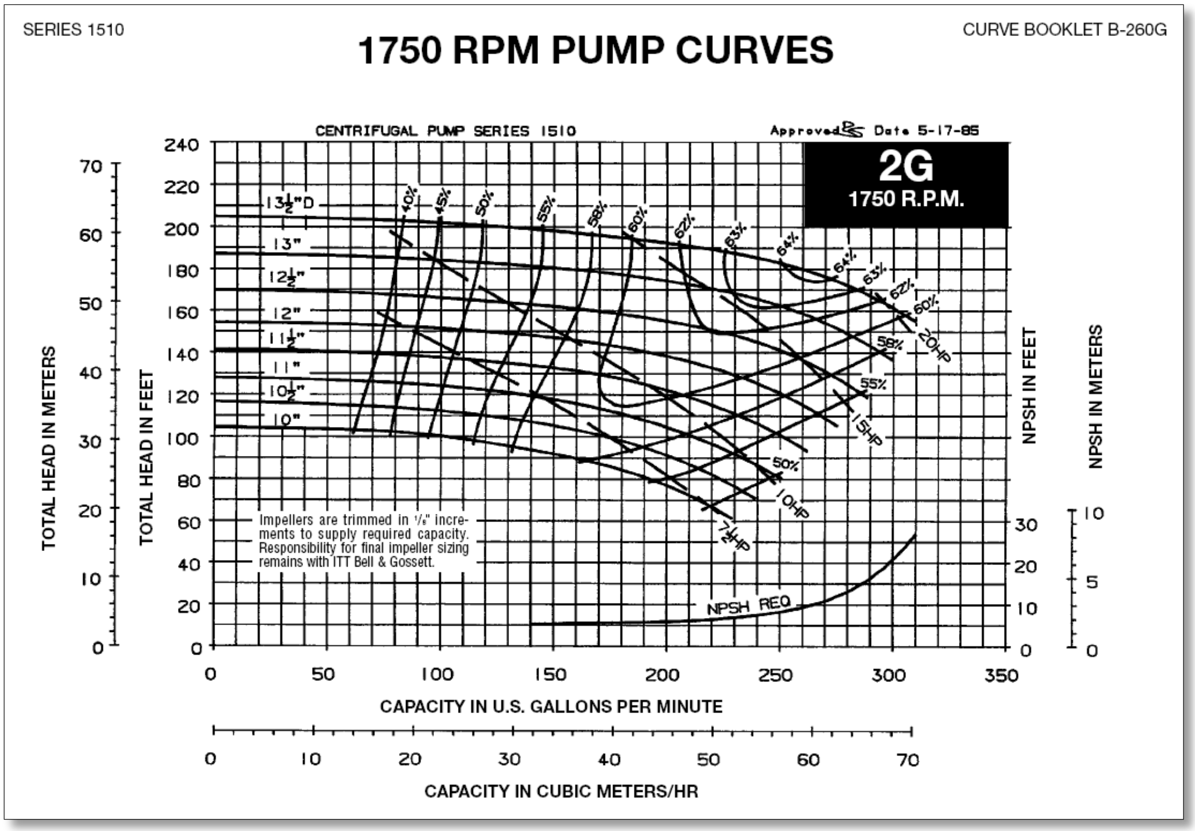


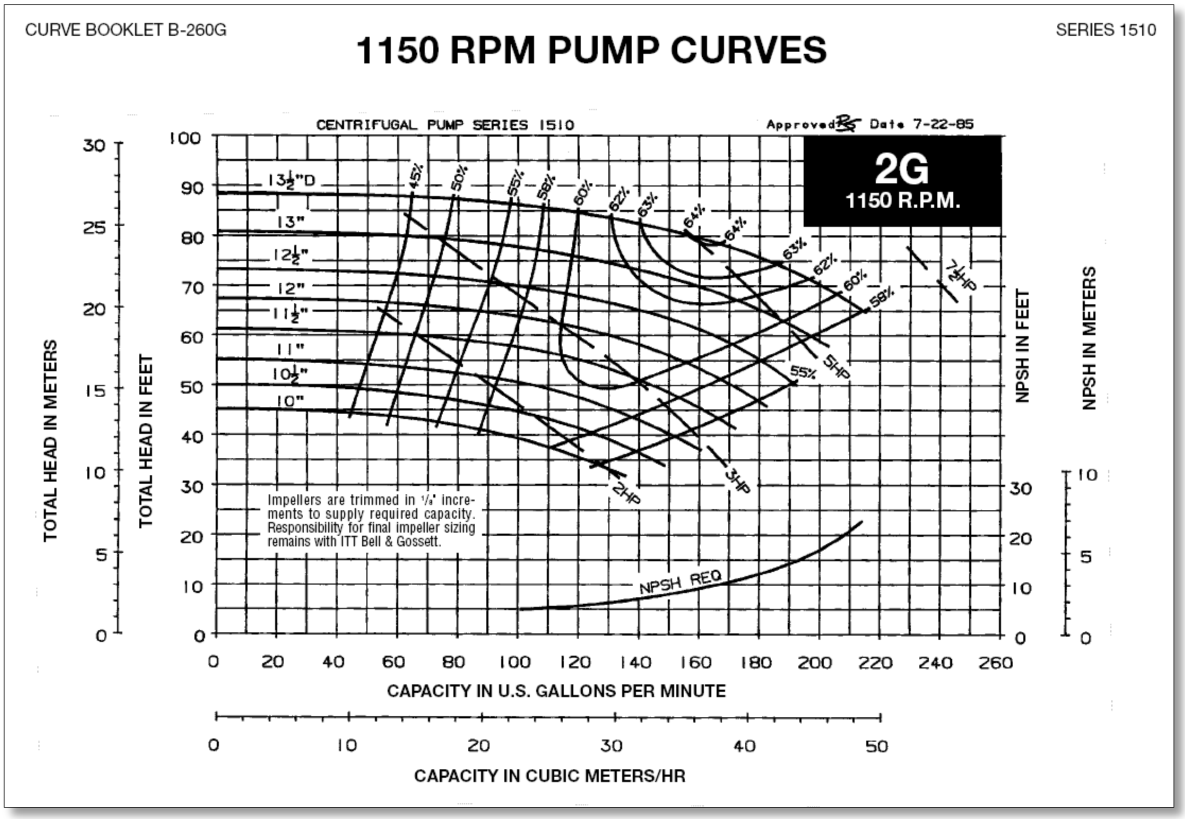


ARMSTRONG


Head (m) ft
3500 RPM
6.19 in
5.81 in
5.11 in
(48.8) 160
(36.6) 120
(24.4) 80
(12.2) 40
(0.0) 0
15 hp
10 hp
7.5 hp
5 hp
3 hp
NPSHr
0 50 100 150 200 250 (usgpm)
0.00 3.15 6.31 9.46 12.62 15.77 (lps)
Flow
Water, spgr= 1.0000
CURVE NO.
PT38-2-0-3500
SERIES
4300 IVS
4380 IVS
SIZE
2x2x6
RPM
3500
BHP based on shown Fluid's sp. gr.
AVAILABILITY
4300 IVS All Ratings
4380 IVS All Ratings


Head (m) ft
1740 RPM
5.44 in
4.76 in
(12.2) 40
(9.8) 32
(7.3) 24
(4.9) 16
(2.4) 8
(0.0) 0
NPSHr
0 20 40 60 80 100 120 140 (usgpm)
0.00 1.26 2.52 3.79 5.05 6.31 7.57 8.83 (lps)
Flow
Water, spgr= 1.0000
CURVE NO.
PT37-2-0-1740
SERIES
4300 IVS
4380 IVS
SIZE
2x2x6
RPM
1740
BHP based on shown Fluid's sp. gr.
AVAILABILITY
4300 IVS FR 143 Min.
4380 IVS All Ratings


SERIES 1510
1750 RPM PUMP CURVES
CURVE BOOKLET B-260G
CENTRIFUGAL PUMP SERIES 1510
Date 5-17-85
2G
1750 R.P.M.
Impellers are trimmed in 1/8" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
NPSH REQ
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN FEET
NPSH IN METERS
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR


CURVE BOOKLET B-260G
1150 RPM PUMP CURVES
SERIES 1510
CENTRIFUGAL PUMP SERIES 1510
Date 7-22-85
2G
1150 R.P.M.
Impellers are trimmed in 1/8" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
NPSH REQ
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN FEET
NPSH IN METERS
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR

Appendix F: Pump Calculations

Central System - 2 VSD Pumps in Parallel

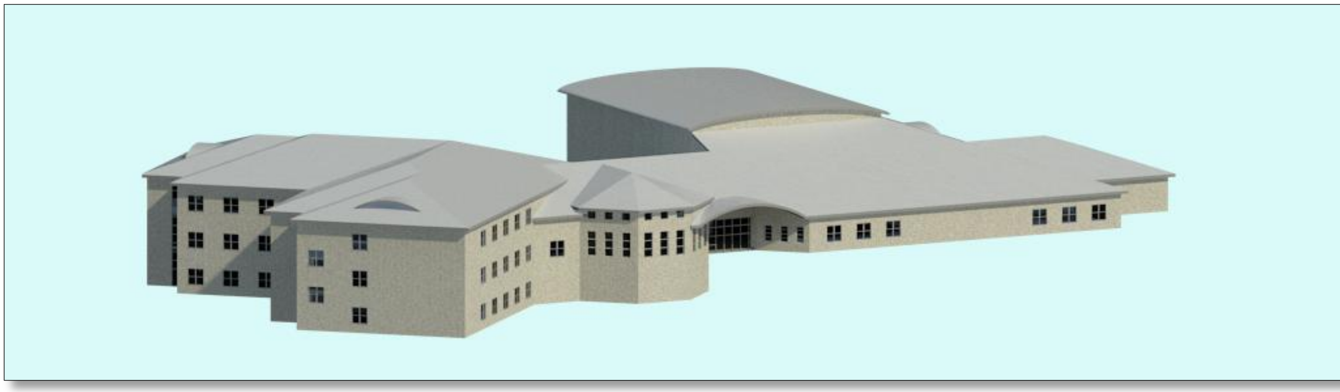
			Pump Selection					GPM	Head	Annual Hours	Annual
Pump Location	Total Head	Total GPM	Manuf	Size	RPM	Impeller Size	Effciency			Operation	kW
Mechanical Room	130	275	B&G 1510	2G	1750	13 in	0.58	0-180	56	3480	11389
	56	180	B&G 1510	2G	1150	13 in	0.58	180-275	130	663	7695
								275-360	112	319	4176
								360-455	186	55	1511
								455-550	260	10	464
										Total	25236

Decentralized Pump Calculations

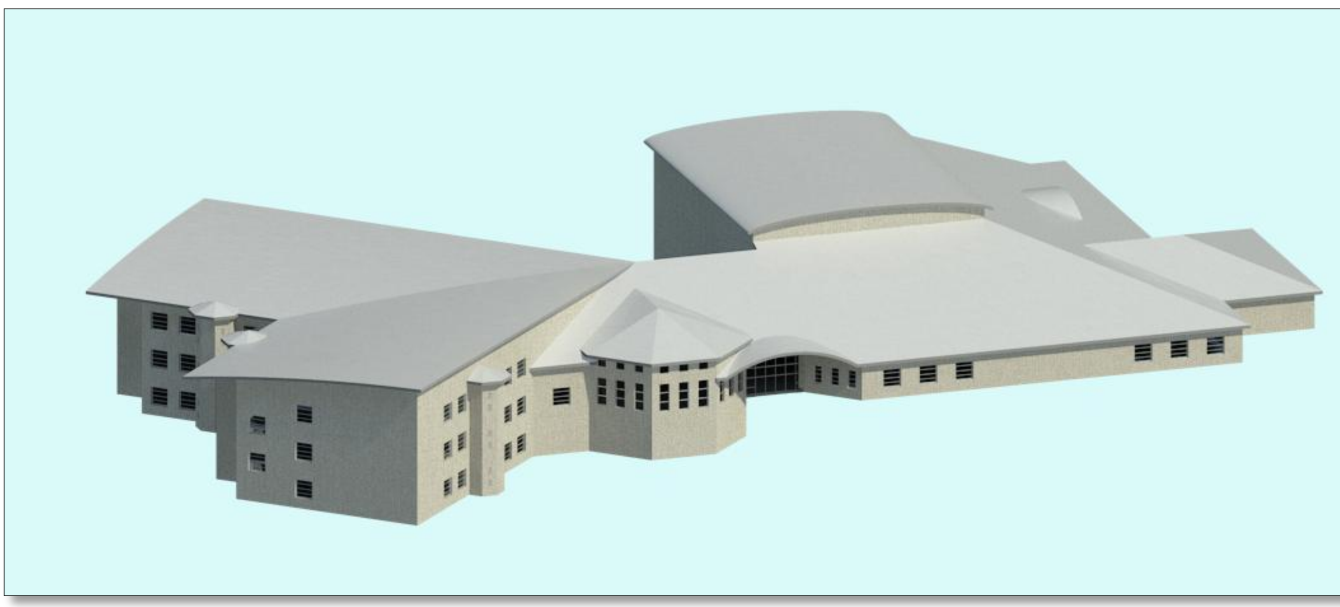
						Pump Selection					Annual Hours of	Annual
Pump Location	Piping PD	Unit PD	Well Field PD	Total Head	Total GPM	Manuf	Size	Impeller Size	RPM	Effciency	Operation	kW
Tower 1	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2328	4956
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	550	141
Tower 2	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2238	4764
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	687	176
Tower 3	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2359	5022
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	645	165
Tower 4	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2240	4768
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	752	193
Tower 5	15'	6'	90'	125	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.45	2692	5633
				31	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	232	58
Interior Area	19'	6'	90'	115	85	Arm 4300IVS	2x2x6	5.81 in	3500	0.53	1757	6102
				28	42	Arm 4300IVS	2x2x6	5.81 in	1740	0.51	1648	716
Admin Area	25'	3'	90'	115	65	Arm 4300IVS	2x2x6	5.81 in	3500	0.42	2139	7169
				28	33	Arm 4300IVS	2x2x6	5.81 in	1740	0.45	1056	408
RTHP-B2	20'	6.2'	90'	125	69	Arm 4300IVS	2x2x6	5.81 in	3500	0.44	1746	6445
				31	34	Arm 4300IVS	2x2x6	5.81 in	1740	0.46	42	18
RTHP-B3	20'	5.4'	90'	125	26	Arm 4300IVS	1.5x1.5x6	5.89 in	3500	0.32	3526	6743
				31	13	Arm 4300IVS	1.5x1.5x6	5.89 in	1740	0.41	0	0
RTHP-B4	20'	7.1'	90'	125	102	Arm 4300IVS	2x2x6	5.81 in	3500	0.55	1755	7661
				31	51	Arm 4300IVS	2x2x6	5.81 in	1740	0.58	677	348
											Total	61138

Appendix G: Architectural Breadth Images

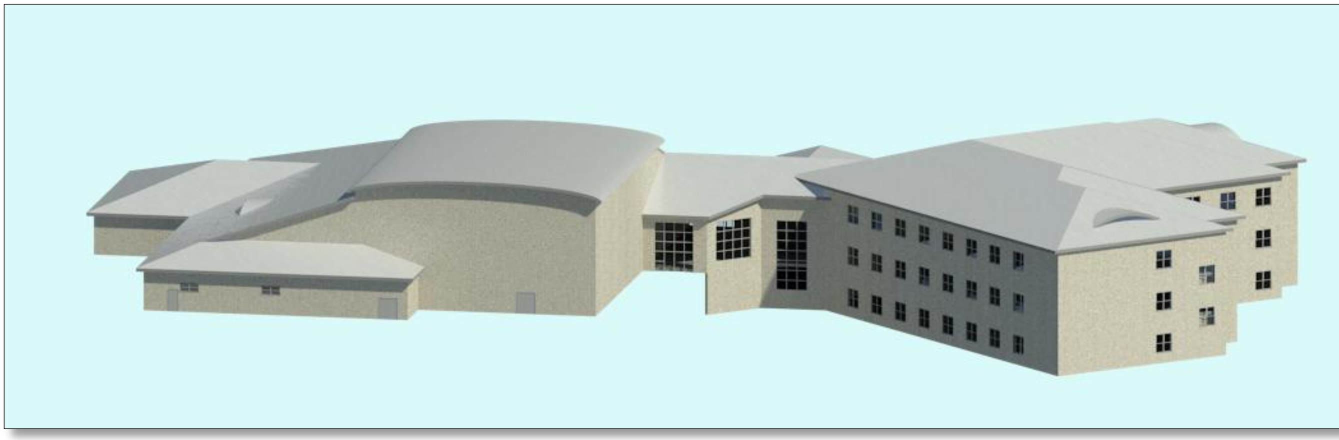
As Designed Entrance 3D View



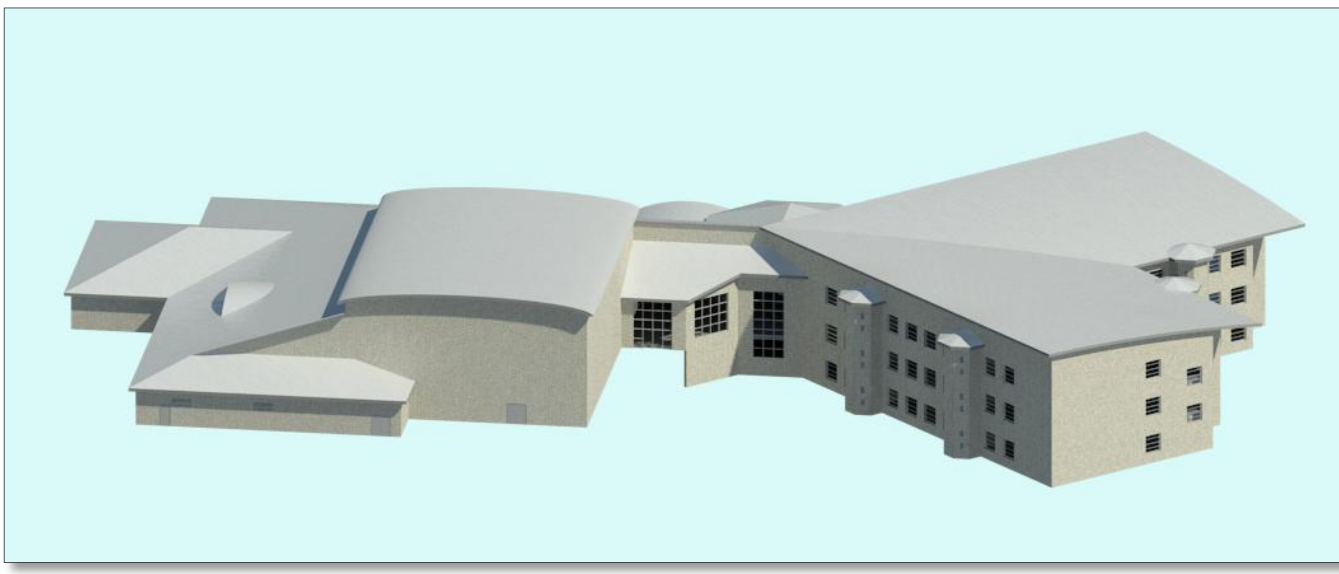
Redesigned Entrance 3D View



As Designed Rear 3D View



Redesigned Rear 3D view



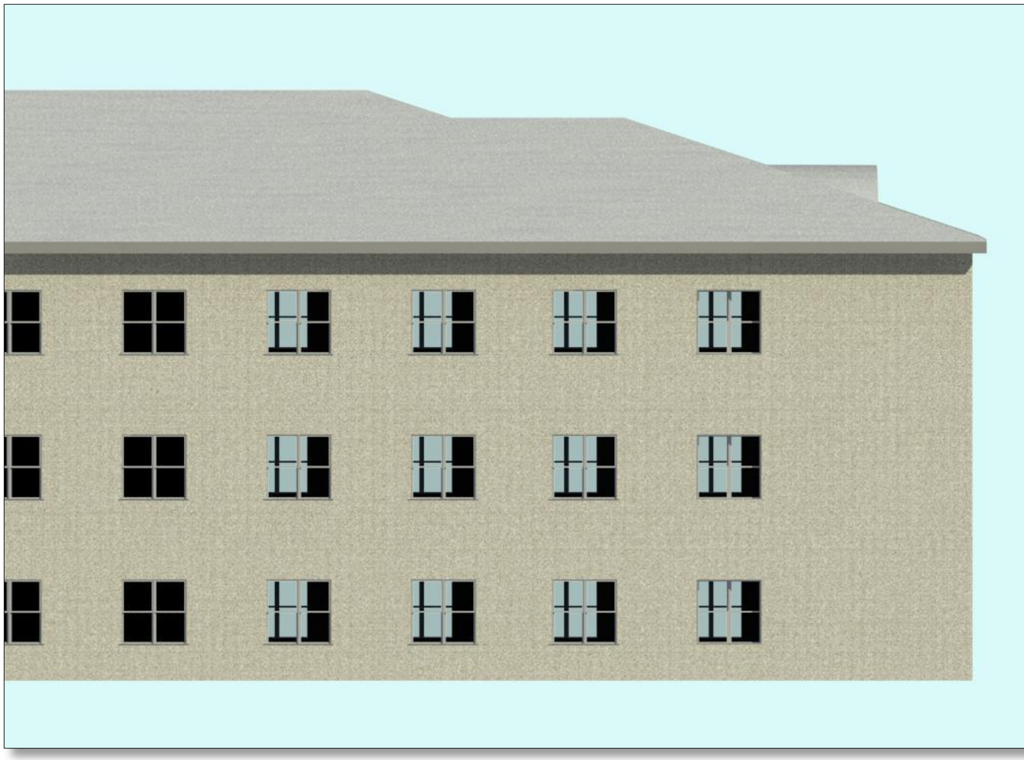
As Designed Front Elevation

Redesigned Font Elevation

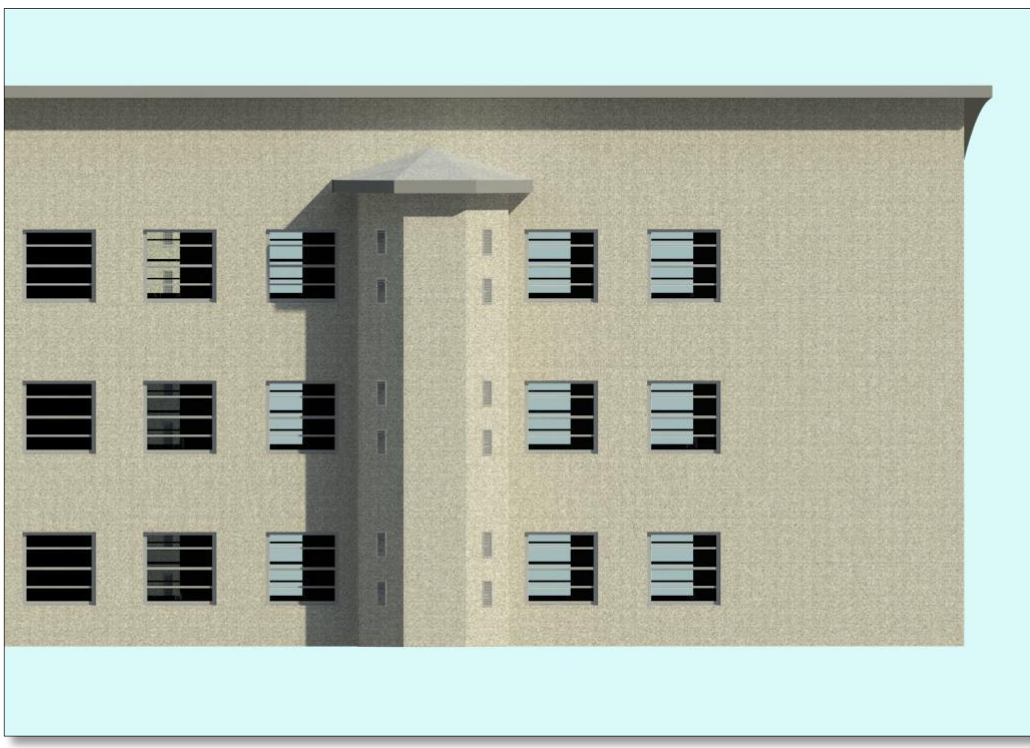
As Designed Rear Elevation

Redesigned Rear Elevation

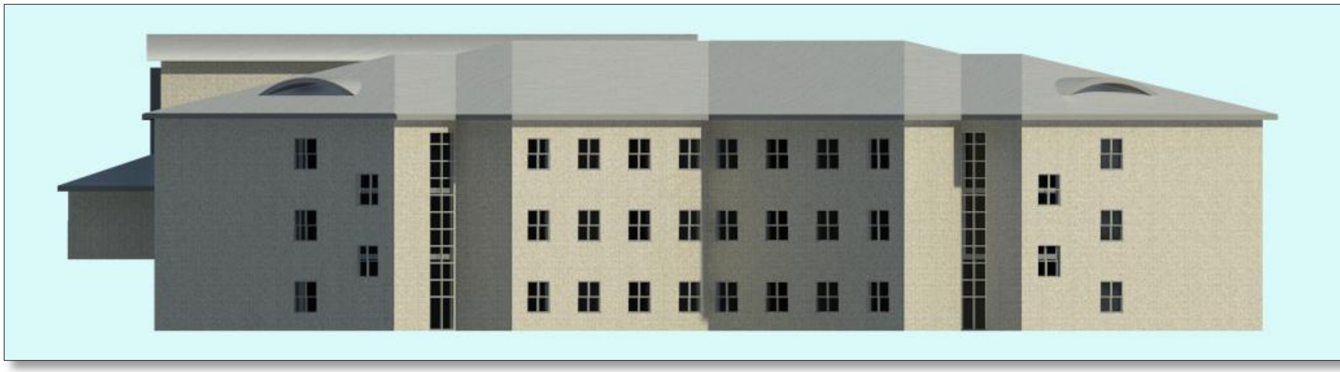
As Designed Windows



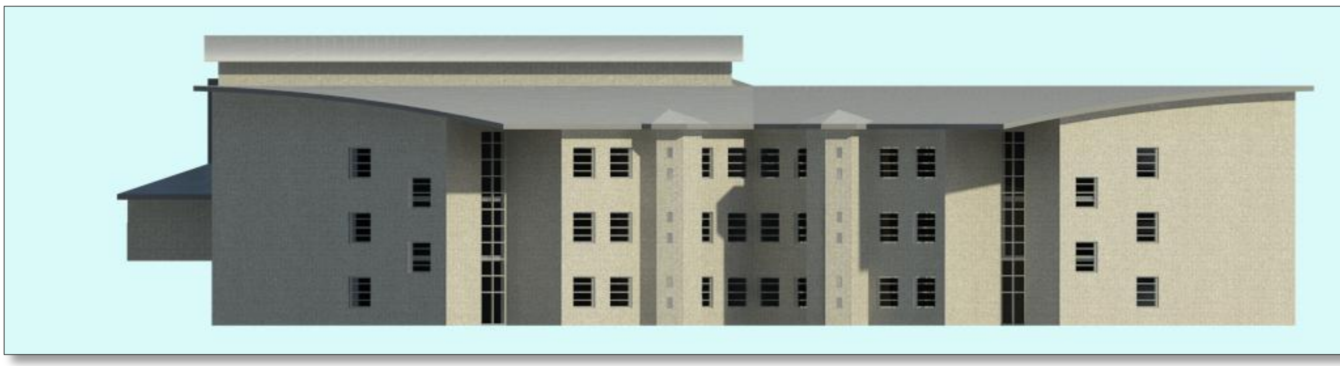
Redesigned Windows



As Designed Academic Wing Elevation



Redesigned Academic Wing Elevation



Appendix H: Solar Information

Benefits of your BP Solar system

Estimated System Cost	$1,680,000
Federal / State / Local Tax Credits	$504,000
State / Utility Rebate	$52,500
Net Cost	$1,123,500
Cumulative Lifetime Savings	$788,204 over 25 years
Investment Return	6.5%

Annual Consumption and Production

	Nameplate Rating (kWdc-stc)	AC Rating (kWac)	System Production (kWh/year)
PV System	210.000	189.000	237,430
Power Purchased			1,403,384
TOTAL CONSUMPTION			1,640,814

Monthly Electric Bill

	Before BP Solar	After BP Solar	Bill Savings
January	$8,689	$7,902	$787
February	$8,513	$7,419	$1,094
March	$8,269	$6,985	$1,284
April	$8,721	$7,056	$1,664
May	$8,536	$6,832	$1,704
June	$9,723	$7,758	$1,966
July	$10,220	$8,322	$1,898
August	$10,353	$8,465	$1,888
September	$9,848	$8,149	$1,699
October	$8,593	$7,192	$1,401
November	$8,064	$7,397	$667
December	$8,475	$8,012	$463
TOTAL	$108,004	$91,489	$16,515

Annual Net Cash Flow

	Annual Electric Bill Savings	Electric Bill Tax Savings	Loan Payment	Loan Tax Savings	Depreci-ation Tax Savings	Total Net Cash Flow
2011	$16,515	$-6,704	$-106,030	$36,958	$494,462	$435,201
2012	$17,341	$-7,039	$-106,030	$36,453	$8,942	$-50,334
2013	$18,208	$-7,391	$-106,030	$35,906	$8,942	$-50,366
2014	$19,118	$-7,761	$-106,030	$35,314	$8,942	$-50,417
2015	$20,074	$-8,149	$-106,030	$34,672	$8,942	$-50,490
2016	$21,078	$-8,556	$-106,030	$33,978	$8,942	$-50,589
2017	$22,131	$-8,984	$-106,030	$33,225	$8,942	$-50,715
2018	$23,238	$-9,433	$-106,030	$32,411	$8,942	$-50,872
2019	$24,400	$-9,905	$-106,030	$31,528	$8,942	$-51,064
2020	$25,620	$-10,400	$-106,030	$30,573	$8,942	$-51,295
2021	$26,901	$-10,920	$-106,030	$29,538	$8,942	$-51,569
2022	$28,246	$-11,466	$-106,030	$28,417	$8,942	$-51,891
2023	$29,658	$-12,039	$-106,030	$27,203		$-61,208
2024	$31,141	$-12,641	$-106,030	$25,889		$-61,642
2025	$32,698	$-13,273	$-106,030	$24,465		$-62,140
2026	$34,333	$-13,937	$-106,030	$22,923		$-62,711
2027	$36,050	$-14,634	$-106,030	$21,253		$-63,361
2028	$37,852	$-15,366	$-106,030	$19,445		$-64,098
2029	$39,745	$-16,134	$-106,030	$17,486		$-64,933
2030	$41,732	$-16,940	$-106,030	$15,365		$-65,873
2031	$43,819	$-17,788	$-106,030	$13,068		$-66,931
2032	$46,010	$-18,677	$-106,030	$10,581		$-68,117
2033	$48,310	$-19,611	$-106,030	$7,886		$-69,444
2034	$50,726	$-20,591	$-106,030	$4,969		$-70,927
2035	$53,262	$-21,621	$-106,030	$1,809		$-72,580

Annual Consumption and Production

	Nameplate Rating (kWdc-stc)	AC Rating (kWac)	System Production (kWh/year)
PV System	210.000	189.000	237,430
Power Purchased			1,403,384
TOTAL CONSUMPTION			1,640,814