Revised Thesis Report for Berks Classroom and Lab Building

Berks Classroom and Lab Building - Berks Campus Reading, PA

Authored by Julia Broskey - Mechanical Option

Prepared for Dr. William P. Bahnfleth PE

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1. Thesis Abstract

Berks Classroom And Lab Building

Reading PA | Julia Broskey | Mechanical Option

Building Stats
Occupancy: Business
Size: 62,188 sq ft
Levels: 3
Cost: Withheld at owners request
Project Delivery: Design-Bid-Build
Construction Dates: April 2010 - Aug/Sept 2011

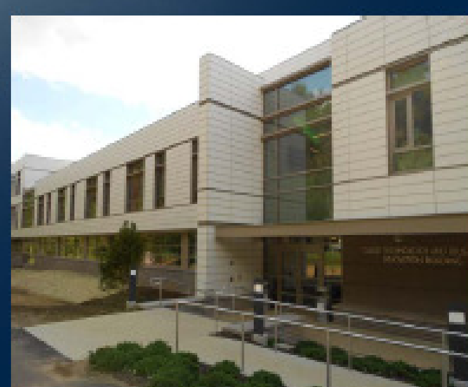
Architecture
Located on Penn State Berks Campus, Berks Classroom and Lab Building is a new construction building. The building is a 3 story building consisting of classrooms and laboratory space and is designed to be LEED silver.

Project Team
Owner: Penn State Berks
Architect: RMJM Hiller
GC: Alvin H. Butz., Inc
Construction Cost Estimator: Becker & Fondorf
Structural Engineer: Greenman-Pedersen, Inc
MEP: H.F. Lenz Company
Civil Engineer: Gannett Fleming Engineers
Lighting Consultant: Illumination Arts, LLC
Acoustical Consultant: Shen Milsom Wilke, Inc.

Mechanical
3 electrical roof top units serve the majority of the building providing supply air to VAV boxes that serve the spaces. The roof top units are supplemented by a computer room unit to provide cooling to the server room.

Electrical
The electrical system uses both 480/277V and 208/120V systems throughout the building. The lighting of the building is run on the 480/277V system and the plug loads are run using the 208/120V system.

Structural
The foundation of the building is cast in place concrete slab on grade with pile caps and piers. Typically the Building's framing is steel and the floor construction is concrete with some thickened slabs where needed.



http://www.engr.psu.edu/ae/thesis/portfolios/2011/jab791/index.html

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2. Executive Summary

This report shows the results of work done in line with the approved proposal submitted 11 January 2012. This proposal states for the depth work, that a ground source heat pump will be designed to meet the load of the Berks Classroom and Lab building. For the two breadths to be completed; the proposal states for the electrical breadth that the components that feed the proposed ground source heat pump will be sized and for the construction management breadth that a cost and schedule analysis will be completed for the proposed system.

Upon analysis of the proposed system in Trane Trace it was determined that 89, 5 ton spilt system ground source heat pumps would meet the required load for the building. The site analysis requires that a horizontal configuration of pipe be used since the depth to bedrock is estimated to be between 48 – 120 inches or 4 – 12 feet. The length of pipe required is 263,460 linear feet of 1 inch polyethylene pipe. The proposed system showed the energy cost per square foot of the building drops from $14.12 to $12.80, with this particular configuration. This translates to an $82,240.50 annual savings in energy cost. Since the proposed system costs $3,039,707.31 upfront for materials and installation the payback period for this system is about 37 years.

Each unit as a total ampasity of 37.5 resulting in a total ampasity for the 89 units of 3,337.5, this results in needing a minimum of 5 panels to serve these units. The panels break down as follows, 4 panels at 750 amps and 1 panel at 337.5 amps to accommodate the electrical load. The estimated wire to distribute the required electricity to the units is 3,693.5 linear feet with the assumption that all the units are located in the mechanical room.

Using either cost data from Lowe's Home Improvement Store, Granger's website or MC2 to obtain estimated cost information for materials and cost for typical crews to install it was determined that the total material cost for the proposed system was $1,655,560.86 and the installation costs are $1,297,905. The installation cost includes the cost for equipment used to excavate for the pipe installation. The cost of a dedicated crane was done separately and resulted in an additional cost of $86,241.45. This results in a total cost for the system of $3,039,707.31.

Revised Executive Summary

The breadth work is still based on the original report work and will not be updated with the additional work done. The original proposed system consists of the pipe work and the 89 Carrier split-system units. This work will be revised and the revised work will be shown in **bolded red** as well as any section with revised work will be noted either as a new heading or in the existing heading by adding Revised.

3. Acknowledgement

I wish to acknowledge the faculty and staff of The Pennsylvania State University Department of Architectural Engineering and additional contacts that helped with information regarding this project including:

Thesis Advisor: Dr. William P. Bahnfleth, P.E.

Project Sponsor: The Pennsylvania State University

Sponsor Contact: Thomas M. Wojcik, P.E.

Additional Contacts:

Jennifer Wahl, Manager of Wahl Heating and Cooling, Inc., Carnegie, PA

Charlie Bovard, V.P./General Manager of Bovard Heating & Cooling, Altoona, PA

I wish to thank my family and friends for all their support!

4. Project Overview

The Berks Classroom and Lab Building is a 62,188 sq. ft. building that was designed with the growing need for Penn State Berks Campus for technology based lab spaces. It was designed with three levels all above ground as a New Building Group B – Business occupancy type. The third floor houses faculty offices where the first and second floors house the classroom and lab spaces for student use. The first floor also has a cafe space, which offers seating and a convenience type store where students and faculty can eat and provides a prominent meeting space.

The building's project team is as follows:

- Owner: The Pennsylvania State University Berks Campus
- General Contractor: Alvin H. Butz, Inc.
- Construction Cost Estimator: Becker & Frondorf
- Building Architect: RMJM Hiller
- Engineers:
    - Structural: Greenman-Pedersen, Inc
    - MEP: H.F. Lenz Company
    - Civil: Gannett Fleming Engineers
    - Lighting Consultant: Illumination Arts, LLC
    - Acoustical Consultant: Shen Milsom Wilke, Inc

The project was delivered using the traditional Design-Bid-Build method and construction was started in April of 2010 and was completed and in use prior to 17 September 2011. The building was designed to obtain a LEED Silver certification.

5. General Architecture

The building's façade on the first floor consists of two different types of materials. The closest to grade, the façade uses architectural precast concrete panels backed with two airspaces, rigid insulation and a masonry wall. The second part of the first floor façade has an aluminum curtain wall system. The upper two floors the façade has an exterior finish of a terracotta rain screen backed by rigid insulation backed by cold formed metal framing (CMFM). The roof of the building starts with metal decking covered by a rigid composite insulation and a KEE membrane. The entire system slopes towards the roof drains.

The building's structural system is comprised of three different materials, cast-in-place concrete, structural steel and masonry. The foundation of the building is a cast-in-place concrete slab integrated with pile caps and piers. Typically the building's framing is steel and the floor construction is concrete with some areas requiring a thickened slab. Masonry was used in some wall construction.

The building utilizes both 480/277V and 208/120V electrical systems throughout the building. The lighting system of the building is run using the 480/277V system primarily on 277V. Generally speaking the lighting system is comprised of T8 fluorescent luminaries with other luminaries that include metal halide and LED. The luminaries are mostly run with 277V electronic ballasts, with very few exceptions. The standard receptacles are wired on the 208/120V system. This is done because most standard office and classroom equipment including computers are designed to run on a 120V 60Hz system. The power for the building is distributed from the main switchboard with a 35,000 amp serves that then supplies power to other switchboards and panels throughout the building.

Berks Classroom and Lab Building utilizes a grey water system to supply water to flush the toilets and urinals in the building. This system collects rain water and puts it to use within the building before it ends up in a sewer system. The collection system can hold up to 70,000 gallons of water in two holding tanks located directly in front of the building on the side where the café is located.

Existing Mechanical System

The existing mechanical system is comprised of three electrical roof top air-handlers (RTUs) that supply air to the spaces via VAV boxes located throughout the building. The main units are supplemented by a computer room air conditioner (CRAC) that is dedicated to cooling the server room. The heating capacity for the roof top units is hot water supplied from one of the 6.2 gallon boilers located in the mechanical room. Hot water is distributed within the system by five hot water pumps. Three of these pumps supply water to the boilers, of those three two are considered duty pumps and one is a stand-by pump. Of the two that supply hot water to the domestic hot water system and the VAV boxes, one is considered the duty pump and one the stand-by. The focus of study on the mechanical systems was confined to the three roof top units.

6. General History of Site

The Berks Classroom and Lab Building is located on Penn State Berks campus just outside of Reading, Pennsylvania. Berks campus is 258 acres of land that holds 17 academic buildings and 14 residence halls. These buildings serve a total enrolment of 2,824 students with about 800 of them residing in residence halls on campus. The Berks Classroom and Lab Building became the 17th academic building on camps and is located adjacent to Thun Library.

Penn State Berks campus has a longer history prior to becoming part of the Penn State Commonwealth Campuses. Its history started when Ferdinand Thun and Henry Janssen opened Textile Machine Works (TMI) in Reading in 1892. They went on to start an education program for their workers in 1928 called the Educational Department of Textile Machine Works. Instructors from Penn State helped facilitate the school in the beginning with just 16 young men.

The education program that Thun and Janssen started was renamed in 1933 to Wyomissing Polytechnic Institute (WPI) after it was granted a state charter. That same year Penn State gave two years' credit to those who graduated from the WPI program. The school closed in 1958 due to difficult economic time hitting the textile industry and graduated about 1,500 students during its operation. After closing WPI's founders offered its buildings to Penn State to be used as an extension center, Penn State accepted the offer.

After Penn State accepted WPI's offer for an extension center, the University opened The Wyomissing Center of The Pennsylvania State University and on July 1, 1958 it became the fourteenth commonwealth campus. In the 1960s the school was renamed the Berks Center and almost all baccalaureate degrees were offered to start the first two years there. The campus was renamed again in 1972 to Penn State Berks campus and moved to the 106-acre site in Spring Township. The first four buildings were built between 1972 and 1979, the Luerssen Building, Perkins Student Center Thun Library and the Beaver Community Center, this was the first campus structure.

In the 1980s the campus got a new director, Dr. Frederick H. Gaige, and the campus enrolment increased from 1,092 students to more than 2,000 students over 16 years. The campus continued to grow adding the Franco Building and acquiring a 110-acre farm that in the1990s saw the construction of a greenhouse, a bookstore and athletic fields. In the fall of 1990 the campus added the option for students to reside on campus in the first two years the campus had housing for 400 students.

Another major change came in 1997 when Penn State reorganized its commonwealth campus structure, Penn State Berks merged with Penn State Lehigh Valley to form Penn State Berks-Lehigh Valley College. This merger granted the institution the ability to grant baccalaureate degrees. Berks also added a learning and technology addition to the library during this time.

In the late 1900s and early 2000s Berks added 400 more beds to campus bringing the total resident population to over 800 students. Upon Gaige's retirement in 2001 Dr. Susan Phillips Speece was named dean of the new college, she increased focus on technology and is committed to protecting and preserving the environment to the college. The NCAA accepted the college as a provisional member of NCAA Division III which allowed the students to participate in sports all four years, in 2003. The University decided again in 2005 to reorganize and two-campus colleges returned to being separate campuses, as a result the successful Berks-Lehigh Valley college returned to being Berks and Lehigh Valley campuses. (The Pennsylvania State University, 2010)

7. Proposal Information

For the mechanical redesign I chose to design a closed loop ground source heat pump. An expected savings on energy consumption of 25 – 50% is typical depending on the climate it is implemented in. In South Eastern Pennsylvania I would expect the savings to be closer to 25% than the 50% side of the spectrum. In the proposal it was stated that a comparison was to be done with a similar system put to use in the western Pennsylvania area but due to confidentiality concerns this comparison was unable to be completed.

For the breadth topics I proposed a construction management breadth and an electrical breadth. The construction management breadth is to include a budget and schedule study of the heat pump, due to concerns of the owner the difference in total cost is not able to be published and therefore will be represented in a difference in only the current HVAC system and the proposed system. The schedule analysis will look at how many days difference the heat pump would make in the critical path.

The electrical breadth will include of designing the components of the electrical system that would be needed for the heat pump design. This will also include an evaluation of any other equipment affected by the implementation of the heat pump.

8. Mechanical Redesign

Site

The Berks Classroom and Lab Building is located next to the Thun Library on Penn State Berks Campus see Figure 1 below for exact location. The yellow arrow indicates the general location of the building, while the red oval indicates the general location of the underground storage tanks for the grey water system.

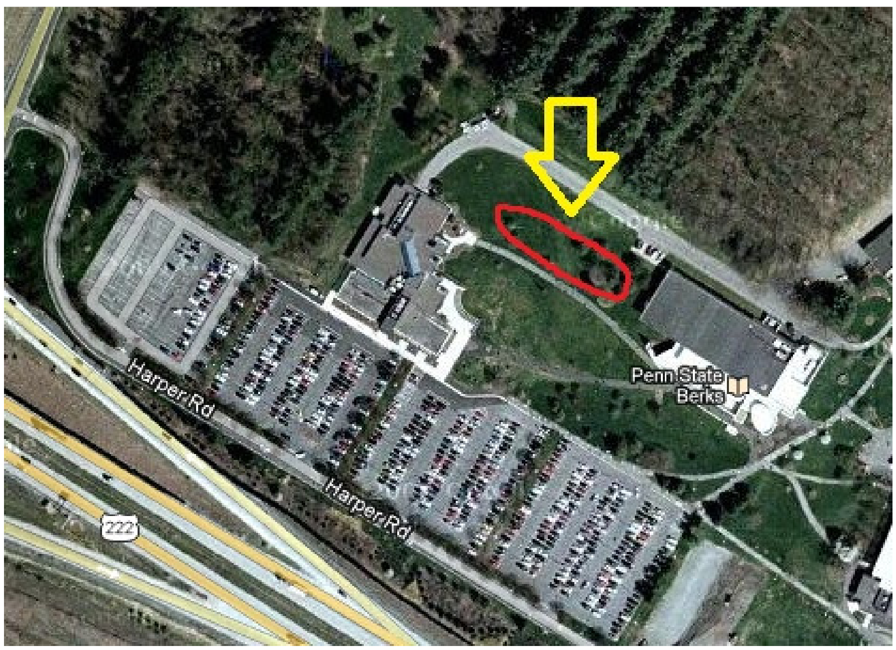

FIGURE 1: LOCATION OF THE BERKS CLASSROOM AND LAB BUILIDING (GOOGLE MAPS)

Since the grey water tanks take up a good portion of the available land directly adjacent to the building on the side of the parking lots, suggested locations for the wells or horizontal pipes would be either between the pathway and the parking lots or in the wooded / brush covered area located in the area above the yellow arrow.

The soil type for the site can be seen in Figure 2 below. The red flag shows the location of Thun Library which is directly adjacent to Berks Classroom and Lab Building.

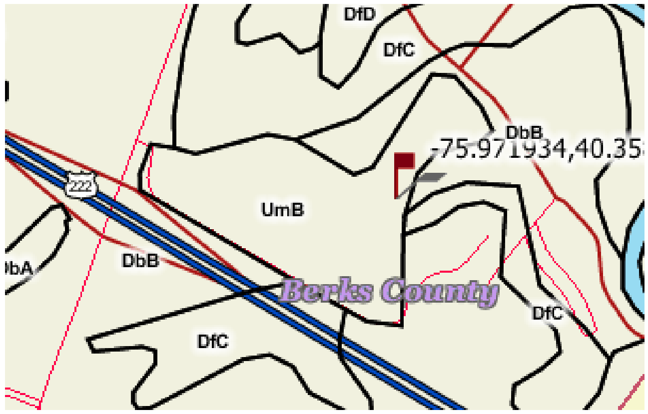

FIGURE 2: SOIL TYPES FOR THE SITE (SOILMAP 2)

The site sits entirely within the soil type of UmB or urban land duffield complex, with an urban land component and a duffield land component.

PROPERTIES AND QUALITIES FOR URBAN LAND

- Slope: 0 to 8 percent
- Depth to restrictive feature: 10 to 100 inches to lithic bedrock
- Available water capacity: Very low (about 0.0 inches)

PROPERTIES AND QUALITIES FOR DUFFIELD LAND

- Slope: 0 to 8 percent
- Depth to restrictive feature: 48 to 120 inches to lithic bedrock
- Drainage class: Well drained
- Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
- Depth to water table: More than 80 inches
- Available water capacity: High (about 10.4 inches)

TYPICAL PROFILE FOR DUFFIELD LAND

- 0 to 10 inches: Silt loam
- 10 to 53 inches: Silty clay loam
- 53 to 72 inches: Silt loam

8.1. DESIGN CONSIDERATIONS

Once a ground source heat pump was chosen as the redesign topic, many things had to be considered such as building size, type of heat pump and total load on heat pump. Since the Berks Classroom and Lab building is just over 62,000 sq. ft., it is well between two examples that were found in the 10th edition of Mechanical and Electrical Equipment for Buildings. There was an example of both a horizontal type of heat pump and a vertical type. The horizontal example was the Wildlife Center of Virginia at Waynesboro that is 5,700 sq. ft. of floor area served by four ground source heat pumps. Two were four ton units and two were five ton units that were connected to 11,350 feet of underground pipe. To accomplish fitting the amount of pipe in the 2,500 feet of trench, it was laid in a "slinky" or spring configuration. This particular configuration for the wildlife teaching-research hospital reduced the estimated 35,000 kWh to 66,000 kWh, just under a 50% yearly savings

The second example is a vertical type ground source heat pump at the Daniel Boone High School near Johnson City, Tennessee. This particular project is 160,000 sq. ft. school was retrofitted with a 320 borehole vertical heat pump. These 320 boreholes have loops of 300 ft on ¾ in. polyethylene pipe and are arranged in section of 20 holes 15 ft. on center with the section being separated by 20 ft. Each loop was connected to an 8 in. supply line to a heat exchanger in the existing mechanical room. This system won the ASHRAE Technology Aware in 1998. (Stein, Reynolds, Grondzik, & Kwok, 2006)

In considering a ground source heat pump, there were several to choose from. The two main types are open loop and closed loop. Within the closed loop there are two main types which deal mostly with the orientation of the pipes either horizontal or vertical and there is a lake or water source.

Since the Berks Classroom and Lab Building is between 5,700 sq. ft. and 160,000 sq. ft. at just over 62,000 sq. ft. A ground source heat pump could supply enough cooling capacity for the square footage of the building.

Considering the location of the site a closed loop would be the best choice. The harder part was choosing the best type of closed loop, each type has its pros and cons see Table 1 for the main points in relation to the site.

TABLE 1: SUMMARY OF THE PROS AND CONS OF HEAT PUMP TYPES

Type of Heat Pump	Pro	Con
Horizontal	• require trenches 3 – 6 feet	• 400 – 600 feet of pipe are needed per ton of capacity
Vertical	• can be used in limited space • holes can be 150 – 450 feet deep	• minimum distance between holes 15 – 25 feet, 20 feet is recommended
Lake or pond	• more rapid heat conduction	• building must be located near the body of water • minimum water level of 8 feet

Since there is no lake or pond near the site, the two choices would be a horizontal or vertical system. I will compare the two on total length of pipe and cost of system. The heat pump would be required to supply 50,399 ton-hours or 604,783 kBtu of capacity to the building, and would be required to reject 2,815,170 ton-hours or 33,782,040 kBtu to the surrounding ground annually, with the peak load being 3,633 tons annually. The Reading, PA area had an average yearly Earth temperature of 66.8 °F to drive the heat exchange between the fluid and the ground. The heat pump would also rely on fluid temperatures, see summary in Table 2 below.

TABLE 2: SUMMARY OF FLUID TEMPERATURES

Temperature Type	Temperature in °F
Average Leaving	63.9
Average Entering	69.8
Minimum Entering	62.5
Maximum Entering	81.5

8.2. Heat Pump Units

Unit Selection

The redesign objective was to keep the existing roof top air handlers and to change the supply to their heating and cooling coils. After comparing units manufactured by Trane and Carrier it became apparent that to meet the loads of the roof top units (RTUs) that multiple pumps would be required. Trane manufactured pumps that were sizes 8 – 15 tons resulting in 31 of the 15 tons units and 3 of the 8 ton units to meet the required load. Carrier manufactured a split system pump that is designed to be used in conjunction with an air handling unit (AHU), but this design is manufactured in sizes of 2 - 5 tons resulting in a total of 89 units.

To determine which manufacturer was used, it was based on the amount of information that was available for each, particularly cost information for the units themselves. In this case multiple independent distributors of Carrier and Trane were contacted and Bovard Heating and Cooling out of Altoona, Pennsylvania was able to supply a price just for the 5 ton Carrier pump introduced in the above paragraph. The cost is not a wholesale cost nor does it include installation of the unit.

Summary of Pump Information

Since the selection was based on which manufacturer was able to supply a cost, this section supplies a summary of information used in calculating the number of pumps needed, all information referring to the geothermal pump is based on Carrier information.

TABLE 3: LOAD AND UNIT SUMMARY

AHU	Load in tons	Number of units @ Capacity	Model Numbers
RTU-1	281.3	• 57 @ 5 Tons	• 50YDS064NCP301
RTU-2	98.7	• 20 @ 5 Tons	• 50YDS064NCP301
RTU-3	59.1	• 12 @ 5 Tons	• 50YDS064NCP301

To meet the required loads you would need a total of 89 50YDS064NCP301 units. The cost for one of these units is $6,066.00; Table 4 summarizes the cost per RTU.

TABLE 4: SUMMARY OF COST BY RTU

RTU	Quantity of Pumps	Cost per Pump	Total Cost
RTU-1	57	$6,066	$345,762
RTU-2	20	$6,066	$121,320
RTU-3	12	$6,066	$72,792
Total	**89**		**$539,874**

PUMP REQUIREMENTS

The Carrier pump model number 50YDS064NCP301 has one Copeland UltraTech Two-Stage Scroll compressor and use 168 ounces of Puron refrigerant. This particular unit requires a 1-1/8 inch vapor line sweat connection and a ½ inch liquid line sweat connection and while operating weighs 265 pounds. Water connections for this unit require 1 inch Swivel connection and the refrigerant connections are 5/8 inch connections.

8.3. PIPE REQUIRED

For a horizontal heat pump the minimum length of pipe required would be 175,640 feet with the maximum being 263,460 feet. For a vertical heat pump the minimum length of pipe is 146,420 feet with the maximum being 409,860 feet, assuming a range of 150 – 250 feet of borehole per ton and the total length of pipe would be twice that since the pipe has to go down and come back up.

The next part was to choose the type of pipe to use for the heat pump. The piping usually used for HVAC equipment within buildings is typically made of copper or steel, the metal does not seem to be the best to be buried underground with a solution flowing through them due to corrosion. The standard ground piping for heat pumps that seems to be ¾ in. polyethylene pipe, which is a thermoplastic. The cost for polyethylene pipe is $42.08 per 100 foot of ¾" pipe and $96.10 per 100 foot of 1" pipe. See Table 5 for a summary of costs per 100 foot of pipe prices are subject to change and were collected at Lowes located at 2100 Washington Pike Carnegie, PA on Friday 17 February 2012 for the ¾ inch pipe and on Grainger, Inc.'s website on 19 March 2012 for the 1 inch pipe (W.W. Grainger, Inc).

TABLE 5: SUMMARY OF COSTS PER FOOT OF PIPE

Diameter of Pipe	Cost per 100 foot of pipe
3/4 inch	$ 42.08
1 inch	$96.10

The other point that needs to be taken in to consideration for the pipe is that the required connection for the units is 1 inch. The 1 inch diameter pipe would be run along the top of the boreholes for the vertical layout of pipe and in the horizontal layout would run the entire length of pipe. See Table 6 for the total cost for the horizontal minimum, horizontal maximum, vertical minimum and vertical maximum.

TABLE 6: TOTAL COST FOR PIPE

	Length of Pipe	Pipe Dia.	Cost per 100 foot of Pipe	Total Cost of Pipe
Horizontal Minimum	175,640 ft	1 in	$ 96.10	$ 168,790.04
Horizontal Maximum	263,460 ft	1 in	$ 96.10	$ 253,185.06

Vertical Minimum	131,750 ft	¾ in	$ 42.08	$ 55,440.40
	14,670 ft	1 in	$ 96.10	$ 14,097.87
Vertical Maximum	395,190 ft	¾ in	$ 42.08	$ 166,295.95
	14,670 ft	1 in	$ 96.10	$ 14,097.87

In this situation it would seem basted on cost alone the vertical configuration would be the better choice. There is another consideration to look at since the depth of soil to rock is a maximum of 120 inches the vertical layout is not feasible in this area so a horizontal layout of pipe is required. The cost of pipe for this layout is between $168,790.04 and $253,185.06 since this area a geothermal heat pump is not used very often, the total pipe layout will be the maximum.

While determining the excavation time for the horizontal configuration it was found that doing a double layer of the same distance of pipe was going to 80 days and a single layer would take 96 days, since excavation equipment is expensive it was decided that a double layer of pipe would be installed. The lower layer being at 5 feet below grade and the upper layer being at 3 feet below grade, these distances are below the approximated 32 inches for the frost line in the area and above the approximated 10 feet to rock.

8.4. BUILDING ENERGY USAGE

It was assumed in the proposal that a ground source heat pump could save a building 25 – 50% on energy consumption depending on the climate the building is located in. Since the building is located near Reading, Pennsylvania it was assumed that the savings would be closer to the 25% than the 50%.

Using Trane Trace to analyze both the original roof top units and the proposed ground source heat pump redesign it was found that the building would use less energy, see Table 7 and Table 8 for the summary of energy usage for both.

TABLE 7: ENERGY CONSUMPTION OF ORIGINAL SYSTEM

Load	Electrical Consumption (kWh)	Gas Consumption (kBtu)	Total Building Energy (kBtu/yr)	% of Total Building Energy
Heating				

Primary Heating		903,312	903,312	3
Other Accessories	18,118	-	61,836	0.2
Cooling				
Compressor	1,920,466	-	6,554,551	21.6
Condenser Fans	250,438	-	854,711	2.8
Cooling Accessories	876	-	2,990	0.0
Lighting	3,924,145	-	13,393,105	44.2
Receptacle	2,506,134	-	8,553,434	28.2
Totals	8,620,166	903,312	30,323,938	

TABLE 8: ENERGY CONSUMPTON PROPOSED REDESIGN

Load	Electrical Consumption (kWh)	Gas Consumption (kBtu)	Total Building Energy (kBtu/yr)	% of Total Building Energy
Heating				
Primary Heating	43,269	-	147.677	0.6

Other Accessories	7	-	23	0
Cooling				
Compressor	1,336,404	-	4,561,148	17.1
Condenser Fans	-	-	-	0
Cooling Accessories	212	-	724	0.0
Auxiliary				
Pumps	2,608	-	8,902	0
Lighting	3,924,145	-	13,393,105	50.2
Receptacle	2,506,134	-	8,553,434	32.1
Totals	7,812,779	-	26,665,013	

As you can see from the tables above the original design uses 30,323,938 kBtu/yr and the proposed redesign uses only 26,665,013 kBtu/yr, a total reduction of 3,658,952 kBtu/yr which is about a 12% reduction in total building energy usage. The primary reduction came in the heating and cooling categories since the building's lighting and receptacle loads remained the same in both analysis. The proposed redesign also eliminates the use of gas in the heating component of energy consumption. In Table 9 and

Table 10 we get the original and proposed operation costs for the Berks Classroom and Lab Building broken down by system.

TABLE 9: ORIGINAL DESIGN COST SUMMARY

Load	Electrical Consumption ($)	Gas Consumption ($)	Total Building Energy ($/yr)
Heating			
Primary Heating		6.77	6.77
Other Accessories	1,845.32	-	1,845.32
Cooling			
Compressor	195,599.46	-	195,599.46
Condenser Fans	25,507.11	-	25,507.11
Cooling Accessories	89.23	-	89.23
Lighting	399,674.17	-	399,674.17
Receptacle	255,249.75	-	255,249.75
Totals	877,965.04	6.77	**877,971.81**

TABLE 10: PROPOSED DESIGN COST SUMMARY

Load	Electrical Consumption ($)	Gas Consumption ($)	Total Building Energy ($/yr)
Heating			

Primary Heating	4,406.95	-	4,406.95
Other Accessories	0.73	-	0.73
Cooling			
Compressor	136,112.75	-	136,112.75
Condenser Fans	-	-	-
Cooling Accessories	21.60	-	21.60
Auxiliary			
Pumps	265.63	-	265.63
Lighting	399,674.17	-	399,674.17
Receptacle	255,249.75	-	255,249.75
Totals	795,731.31	-	**795,731.31**

From Table 9 and Table 10 we see that with the implementation of the ground source heat pump the total building operation costs drop $82,240.50 per year. In Table 11 we see the operation cost per square foot summarized for the original and proposed designs. We see that the operation costs drop $1.32 about a 9% reduction in operation costs between the two systems.

TABLE 11: COST PER SQUARE FOOT SUMMARY

Design	Cost per Square foot

Original	$ 14.12
Proposed	$ 12.80

In order to figure out if the system is worth the initial investment is to look at the payback period for the proposed system. Since the proposed system in generally the same except for the pumps and all the work that goes with it, the payback period is calculated by using the total cost for the pumps, underground piping, excavation work, and electrical work this cost was taken from the construction management breadth cost analysis. The net annual cash flow was calculated by subtracting the proposed system annual design cost from the existing system annual design cost resulting in a savings of $82,240.50 per year.

$$Payback\ period = \frac{Investment\ Required}{Net\ Annual\ Cash\ Flow}$$

$$Payback\ Period = \frac{\$\ 3{,}039{,}707.31}{\$\ 82{,}240.50\ /year}$$

The payback period for this particular system configuration would be about 37 years.

8.5. Proposed System Recommendations

The proposed system in its entirety would not fit within the existing mechanical room; only 17 of the 89 pumps will fit. The recommendation for the remaining 72 pumps is to either enclose space adjacent to the mechanical space or enclosing either the upper or lower roof space.

In a brief analysis using only the major equipment located on the lower roof and the size of the pumps it is possible that all 72 pumps will fit in this space. A structural analysis would need to take place to prove that the building is structurally able to support the combined weight of the pumps as well as additional facade and support structure. A structural analysis was outside the scope of my proposal. Appendix B has diagrams of the proposed locations of the pumps.

9. Proposed Electrical Breadth

This breadth is to include sizing of wire needed to operate the geothermal system and all electrical equipment needed to operate the 89 pumps needed.

9.1. Power Distribution

The proposed geothermal system requires a large number of pumps, when the pumps turn on they draw a substantial amount of power to start up. There are a few ways to manage this number of pumps the two easiest ways would be to customize a motor control center (MCC) or use multiple panels. The number of panels is determined by how may circuits it can hold; most have a maximum of twenty single phase circuits. Based on the electrical data provide from Carrier summarized in Table 12 and that most panels have a maximum of twenty circuits a minimum of five panels will be needed to supply electricity and protect the pumps. The panels selected are I-line power distribution panelboards manufactured by SqurareD by Schneider Electric.

TABLE 12: PUMP ELECTRICAL DATA

Model	Compressor			HWG Pump FLA	External Pump FLA	Total Unit FLA	Min Circuit Amps	Max Fuse/ HACR (2)	Supply Wire (2)	
	RLA	LRA	Qty						Min AWG	Max Length ft. (3)
064	25.6	118.0	1	0.4	4.0	30	36.4	60	8	81

The wire size was found by using the full load amps (FLA) listed in the table above and Table 310.16 from NEC 2008 came out to be 10 AWG. The minimum circuit Amps exceeds the 30 FLA listed therefore since 30 Amps is the maximum load to be carried by 10 AWG the wire size minimum must be 8 AWG. The total wire needed for the new system is 3,693.5 linear feet and costs $ 176 per 125 feet price found at Lowes located at 2100 Washington Pike Carnegie, PA on Friday 17 February 2012 and is subject to change.

10. Proposed Construction Management Breadth

In this breadth I proposed to complete a cost and schedule analysis for the proposed redesign of the HVAC system. In the HVAC analysis it was discovered that the existing system was sufficient to meet the load of the Berks Classroom and Lab Building. This will then focus on the cost and schedule impact of the proposed geothermal system and its components.

10.1. SCHEDULE ANALYSIS

Scheduling of activities in construction is of great importance, especially when a project is fast tracked. This activity of the greatest importance in this installation is the lifting of the pump into place. There is both an interior and an exterior component to this particular model. It is intended that the interior units be placed within the existing mechanical room, but due to the amount of units required they will not all fit. A solution to this problem would be to expand the existing mechanical space or enclose the lower roof and place the units there. In order to place the units on the roof a detailed structural analysis would have to be complete and this would increase material costs all around and included new ones.

Duration calculations and proposed schedule can be found in Appendices A & C respectively the interior units would need to be completed prior to the start of the close in of the building's façade on 7 December 2010 per the original schedule. Since this problem was discovered late in the semester the calculations do not take this in to consideration and assume that all units are located within the existing mechanical space. With the limited mechanical space within the building only 17 pumps can be accommodated leaving the other 72 to be located within mechanical penthouses created on the lower roof.

The amount of time needed for each material is summarized in Table 13 and the amount of time the equipment is on site is summarized in Table 14.

TABLE 13: INSTALLATION TIME FOR MATERIALS

Material	Amount	Total Time
1" PE Pipe	2,179,800 LF	1,099 Days
Carrier Units	89 Units	81 Days
Excavation work	127,055 CY	80 Days
Wire	3,693.50 LF	47 Days
Panels	5 Panels	4 Days

TABLE 14: SUMMARY OF EQUIPMENT AND TIME USED

Equipment	Total Used	Total Time
Excavator	1	80 Days
Dozers	6	79 Days
Crane	1, 25 Ton	103 Days Rented 89 Days on Site

The critical item for the items listed above will be the lifting of the pumps into place. This will be the critical item because everything else can be done once the building is enclosed; the units are too big to be put into place after the building is enclosed. The panels and wire need walls to be in place prior to be installed. The entire installation can be done in 1,099 days that it takes to install the pipe, assuming no inclement weather.

10.2. Cost Analysis

To obtain a cost summary of the proposed geothermal installation, MC2 was used to estimate material and labor costs that were not otherwise known. The cost summary includes the horizontal PE piping, 89 geothermal pumps, electrical work and all site work, including equipment. Some assumptions were made to make the estimate go a little smother and are listed below,

- Equipment used:
  - 1 Excavator
    - Bucket size: 3 cubic yards (cy)
    - Cycle time: 1.13 minutes
    - Cost: $ 2,867 / day
  - 2 Dozer
    - Each dozer moves: 270 cy / day to stockpile
    - Cost per dozer: $ 1,328 / day
- Swell factor is 25%
- Crews work 10 hr days
- Stockpile is on site located in the nearby parking lot
- Cost of electrical equipment from electrical breadth
  - 3' extra for panels
  - top of panels mounted at 5' above finished floor
  - 3' of wire between indoor and outdoor units

- 1’ extra for unit connections
- MC cable is used

- Pipe used is 1 inch Polyethylene pipe

Table 15 summarizes the material take offs for the proposed systems. These take offs are what the estimate costs and schedule calculations are based on.

TABLE 15: MATERIAL TAKE OFFS

Material	Amount	Units
1” PE Pipe	263,460	Linear Feet
Carrier 50YDS, 5 ton Unit	89	Each
Excavation work	127,055	Cubic Yards
Wire	3,693.50	Linear Feet
Panels	5	Each

The final cost for material is $1,655,560.86 and a total installation cost of $1,297,905 for all of the materials listed above.

Table 16 and Table 17 show the costs used to determine the total material and installation costs.

TABLE 16: MATERIAL COSTS

Material	Amount	Unit Cost	Total Cost
1” PE Pipe	263,460LF	$ 0.961/ LF	$ 253,185.06
Carrier 50YDS, 5 ton Unit	89 Units	$ 6,066 / Unit	$ 539,874
Excavation work	127,055 CY	$ 6.74 / CY	$ 856,276

Wire	3,693.50 LF	$ 176 / 125 LF	$ 5,200.45
Panels	5 Panels	$ 205.07 / Panel	$ 1,025.35
Total			**$ 1,655,560.86**

TABLE 17: INSTALLATION COST

Material	Amount	Labor	Crew	Total Time	Cost	Total Cost
1" PE Pipe	2,179,800 LF	79.923 LF / Day / Plumber	3 Plumbers	1,099 Days	$33.25 / Hr / Plumber	$1,096,252.50
Carrier 50YDS, 5 ton Unit	89 Units	9 Hrs / Unit	1 HVAC tech	81 Days	$ 33.25 / hr	$ 26,932.50
Excavation work	127,055 CY	1 Excavator 6 Dozers	1 driver 6 drivers	80 Days 79 Days	$28.50 / driver / hr (both types)	$ 22,800 $ 135,090
Wire	3,693.50 LF	79.923 LF / Day / Electrician	1 Electrician	47 Days	$ 33.00 / hr/ electrician	$ 15,510
Panels	5 Panels	8 hrs / panel	1 Electrician	4 Days	$ 33.00 / hr/ electrician	$ 1,320
Total						**$ 1,297,905**

There is one other major cost associated with this installation are equipment costs. The equipment used in these calculations is 6 dozers, 1 excavator and 1 crane. The costs for the dozers per day and the excavator per day are listed above. It is assumed that a crane will be on site for the major mechanical equipment installation and that this crane would be dedicated for this scheduled activity. The crane is assumed to be a 25 ton crawler crane with costs assumed to be $ 1,990 / week with a crew that cost $ 640 / day. Other items assumed are 2 weeks for transportation of the crane, set up and dismantling 8 days for both. The total cost for the crane to do the installation of the proposed system is $ 86,241.45 and a summary of calculations can be seen in Table 18.

TABLE 18: CRANE CALCULATIONS

Activity	Time	Cost
Transportation To site	1 Week	$ 1,990
Set up	Crane: 4 Days = .6 week Crew: 4 Days	$ 1,137.15 $ 2,560
Set units	Crane: 81 Days = 11.6 Weeks Crew: 81 Days	$23,027.15 $ 51,840
Dismantle	Crane: 4 Days = .6 week Crew: 4 days	$ 1,137.15 $ 2,560
Transportation From Site	1 week	$ 1,990
Total Cost		**$ 86,241.45**

The total upfront cost for this system is $ 3,039,707.31. This cost includes the cost for installation, including the equipment needed for installation, and major material costs.

11. CONCLUSIONS

During the analysis process it was found that it would be possible to meet the load of the building three main RTUs by using 89 Carrier 5 ton split system ground source heat pumps. This analysis was performed using Trane Trace software. The addition of the units resulted in a yearly savings of $82,240.50 with an upfront cost of $ 3,039,707.31 resulting in a payback period of about 37 years.

The proposed electrical work is to use a minimum of 5 distribution panels to manage the 89 pumps needed. There is an estimated minimum 3,693.50 LF of size 8 AWG wire needed to properly wire the 89 units. This number can be affected by waste at the site by the electricians, the waste can be from what needs to be cut to fit in the boxes and how long the wire can go without a junction point.

The critical item of the proposed system is the placement of the units. This would need to be complete by 7 December 2010 which is the start of the facade close in. The pipe work is estimated to take 1,099 days or just over 3 years to install, the maximum time for other work is estimated to take 81 days. The 1,099 days seems to be extraneous. The pipe installation would extend the schedule by 3 years and would greatly impact campus life. The biggest impact on the cost estimate for material is the excavation work; this does not include that cost to for the crews to operate the equipment. The biggest cost for installation is for the pipe. The total cost for the proposed system with assumptions stated is $ 3,039,707.31.

Recommendations for the proposed system is not to implement it for all RTU but to implement it for RTU – 3 or possible the existing CRAC unit. To implement the entire proposed system would cost the university a lot more time and money ultimately someone has to pay for it. Weather it is the tuition dollars or a donor that pays for it.

12. Revised Work

12.1. Revised Heat Pump Units

Revised Unit Selection

Upon realizing that the one of the coils for the above mentioned split system would need to be located inside the air handler this option would not be applicable for this application. There are three options to explore in correcting this over site, one would be to locate the above mentioned units throughout the building and duct to the VAV terminal units, the second one is to replace the 89 units with a water to water heat exchanger with a higher capacity and connect them to the RTUs located on the lower roof of the building and third is to implement a water loop with multiple water to air heat pumps that would be located throughout the building that only provide 100% ventilation air.

The option to be explored for this will be to eliminate the 89 units initial recommended and replace their capacity with a WaterFurnace Envision Series Reversible Chiller, connecting to the existing VAV boxes.

Revised Summary of Pump Information

Since cost is not the driving factor in this selection, the driving factor is the capacity of the unit and how many units will be required to meet the load. Table 19 shows the revised load and unit summary.

TABLE 19: REVISED LOAD AND UNIT SUMMARY

AHU	Load in tons	Number of units @ Capacity	Model Numbers Abbreviated
RTU-1	281.3	• 6 @ 50 Tons	• NXW540
RTU-2	98.7	• 2 @ 50 Tons	• NXW540
RTU-3	59.1	• 1 @ 50 Tons • 1 @ 10 Tons	• NXW540 • NXW120

To meet the required load for each unit a total of 9 NXW540 units would be required as well as 1 NXW120 units, if the loads were grouped together for a total building load of 439.1 Tons only the 9 NXW540 units would be required.

Since Pennsylvania weather varies throughout the year there could be times that both heating and cooling would need to take place this could be dealt with by using a 4 pipe loop system to the RTUs and terminal VAV boxes or by a 2 pipe loop requiring draining of the system between each season. Each option has its advantages and each has its disadvantages. See Table 20 below for a summary of each.

TABLE 20: SUMMARY OF THE PROS AND CONS OF A 4 PIPE AND A 2 PIPE LOOP APPROACH

Solution	Pro	Con
4 pipe loop	• can heat and cool at the same time • less maintenance required	• double units used
2 pipe loop	• less equipment need	• requires more maintenance

Since the ground temperature remains approximately constant year round and the University Park campus uses the seasonal draining for at least the East View residence area on campus a 2 pipe loop is chosen. This solution will require operable windows in the building to help maintain comfortable temperatures with the assistance of thermostats provided in the locations on the original plans.

Revised System Description

The revised system will eliminate the RTUs and supply either chilled or hot water to the VAV boxes within the space via a water loop. This set up will require the same amount of exterior piping and will require interior piping as well. The interior piping would need to accommodate flow rate ranging from 0.5 - 1.0 GPM and the connecting diameter is determined by the connections on the VAV boxes serving building spaces.

The VAV boxes would be served by the interior piping creating a loop throughout the building. This set up would allow for the elimination of one 6.2 gallon boiler and 3 of the hot water pumps in the mechanical room, it would also allow the reduction in size of the other boiler and 2 hot water pumps since they would only be responsible to cover the load of the domestic hot water system.

Since this set up only allows either chilled or hot water to pass through the system at any given time there are a few ways to deal with part load situations. The more expensive way would be to double the equipment and piping for the system creating a 4-pipe water loop which would require much more space and possibly the addition of supplemental equipment or the part load could be dealt with by the 2-pipe system where the occupants would have to open a window.

12.2. Revised Pipe Required

The connections on the reversible chiller are all 2 inch connections, thus meaning a vertical pipe configuration would require 14,670 feet of 2 inch PE pipe and 395,190 feet within boreholes. For the borehole piping ¾" pipe seemed to be a typical size, since the connections are 2" this would be the interior diameter with a 2 1/4" outer diameter. Pricing seen in Table below was found on Grainger's website on 25 April 2012 and will give an idea for total material cost, pricing for the ¾" pipe can be found in Table 5.

TABLE 21: 2 INCH POLYETHYLENE PIPE COST

Tubing	Cost per 100 ft
Excelon, 7242A10	$ 295.00
Excelon, 7242A10BK	$ 300.50

This would increase the material cost for the pipe in the vertical configuration going with the calculations from Table 6 adjusting for the 2" PE pipe with the above costs see Table 22 below for material costs.

TABLE 22: PIPE COST FOR REVISED SYSTEM

	Length of Pipe	Cost per 100 foot of Pipe	Total Cost of Pipe

¾" PE Pipe	395,190 ft	$ 42.08	$ 166,295.96
2" Natural PE Pipe	14,670 ft	$ 295.00	$ 43,276.50
2" Black PE Pipe	14,670 ft	$ 300.50	$44,083.35

With the cost of the 2" pipe differencing in price by $5.50 there is not much difference in choosing natural coloring or black coloring thus the maximum cost being $ 209,572.45 and the minimum being $ 210,379.30. The difference being $806.85 a reduction of less than 1% of the maximum cost not a big difference in the total cost of materials.

12.3. Revised Building Energy Usage

From Table 7 and Table 10 above we see the original system's annual energy usage and cost information. The revised system's annual energy usage and cost were obtained using Trane Trace, in Table 23 and Table 24 below a summary of the analysis can be viewed.

TABLE 23: REVISED ANNUAL ENERGY USAGE

Load	Electrical Consumption (kWh)	Gas Consumption (kBtu)	Total Building Energy (kBtu/yr)	% of Total Building Energy
Heating				
Primary Heating	46,589	$4745.09	159,010	0.6
Other Accessories	6	$0.62	22	0
Cooling				
Compressor	1,547,147	$157,576.92	5,280,414	19.3

Condenser Fans	-	-	-	0
Cooling Accessories	213	$21.70	726	0.0
Auxiliary				
Pumps	-	-	-	0
Lighting	3,924,145	$399,674.17	13,393,105	48.9
Receptacle	2,506,134	$255,249.74	8,553,434	32.1
Totals	8,024,234		27,386,709	

TABLE 24: REVISED ANNUAL COST

Load	Electrical Consumption ($)	Gas Consumption ($)	Total Building Energy ($/yr)
Heating			
Primary Heating	4,745.09	-	4,745.09
Other Accessories	0.62	-	0.62
Cooling			
Compressor	157,576.92	-	157,576.92

Condenser Fans	-	-	-
Cooling Accessories	21.70	-	21.70
Auxiliary			
Pumps	-	-	-
Lighting	399,674.17	-	399,674.17
Receptacle	255,249.74	-	255,249.74
Totals	816,668.24	-	**816,668.24**

The original design uses 30,323,938 kBtu/yr and the revised system only uses 27,386,709 kBtu/yr a total energy savings of 2,937,219 kBtu/yr. The revised system eliminates the use of gas in the HVAC system. The original design costs $ 877,971.81 per year to run and the revised system costs $ 816,668.24 per year to run, this results in an operational savings of $61,249.57 per year. The operational costs per square foot can be seen in Table 25 below.

TABLE 25: REVISED OPERATIONAL SQUARE FOOT COST

Design	Cost per Square foot
Original	$ 14.12
Revised	$ 13.14

This results in a savings of about $1 per square foot, only about a 6% energy savings.

Revised Simple Payback Period

The revised simple payback period is calculated by using a reference chart found on ClimateMaster's website pertinent information is located below as Table 26.

TABLE 26: SUMMARY OF SYSTEM COMPARISON MAINTENCE AND INSTALLATION COST PER SQUARE FOOT

System	Annual Maintenance Expense	Installation Cost
Geothermal Heat Pump	$ 0.07 / sq.ft. yr	$ 10.00 / sq.ft.
VAV	$ 0.14 / sq.ft. yr	$ 9.00 /sq. ft.

This is only an estimated cost since cost information was not readily available on either system. In comparison just by looking at the chart the geothermal system has a high first cost but a lower annual maintenance cost. The total estimated installation cost and annual maintenance expense for both systems is summarized in Table 27 below.

TABLE 27: ESTIMATED COSTS FOR SYSTEMS

System	Annual Maintenance Expense	Installation Cost
Geothermal Heat Pump	$ 4,353.16 /. yr	$ 621,880
VAV	$ 8,706.32 / yr	$ 559,692

Below you can see the simple payback period calculations.

$$Payback\ period = \frac{Investment\ Required}{Net\ Annual\ Cash\ Flow}$$

$$Payback\ Period = \frac{\$\ 621{,}880}{\$\ 61{,}249.57\ /year}$$

This is just biased on the equipment not any other breadth work, and results in a simple payback of about 10 years.

Revised Life Cycle Costs

The above information in Table 27 was used to do a life cycle cost for the revised system. This can be seen below in Table 28. This was done over the calculated simple payback period.

TABLE 28: LIFE CYCLE COST

	Revised System	Revised System Savings	Totals
First Cost	$621,880.00		$621,880.00
Year 1 Maintenance	$4,353.16	($61,249.57)	$564,983.59
Year 2 Maintenance	$4,353.16	($61,249.57)	$508,087.18
Year 3 Maintenance	$4,353.16	($61,249.57)	$451,190.77
Year 4 Maintenance	$4,353.16	($61,249.57)	$394,294.36
Year 5 Maintenance	$4,353.16	($61,249.57)	$337,397.95
Year 6 Maintenance	$4,353.16	($61,249.57)	$280,501.54
Year 7 Maintenance	$4,353.16	($61,249.57)	$223,605.13
Year 8 Maintenance	$4,353.16	($61,249.57)	$166,708.72
Year 9 Maintenance	$4,353.16	($61,249.57)	$109,812.31
Year 10 Maintenance	$4,353.16	($61,249.57)	$52,915.90

Year 11 Maintenance	$4,353.16	($61,249.57)	($3,980.51)

In year 11 Penn State would start seeing the savings of the revised proposed system. Since the savings seen in year 11 is just about $ 4,000 and as long as there is no extreme malfunctions or need to replace the reversible chiller system the savings would continue to go up.

12.4. Revised System Recommendations

The revised system would require a total of 10 units with 9 of them being 50 Ton units and 1 being a 10 Ton unit. The units are reversible chillers manufactured by Water Furnace the units are approximately 24" by 53" and about 6' in height. A revised spatial analysis can be found in Appendix B. It would also be recommended that a geology study be completed to investigate the ability to put in a vertical exterior pipe configuration.

12.5. Revised Conclusions

During the re-analysis process it was discovered that 10 reversible chillers could meet the 439.1 ton load that was originally met by the 3 RTUs. The amount of pipe needed for the vertical configuration would be 409,860 linear feet. The vertical pipe configuration would require 440 boreholes at 450 feet in depth, this would use a total of 396,000 linear feet, and in turn upping the cost of the ¾' pipe to $ 169,488.

Changing the horizontal piping to vertical piping will affect the construction cost a drill would need to be priced. The drill would need to have the capability to drill through bedrock, and have a crew on site this would increase the installation costs and equipment costs directly. The excavation cost would ultimately be lower because there would be less dirt to be excavated and moved.

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14. Appendix A

14.1. Pipe Length Calculations

Mueller

Mueller Associates, Inc.
Consulting Engineers

Project: Brooks Classroom & Lab Building
Project No:
Subject: Pipe Length + Boreholes
Computed by: JAB Date: Feb. 1, 2012

Minimum Pipe Length: Horizontal

400 feet/ton (439.1 ton) = 175,640 ft

Maximum Pipe Length: Horizontal

600 feet/ton (439.1 ton) = 263,460 ft

Minimum Pipe Length: Vertical

150 ft of borehole/ton (439.1 ton)(2 ft of pipe / 1 ft of borehole) = 131,750 ft

Maximum Pipe Length: Vertical

450 ft of borehole/ton (439.1 ton)(2 ft of pipe / 1 ft of borehole) = 395,190 ft

Number of boreholes: minimum pipe length

65,865 ft (borehole / 150 ft) = 440 boreholes

65,865 ft (borehole / 450 ft) = 147 boreholes

Number of boreholes maximum pipe length

197,595 ft (borehole / 150 ft) = 1,318 boreholes

197,595 ft (borehole / 450 ft) = 440 boreholes

14.2. EXCAVATION CALCULATIONS

Excavation for Single Layer of Pipe

Area = $\frac{2,500 \text{ ft}^2}{\text{ft}}$ (439.1 ft) = 1,097,750 ft²   swell factor = 25%

depth = 3'

$1,097,750 \text{ ft}^2 (3 \text{ ft}) \left(\frac{1 \text{ cy}}{27 \text{ ft}^3}\right) = 121,973 \text{ cy} (1.25) = 152,466 \text{ Lcy}$

$152,466 \text{ Lcy} \left(\frac{1 \text{ pass}}{3 \text{ cy}}\right)\left(\frac{1.13 \text{ min}}{1 \text{ pass}}\right)\left(\frac{\text{hr}}{60 \text{ min}}\right)\left(\frac{\text{day}}{10 \text{ hr}}\right)$ = 96 days for excavator

$152,466 \text{ Lcy} \left(\frac{\text{day dozer}}{270 \text{ cy}}\right)\left(\frac{1}{6 \text{ dozers}}\right)$ = 95 days for 6 dozers

Cost for Excavator

$1 \text{ excavator} (96 \text{ days})\left(\frac{\$2,867}{\text{Excavator day}}\right) = \$275,232$

Cost for dozers

$6 \text{ dozers} (95 \text{ days})\left(\frac{\$1,328}{\text{dozer day}}\right) = \$756,960$

Total = $1,032,192

Excavation for Double Layer of Pipe

Area = $\frac{2,500 \text{ ft}^2}{\text{ft}}$ (439.1 ft)$\left(\frac{1}{2}\right)$ = 548,875 ft²   depth = 5'   swell = 25%

$548,875 \text{ ft}^2 (5 \text{ ft})\left(\frac{1 \text{ cy}}{27 \text{ ft}^3}\right)(1.25) = 127,055 \text{ Lcy}$

$127,055 \text{ Lcy} \left(\frac{1 \text{ pass}}{3 \text{ cy}}\right)\left(\frac{1.13 \text{ min}}{1 \text{ pass}}\right)\left(\frac{\text{hr}}{60 \text{ min}}\right)\left(\frac{\text{day}}{10 \text{ hr}}\right)$ = 80 days for excavator

$127,055 \text{ Lcy} \left(\frac{\text{day dozer}}{270 \text{ cy}}\right)\left(\frac{1}{6 \text{ dozers}}\right)$ = 79 day for 6 dozers

Cost for Excavator

$1 \text{ Excavator} (80 \text{ days})\left(\frac{\$2,867}{\text{Excavator day}}\right) = \$229,360$

Cost for 6 dozers

$6 \text{ dozers} (79 \text{ days})\left(\frac{\$1,328}{\text{dozer day}}\right) = \$629,472$

Total = $858,832

14.3. INSTALLATION COST AND TIME

Time for Installation

1" Pipe

263,460 ft $\left(\frac{\text{day crew}}{77.123 \text{ ft}}\right)\left(\frac{1}{3 \text{ CM}}\right)$ = 1,099 days

SOYDS units

89 units $\left(\frac{9 \text{ hr}}{\text{unit}}\right)\left(\frac{\text{day}}{10 \text{ hr}}\right)$ = 81 days

Wire

3,693.5 LF $\left(\frac{\text{day}}{79.125 \text{ LF}}\right)$ = 47 days

Panels

5 panels $\left(\frac{8 \text{ hr}}{\text{panel}}\right)\left(\frac{\text{day}}{10 \text{ hr}}\right)$ = 4 days

Cost of Installation

1" Pipe

3 CM (1,099 days) $\left(\frac{10 \text{ hr}}{\text{day}}\right)\left(\frac{\$33.25}{\text{hr-CM}}\right)$ = $1,096,252.50

SOYDS units

81 days $\left(\frac{10 \text{ hr}}{\text{day}}\right)\left(\frac{\$33.25}{\text{hr}}\right)$ = $26,932.50

Wire

47 days $\left(\frac{10 \text{ hr}}{\text{days}}\right)\left(\frac{\$33.00}{\text{hr}}\right)$ = $15,510.00

Panels

4 days $\left(\frac{10 \text{ hr}}{\text{days}}\right)\left(\frac{\$33.00}{\text{hr}}\right)$ = $1,320.00

Excavation

80 days $\left(\frac{10 \text{ hr}}{\text{day driver}}\right)$ (1 driver) $\left(\frac{\$28.50}{\text{hr}}\right)$ = $22,800.00

47 days $\left(\frac{10 \text{ hr}}{\text{day driver}}\right)$ (6 drivers) ([illegible]/hr) = $135,040

Total Cost

$1,096,252.50 + $26,932.50 + $15,510 + $1,320 + $22,800 + $135,040

= $1,297,905

15. Appendix B

15.1. Mechanical Space Layout

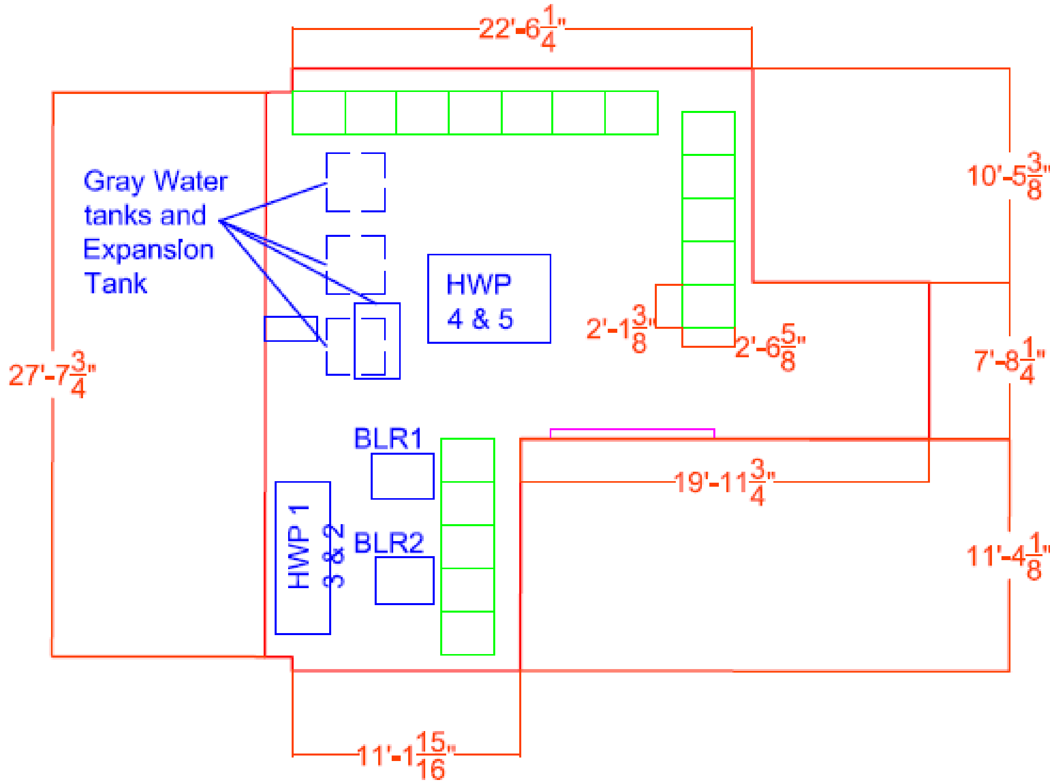

FIGURE 3: MECHANICAL ROOM LAYOUT

15.2. Revised Mechanical Layout

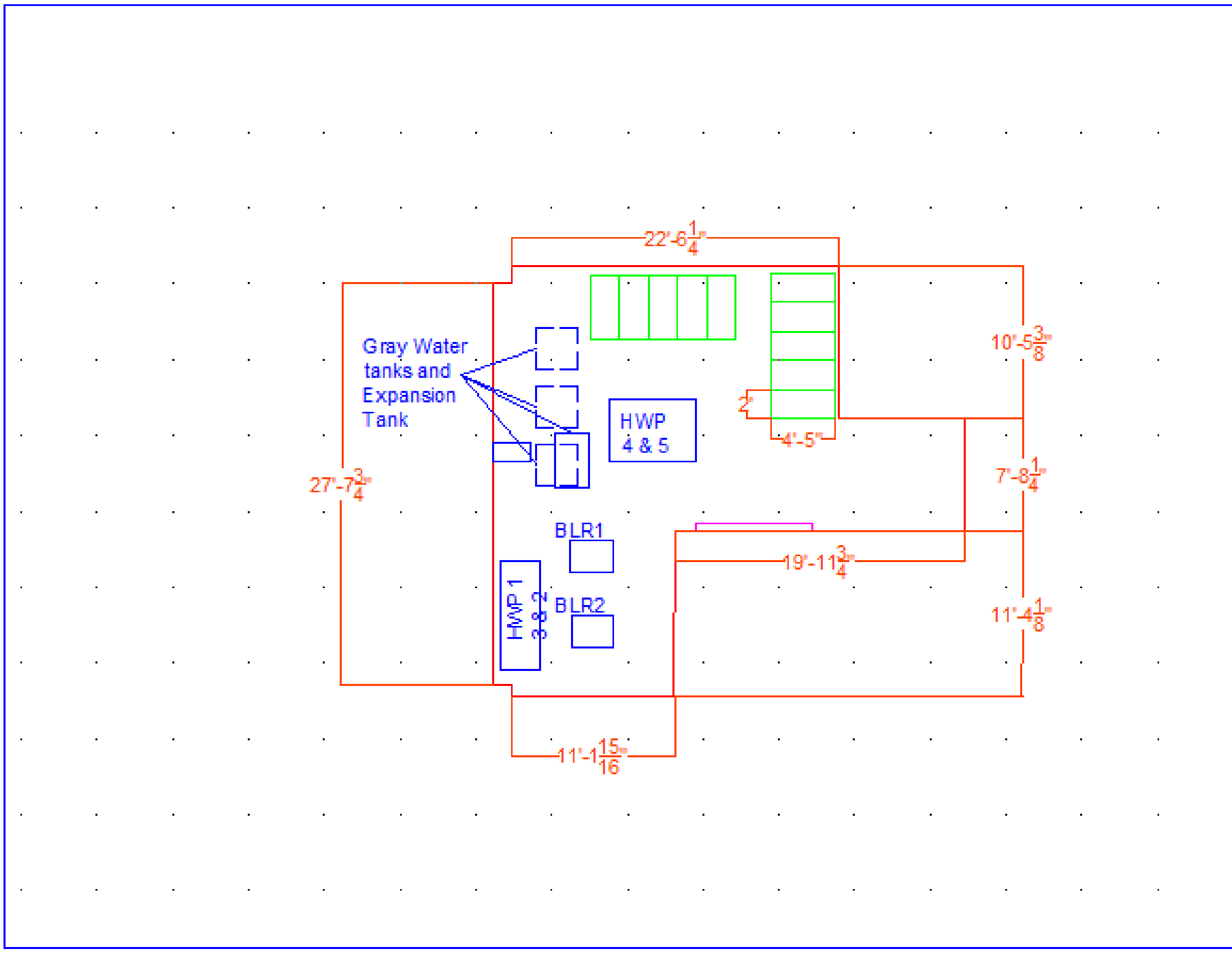

FIGURE 4: REVISED MECHANICAL ROOM LAYOUT

15.3. PROPOSED LOCATION FOR REMAINING PUMPS

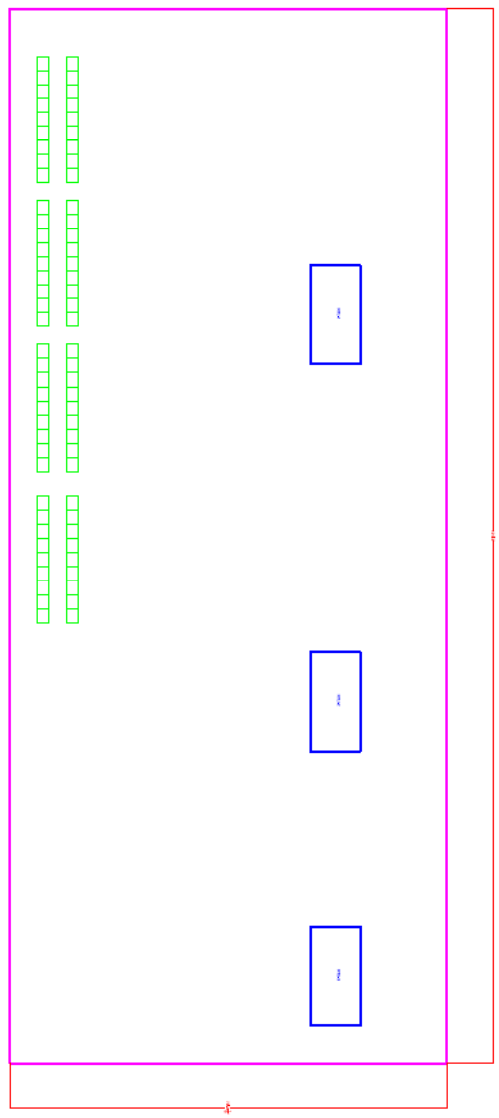

FIGURE 5: LOWER ROOF PROPOSED LOCATION FOR REMAINING PUMPS

15.4. Proposed Schematic Design

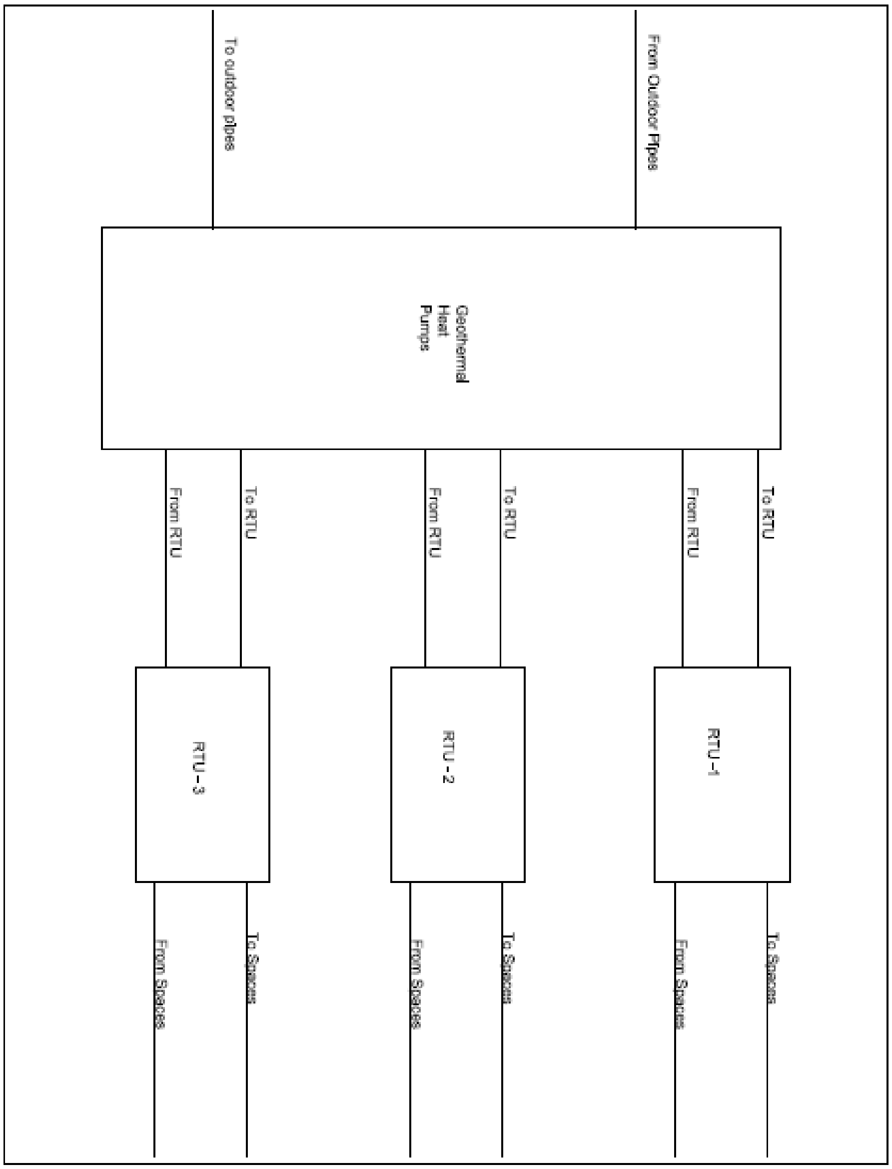

FIGURE 6: SCHEMATIC DESIGN FOR PROPOSED SYSTEM

15.5. Revised Schematic Design

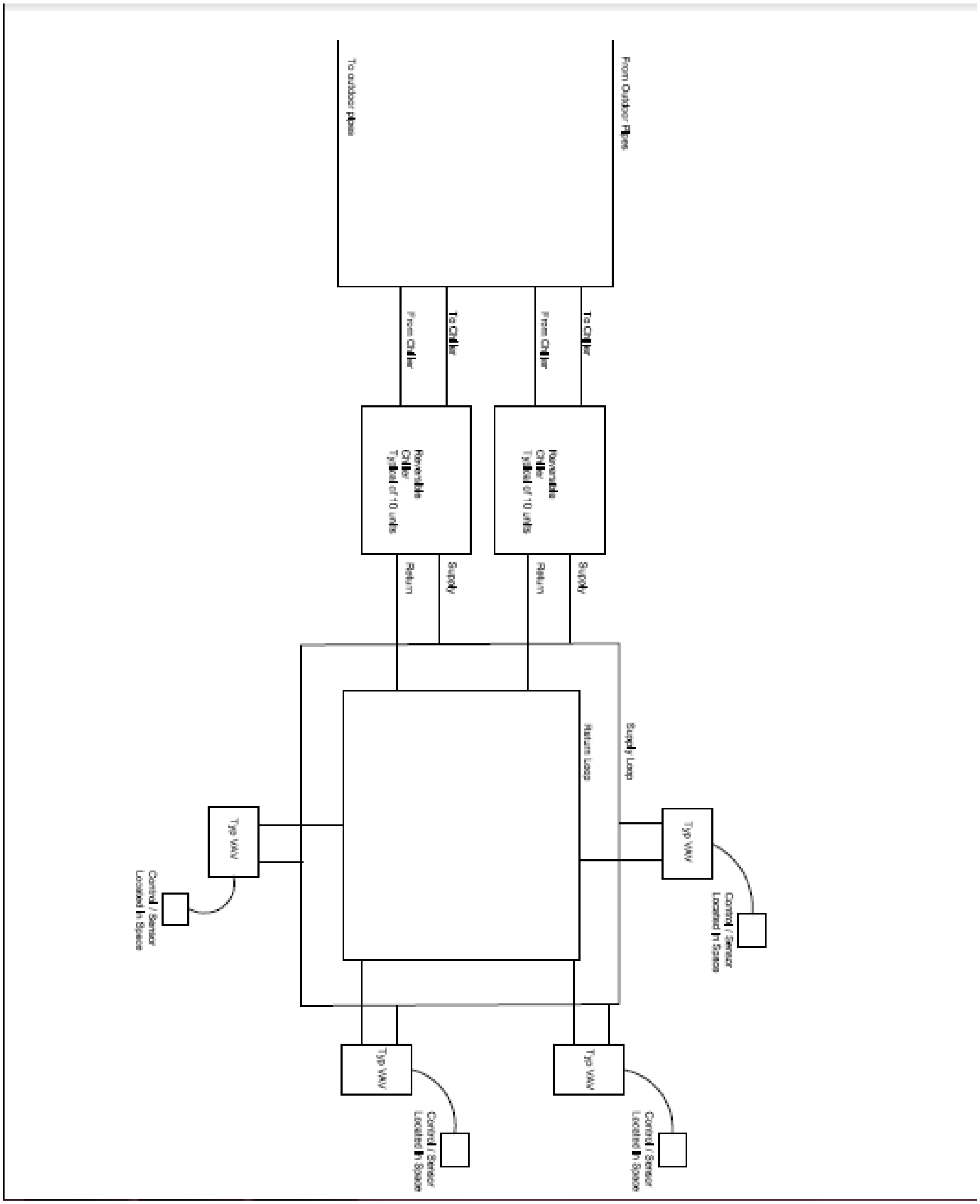

FIGURE 7: REVISED SCHEMATIC DESIGN, EQUPMENT IS TYPICAL OF SIMILAR EQUIPMENT

16. APPENDIX C

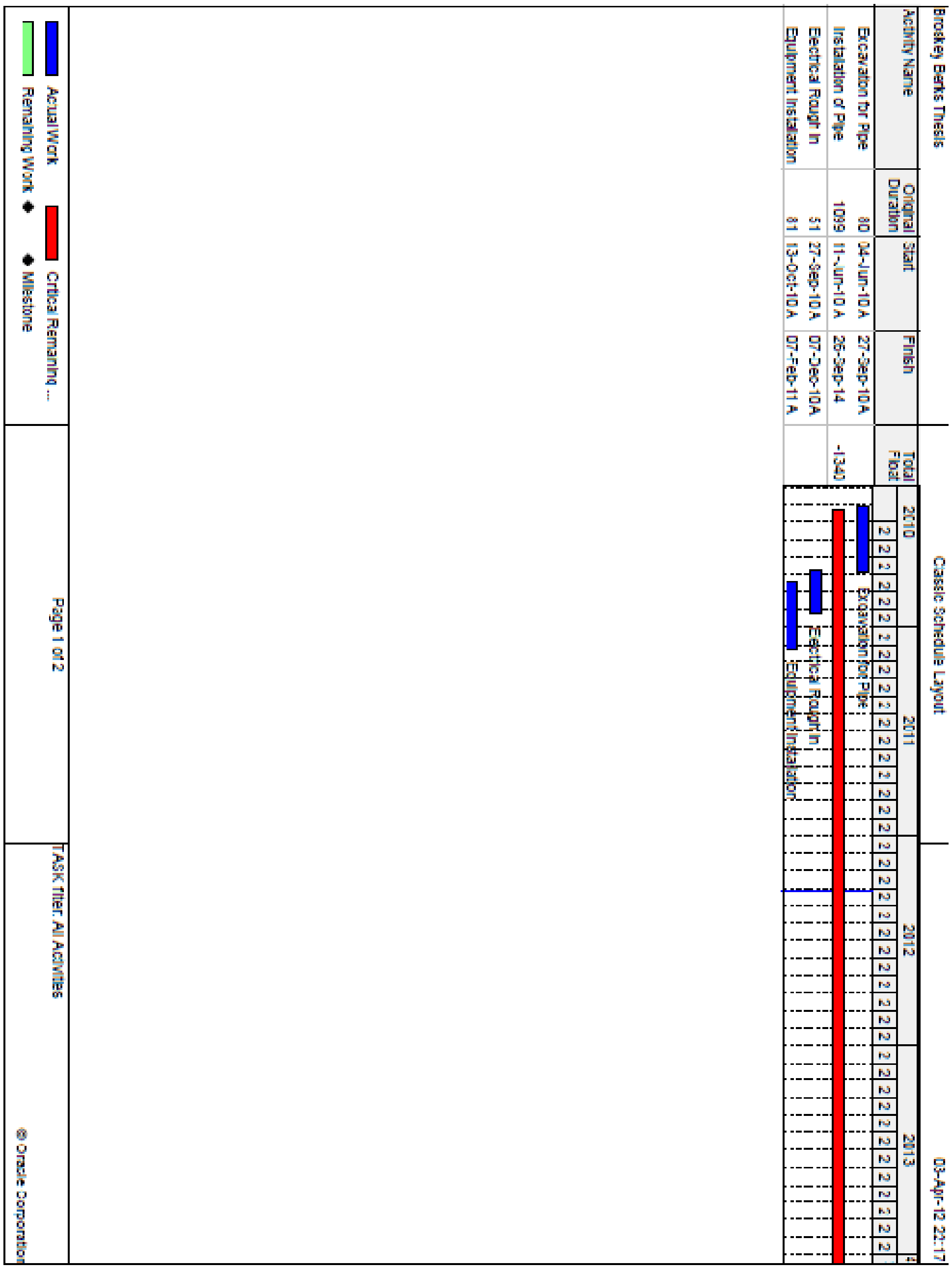

FIGURE 8: PAGE ONE OF THE PROPOSED SYSTEM SCHEDULE

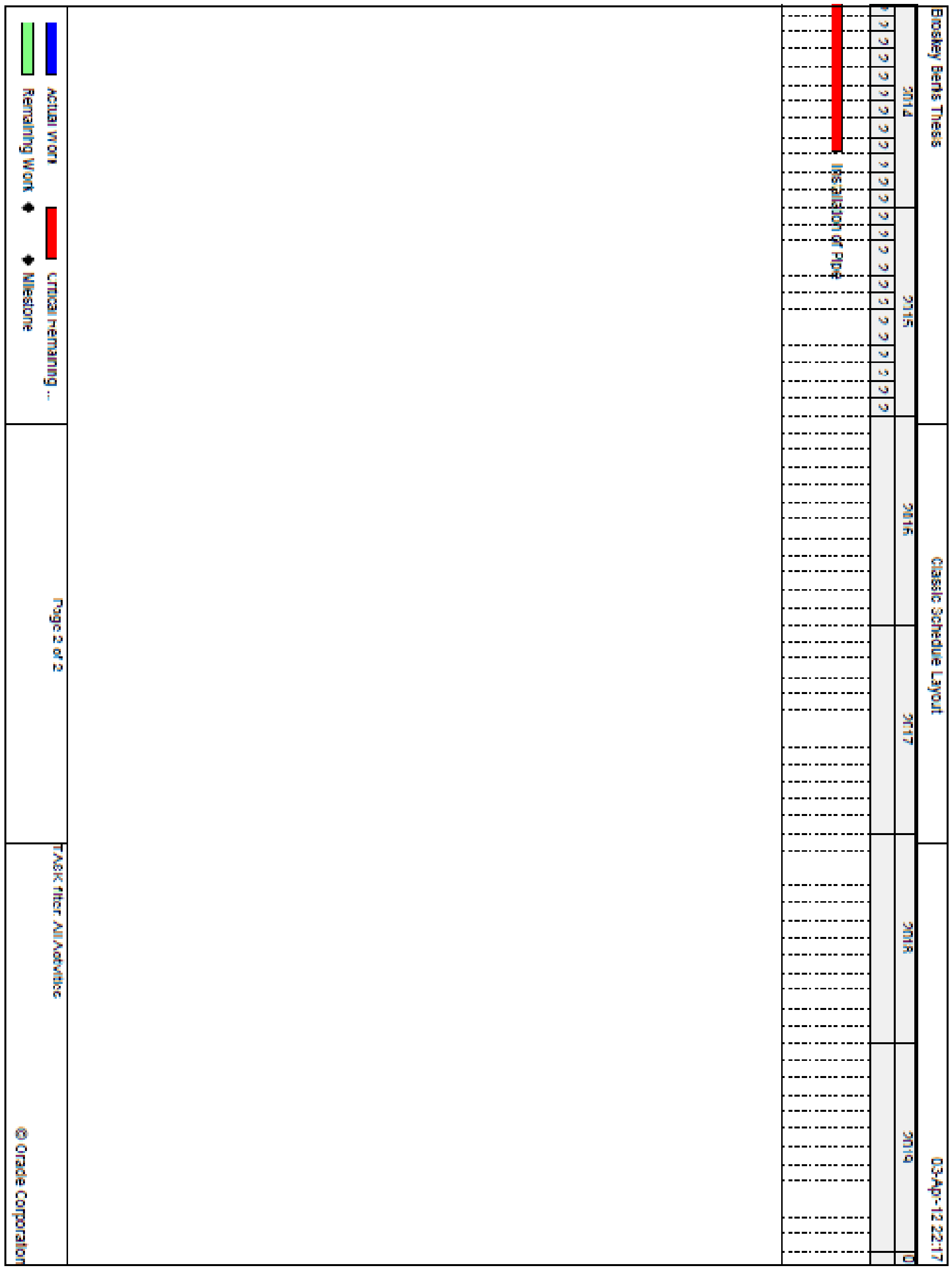

FIGURE 9: PAGE TWO SCHEDULE