



Senior Thesis Final Report

**Dedicated Outdoor Air and
Ground Source Heat Pump
System Redesign Analysis**

4/7/09

WEST VIRGINIA UNIVERSITY ALUMNI CENTER

Morgantown, West Virginia

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MECHANICAL OPTION

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Alumni Center
Morgantown, WV*

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Project Team

Owner: WVU Alumni Association
 Architect: IKM Incorporated
 Civil/Structural: ALPHA Associates
 MEP: H.F. Lenz Company

Project Information

Size: 48,000 Square Feet
 Date of Construction: Spring 2007-Fall 2008
 Cost: \$12 Million
 Project Delivery Method: Design-Bid-Build
 Stories: 3 (Bell Tower Extends to 4th)



Architecture

The WVU Alumni Center presents itself as a large country mansion capped with a large bell tower. The 3-story portion includes office space, conference rooms, and a commercial kitchen while the 2-story portion houses the Grand Hall. The exterior walls are face brick on 6" structural steel studs. Glazing is double paned and argon filled with low-e coating. The visible roof is a pre-fabricated Mansard style truss with synthetic slate shingles.

Mechanical

- 9 AHU's with direct expansion cooling and gas heating serve most spaces
- (1) Kitchen and (3) Banquet Hall AHU's are Constant Air Volume
- Remaining 5 AHU's are Variable Air Volume with electric terminal reheat
- Electric fin-tube heating serves the Pre-Event Loggia
- Direct Digital Control system monitors temperature, humidity and Carbon Dioxide levels

Electrical/Lighting

- 1200 A, 480Y/277 V, 3 Ø, 4-wire main switchboard serves lighting, HVAC and plumbing equipment
- 225 kVA dry transformer steps power down to 208Y/120 V
- 800 A, 208Y/120 V, 3Ø, 4-wire distribution panel serves lighting, receptacles, and HVAC equipment
- Most spaces lit by T-8 fluorescent fixtures with high color rendering
- Emergency Power provided by Fuel Oil Generator

Structural

- Typically 12" or 16" deep steel beams to 16" or 24" deep girders
- 12K1 or 24K10 roof joists spaced @ 4' on center for most roof framing
- 36LH10 Long Span Joists with full diagonal bracing for Banquet Hall
- 1.5 VLI 20 Gage Composite Deck with 3000 psi concrete thickness of 4.5"
- Strip and Spread footing foundations



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1.0 Executive Summary

The West Virginia Alumni Center was originally designed with a central plant mechanical system that included dual fuel (natural gas primary) hot water boilers for heating water and air-cooled chillers for chilled water. The heating water was distributed to each of 9 rooftop AHU's for heating and to VAV boxes for reheat. The chilled water was also distributed to each of the rooftop AHU's. When this design went out to bid the price estimates were much higher than expected and a cheaper design had to be implemented.

The resulting design was a low first-cost, higher annual energy cost system when compared with the central plant design. The new design utilized packaged rooftop AHU's with direct expansion cooling and natural gas furnace heating. Because the new design emphasized first-cost considerations, the benefits of higher first-cost, lower annual energy cost alternatives were not readily explored.

To explore the impact of the installation of a system with a potentially higher first cost and potentially lower annual energy cost an analysis of a ground source heat pump system with a dedicated outdoor air system was conducted for this report. The current packaged rooftop AHU system was replaced with water-to-air heat pumps that reject/gain heat from the earth and a parallel system that provides ventilation air.

The system was then optimized to use appropriately sized ground loops that minimize construction cost and do not significantly add to the construction schedule. Additionally the impact of removing existing mechanical equipment and replacing it with new mechanical equipment on the electrical distribution system was analyzed.

Trane Trace 700 was then used to determine the annual energy use of the original design, existing design and the new proposed heat pump design. The monetary and scheduling impact of the borehole drilling was also calculated along with the monetary impact of the electrical system changes.

After all analysis was complete a 20-year life-cycle cost analysis was conducted to determine the simple payback period of implementing the new design. The 7% increase in capital cost was found to be paid back by energy savings and maintenance savings in approximately 5 years as shown below. With such a quick payback period it was determine that the implementation of the ground source heat pump system with a parallel dedicated outdoor air system would be a worthwhile investment and could be a successfully implemented design.

System	Capital Cost	Maintenance and Replacement	Energy Costs	Total Present Value Cost	Savings	Simple Payback
As-Designed	\$1,420,000	\$218,000	\$1,351,600	\$2,989,600	-	N/A
Redesign	\$1,515,000	\$96,000	\$998,200	\$2,609,200	\$380,400	4.99

2.0 Building Design Background

The new West Virginia University Erickson Alumni Center was designed by IKM, Inc. of Pittsburgh and is owned by the West Virginia University Alumni Association. The 3-story building is home to the Alumni Association's offices, conference spaces and assembly/reception facilities. Construction of the 48,000 square foot facility began in June 2007 and was completed in September of 2008 at a final estimated cost of \$12 million following a Design-Bid-Build project delivery method under the supervision of March-Westin Company of Morgantown, WV.

2.1 Building Envelope

The exterior walls of the Alumni Center are constructed of 18 gage structural metal studs with a brick veneer while the windows are double paned, with low-emissivity coating, 0.27 Solar Heat Gain Coefficient and 73% visible light transmittance. The architecturally visible roof is a pre-fabricated light-gage Mansard style truss with synthetic slate shingles. The non-visible flat roof is a constructed of 20 gage steel roof deck and R-30 insulation with a glass mat gypsum roof board.

2.2 Electrical System

Electrical service for the Alumni Center is provided by a 1200 Amp, 480Y/277 Volt, 3-Phase, 4-wire main switchboard that serves the main lighting system, a majority of the HVAC equipment and some of the plumbing equipment. A 225 kVA dry-type transformer steps the 480Y/277 Volt service down to 208Y/120 Volt service. The 208Y/120 service is distributed through an 800 Amp, 3-phase, 4-wire distribution panels that serves task lighting, receptacle and additional HVAC loads. Emergency power for the building is provided by a Fuel Oil Generator. The electrical design was performed by H.F. Lenz Company of Johnstown, PA.

2.3 Lighting System

Most spaces in the Alumni Center are lit by T-8 recessed fluorescent fixtures with a minimum CRI of 82 and minimum Color Temperature of 3500 Kelvin. Some of the meeting rooms, the board room and the lobbies utilize wall sconces and pendants. Occupancy sensors are provided for some of the restrooms however they are not provided for any of the meeting rooms. The lighting design was performed by H.F. Lenz Company of Johnstown, PA.

2.4 Structural System

Structural steel is the main structural element of the Alumni Center. Typical element sizes are 12" deep beams bearing on 16" or 24" deep girders. Columns run to 12" thick spread footings. Roof structure is provided by open web steel joists spaced at 4 ft on center. The large spans in the Banquet Hall are accomplished with long span joists with full diagonal bracing. Floor decks are 4.5" thick 3000 psi concrete. The structural design was performed by ALPHA Associates, Inc. of Morgantown, WV.

2.5 Fire Protection

The Alumni Center is fully sprinklered and is divided into 4 different occupancies. The mechanical and electrical rooms are protected with a wet-type system with sprinklers rated at 200° F. The loading dock is

served by a dry-type system that is triggered at 155° F. The kitchen area and all other areas in the building are protected with a wet-type system that is triggered at 155° F for the kitchen and 135° F for all other areas. The fire protection design was performed by H.F. Lenz Company of Johnstown, PA.

2.6 Transportation

There are three sets of stairs and one elevator in the Alumni Center. The first set of stairs is in the main lobby and only moves occupants from the ground floor to the first floor. The other two sets of stairs provide access to all three levels of the building and provide direct access to grade for emergency egress. The one elevator serves all 3 levels and is used to move occupants and catering equipment to each level.

2.7 Audio/Visual

The Banquet Hall is equipped with 3 projectors and projection screens. Each meeting room also has a projector and projector screen. Flat panel TVs are placed throughout the building with several placed in various meeting rooms. The Audio/Visual design was performed by S2N of Bethesda, MD.

2.8 Original Mechanical System Design

The minimal capital budget for this project dictated the complexity and performance of the designed system. The original design for the project included a central plant that included several air-cooled chillers with a water/glycol mix for the chilled water coils of each AHU and a central boiler system that provided hot water to the heating coils of each AHU and the reheat coils in each VAV box. The bids for this system came in over budget and the design had to be modified. Since this project was first cost driven and the annual energy expenditure was not a deciding factor the design was changed to packaged rooftop AHU's.

2.9 Existing Mechanical System Summary

The 48,000 ft² West Virginia University Alumni Center is conditioned by 9 Air Handling Units that serve four distinct space types. As shown in Figure 1, AHU-1, AHU-2, AHU-3, and AHU-9 serve the lobbies, hallways, and office areas of the ground floor, first floor and second floor. These four AHU's provide conditioning through air-cooled direct expansion cooling and gas-furnace heating. AHU-1, AHU-2 and AHU-3 are variable volume AHU's and serve VAV boxes with electric reheat. AHU-9 is a single zone constant volume AHU.

Figure 1 also show AHU-4, AHU-5 and AHU-6 which each provide conditioning to 1/3 of the Banquet Hall while AHU-7 serves the two loggias surrounding the Banquet Hall. These four AHU's also operate with air-cooled direct expansion cooling and gas-furnace heating and they are all single zone constant volume systems with AHU-7 supplying 100% outdoor air.

AHU-8 is a make-up air unit that provides air directly to the kitchen exhaust hoods and is only equipped with gas-fired furnace heating designed to provide 100% outdoor air.

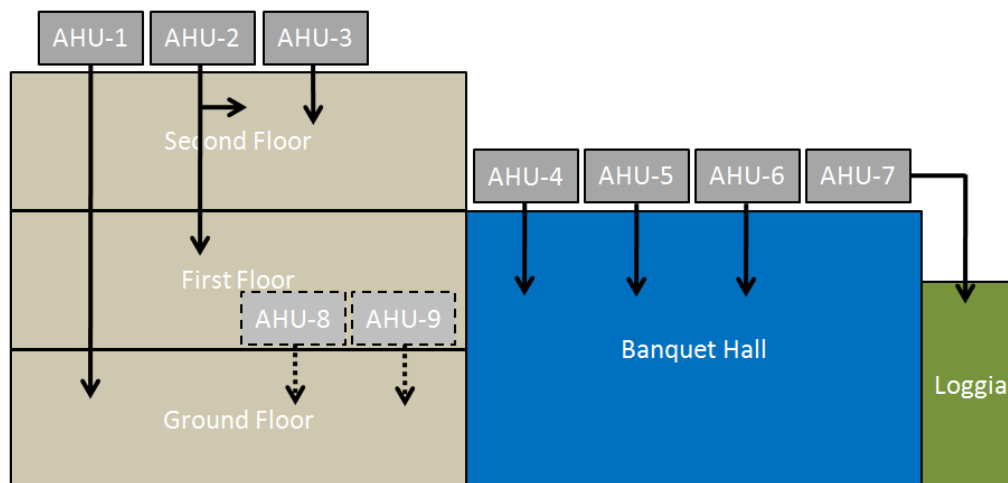


Figure 1 – Simplified AHU Distribution Schematic

2.10 Existing Mechanical System Equipment Summary

Important information for all AHU's including CFM, fan power, cooling capacity and heating capacity, is summarized in Appendix 1.

2.11 Existing Mechanical System Control

AHU-1, AHU-2 and AHU-3 all follow the same sequence of operation. These AHU's will operate in one of two control modes, occupied or unoccupied, which allow for heating or cooling anytime a VAV box requires. The cooling supply air temperature is 55°F leaving the AHU and the VAV boxes modulate to control the room cooling set point at 72°F during occupied mode and 85° F during unoccupied mode. The heating supply air temperature is 75° F leaving the AHU and the VAV boxes modulate to control the room heating set point at 70° F during occupied mode and 55° F during unoccupied mode. Optimal starting of the AHU's in the morning allows each zone to reach their occupied set points prior to occupancy each day. Because these AHU's serve variable volume boxes, the fans in each AHU are equipped with variable frequency drives (VFD's) that modulate the supply fan speed to maintain the required static pressure in the system based on a static pressure reading 75% down the longest duct run. The return fans for these systems runs continuously when the supply fan is running and the VFD's for the return fans modulate in unison with the supply fan VFD's. These AHU's are equipped with an economizer control sequence that allows for free cooling under specified conditions.

AHU-4, AHU-5, AHU-6, and AHU-9 all follow the same sequence of operation. These AHU's will operate in one of two control modes, occupied or unoccupied. The cooling supply air temperature leaving the AHU modulates to control the room cooling set point at 72°F during occupied mode 85° F during unoccupied mode. The heating supply air temperature leaving the AHU modulates to control the room heating set point at 70° F during occupied mode and 55° F during unoccupied mode. Optimal starting of the AHU's in the morning allows each zone to reach their occupied set points prior to occupancy each day. Because these AHU's serve constant volume systems the supply fan operates in two modes, ON or

OFF. The return fan runs anytime that the supply fan is in ON mode. These AHU's are equipped with an economizer control sequence that allows for free cooling under specified conditions.

AHU-7 follows the same sequence of operation of AHU-4, AHU-5, AHU-6 and AHU-9 except for one small difference. Because AHU-7 serves the kitchen area, the system is designed to provide the minimum required ventilation during occupied mode. However, when Kitchen Exhaust Fans 1, 3 and 4 are on the AHU provides 100% outdoor air. All cooling and heating set points are the same as stated for the previous air handlers and the supply and return fan operations are also the same as stated for AHU-4, AHU-5, AHU-6 and AHU-9.

2.12 ASHRAE Standard 62.1 Compliance

Section 6 of ASHRAE Standard 62.1 outlines the Ventilation Rate Procedure, which is a prescriptive procedure to determining the minimum outdoor air intake rates based on the amount of occupants, floor area, space type and other factors. The Ventilation Rate Procedure uses specific methods and formulas, which are detailed in Section 6 of Standard 62.1 and were utilized for the calculation of minimum outdoor air flow for the Alumni Center. The results of these calculations for AHU-1, AHU-2 and AHU-4 are summarized in Table 1.

Table 1 – Ventilation Rate Compliance Summary

Ventilation Rate Compliance Summary				
	Calculated OA (cfm)	Design Supply Air Flow (cfm)	Design Minimum OA (cfm)	ASHRAE 62.1 Compliance
AHU 1	2980	8690	2173	No
AHU-2	5969	15215	5325	No
AHU-4	5000	1218	2500	Yes

AHU-1 and AHU-2 both did not meet the requirements of ASHRAE Standard 62.1 as calculated for this table. However, those calculations did not take into account the short term conditions of several conference rooms and pre-event lobbies as specified in Section 6.2.6.2 of Standard 62.1. If the requirements of Section 6.2.6.2 were included in the calculations, both AHU-1 and AHU-2 would comply with the standard.

2.13 ASHRAE Standard 90.1 Compliance

ASHRAE Standard 90.1 provides minimum requirements for energy efficiency in buildings. Analysis of the Alumni Center's compliance with Standard 90.1 is divided into Building Envelope; Heating, Ventilating and Air Conditioning; Service Water Heating; Power and Lighting. A summary of the Alumni Center's compliance with Standard 90.1 is outlined below.

Building Envelope

Section 5 of ASHRAE Standard 90.1 provides minimum requirements for the building envelope. To determine the requirements for the building envelope that the Alumni Center must follow, the Climate Zone must be determined. Morgantown, WV is in Monongalia County, which is part of Climate Zone 5A as defined in Table B-1 of Standard 90.1.

The Alumni Center has a vertical fenestration area that is less than 40% of the gross wall area and skylight fenestration that is less than 5% of the gross roof area as shown in Table 2. With these requirements met, the building can follow the Prescriptive Building Envelope Compliance Path.

Table 2 – Window Area Summary

	Gross Area	Window Area	Window %
Walls	22575	4603.1	20.4%
Roof	15814	0	0.0%

Construction of the building envelope was compared to Table 5.5-5 of Standard 90.1, which provides the requirements for building envelope compliance for nonresidential buildings in Climate Zone 5A. The details of the building envelope are included below and Table 3 summarizes the Alumni Center’s compliance with the Building Envelope requirements outlined in Table 5.5-5 of the standard.

- Roof Construction – 20 gage steel roof deck with tapered rigid insulation with an average R-Value of 30
- Exterior Wall Construction – 4” face brick, 2” R-14 rigid insulation, ½” sheathing and 6” steel studs
- Glazing – double paned and argon filled with Low-E coating for a maximum U-value of 0.35, Shading Coefficient of 0.48, Solar Heat Gain Coefficient (SHGC) of 0.37 and a Visible Light Transmittance of 73%

Table 3 – Building Envelope Compliance Summary

	Min Roof Insulation R-Value	Wall Insulation Minimum R-Value	Non-Heated Slab on Grade Floors	Fenestration Max U-Value	Fenestration Max SHGC
Required Value	R-20	R-13	N/A	0.35	0.4
Designed Value	R-30	R-14	N/A	0.35	0.37
Compliance	Yes	Yes	N/A	Yes	Yes

The R-value of the roof insulation is significantly higher than required by Standard 90.1. The R-value for wall insulation, fenestration U-value and fenestration SHGC are all slightly better than required by the standard. The Alumni Center meets all of the requirements to have a compliant building envelope under ASHRAE Standard 90.1.

Heating, Ventilating and Air Conditioning

Section 6 of Standard 90.1 defines energy efficiency requirements for the mechanical equipment that provides heating, cooling and ventilation to new buildings and designates the appropriate thickness of insulation for plumbing and mechanical piping. There are two compliance paths for Section 6. The Alumni Center will follow the Mandatory Provisions Method for compliance, as it does not meet the qualifications to follow the Simplified Approach Option. The requirements for the Mandatory Provisions Method are outlined in Section 6.4 of the standard.

Mechanical Equipment

Tables 4, 5 and 6 summarize the Alumni Center’s compliance with the minimum equipment efficiencies, EER’s and SEER’s outlined in Tables 6.8.1 A-J of the Standard. All equipment in the building meet the minimum requirements, therefore the building complies with this section of Standard 90.1.

Table 4 – Gas Furnace Efficiency Compliance Summary

Gas Furnaces									
	AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	AHU-6	AHU-7	AHU-8	AHU-9
Efficiency As Designed	81	81	81	81	81	81	81	81	81
Required Efficiency	80	80	80	80	80	80	80	80	80
Compliance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5 – Air Cooled Air Conditioner EER Compliance Summary

Air Cooled Air Conditioners									
	AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	AHU-6	AHU-7	AHU-8	AHU-9
EER As Designed	9.3	9.3	9.5	9.5	9.5	9.5	9.3	N/A	9.3
Required EER	9.5	12.3	10.6	11.5	11.5	11.5	10.4	N/A	13
Compliance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 6 – Split System Air Conditioner SEER Compliance Summary

Split System Air Cooled Air Conditioners			
	SSAHU-1	SSAHU-2	SSAHU-3
SEER As Designed	13	13	13
Required SEER	13	13	13
Compliance	Yes	Yes	Yes

Pipe Insulation Thickness

Table 7 summarizes the buildings compliance with the minimum pipe insulation thickness required by Table 6.8.3 of Standard 90.1. All of the insulation specified for the building meets the requirements to be compliant with this section of the standard.

Table 7 – Pipe Insulation Thickness Compliance Summary

	Domestic Hot Water Systems 105+ ° Operating Temp Nominal Pipe Size			Cooling Systems 40-60 ° Operating Temp Nominal Pipe Size	
	<1"	1 to < 1-1/2"	1-1/2" to <4"	<1"	1 to < 1-1/2"
	Insulation Thickness			Insulation Thickness	
Required	0.5	0.5	1	0.5	0.5
As Designed	0.5	0.5	1	0.75	0.75
Compliance	Yes	Yes	Yes	Yes	Yes

Service Water Heating

Section 7 of ASHRAE Standard 90.1 defines the minimum performance required for water heating equipment. The Alumni Center utilizes two gas-fired water heaters that require a minimum thermal efficiency of 80% as per Standard 90.1. Both water heaters are rated at 85% efficiency, which complies with the requirements of this section of the standard.

Power

Section 8 of ASHRAE Standard 90.1 defines the maximum voltage drop for both feeders and branch circuits. Feeders must be sized for a maximum voltage drop of 2% at design load and branch circuits must be sized for a maximum voltage drop of 3% at design load. The electrical designer designed the electrical system to comply with Standard 90.1 and therefore sized the feeders and branch circuits to comply with the maximum voltage drop dictated in the standard.

Lighting

Section 9 of Standard 90.1 provides requirements for the lighting power density. There are two compliance paths for this section. The first compliance path is the Building Area Method, which requires the entire building’s lighting power density to be below a certain level for a specified building type. If the building fails to comply using the Building Area Method the Space by Space method can be used. For the Alumni Center the Building Area Method was applied for compliance with the building classified as a School/University building. Table 8 summarizes the Alumni Center’s compliance with Section 9 of the standard.

Table 8 – Lighting Power Density Compliance Summary

Floor	Area (sq. ft.)	Lighting Power (Watts)	Lighting Density (W/sq. ft.)
Ground	27000	25093	0.93
First	10500	11383	1.08
Second	10500	11750	1.12
Total	48000	48226	1.00

ASHRAE Std. 90.1 Max Lighting Density	1.2
Compliance	Yes

Table 8 shows that the Alumni Center has a lighting power density that is less than the maximum allowable for a School/University Building. If the building would be classified as an Office Building, which is its primary function after being a University Building, it would still meet the requirements for compliance as the maximum allowable lighting power density for an office building is 1.0 W/sq. ft. The Alumni Center meets the requirements for compliance with Section 9 of Standard 90.1.

3.0 Proposed Mechanical System Redesign

3.1 Redesign Goals

As shown in Section 5.2 of this report, the Alumni Center's current mechanical equipment barely meets the minimum requirements of ASHRAE Standard 90.1. The reason for this is mainly due to budgetary restrictions. The goal of redesigning the mechanical system for the Alumni Center is to show that in an owner occupied facility that it is beneficial for the owner to consider increasing their capital investment for the project to accommodate the purchase of a more efficient system that will save them money over the lifetime of the building.

The specific goals of this redesign are to reduce the annual energy costs for the owner and to provide a low life-cycle cost solution that will have a return on investment that will make the implementation of the design feasible.

3.2 Preliminary Redesign Ideas

Prior to the final selection of the redesigned system, several alternatives were considered and researched. The following ideas were considered for use in this project but were ultimately not chosen for implementation.

Combined Heat and Power

The use of a combined heat and power plant for the Alumni Center Project was considered for use. However, the implementation of such a plant requires relatively flat electrical and thermal load profiles. Because the Alumni Center is an office building that is occupied and used almost entirely during normal business hours, aside from some evening functions, the electrical and thermal load profiles look similar to those of an average office building. The thermal and electrical loads are at their lowest during unoccupied hours and peak just after the middle of the working day. With such a varying load, in addition to the small size of the project, a combined heat and power plant is not a feasible solution.

Central Plant

A central plant design that utilizes centralized chillers and boilers is another option that was considered for the mechanical redesign. The plant would most likely use natural gas boilers along with chillers that were either air-cooled or water-cooled based on life-cycle cost analysis. Because the original design of the building utilized central boilers and air-cooled chillers, the decision was made to not fully investigate this option for redesign. However, the ground source heat pump design will be compared to both the packaged rooftop VAV system and the original central plant design on an annual energy cost basis.

3.3 Ground Source Heat Pump System

To replace the packaged rooftop AHU's and the VAV terminal units, it is proposed to use packaged unitary water-to-air ground source heat pumps (GSHP) along with a parallel dedicated outdoor air system (DOAS). The use of this type of system has the ability to decouple the sensible and latent loads of each space. The DOAS system is sized to meet the latent loads, while simultaneously meeting up to 30% of the sensible load in the space. The heat pumps are then selected to meet the rest of the sensible load for the space.

The GSHP system will use the earth as a thermal reservoir. Water will circulate through vertical boreholes that will be drilled to a depth that minimizes construction time and cost. The system works as a seasonal thermal storage system where water circulating during the summer will remove heat from the building and deposit that heat in the ground for use during the winter. In winter operation the circulating water will remove heat from the earth and transfer it to the building. The heating and cooling loads on the building must be fairly close on an annual basis to ensure that the earth will always be able to accept or disperse heat.

Figure 2 shows a schematic of how the water-to-air heat pump system works. The water from the ground loop is circulated by a pump to each heat pump. Inside each heat pump is a water-to-refrigerant heat exchanger that works as the evaporating coil. Depending on whether the heat pump is in cooling or heating mode dictates which way the refrigerant goes through the heat pump cycle. The reversing valve allows the refrigerant to reverse direction and provide both heating and cooling for the space.

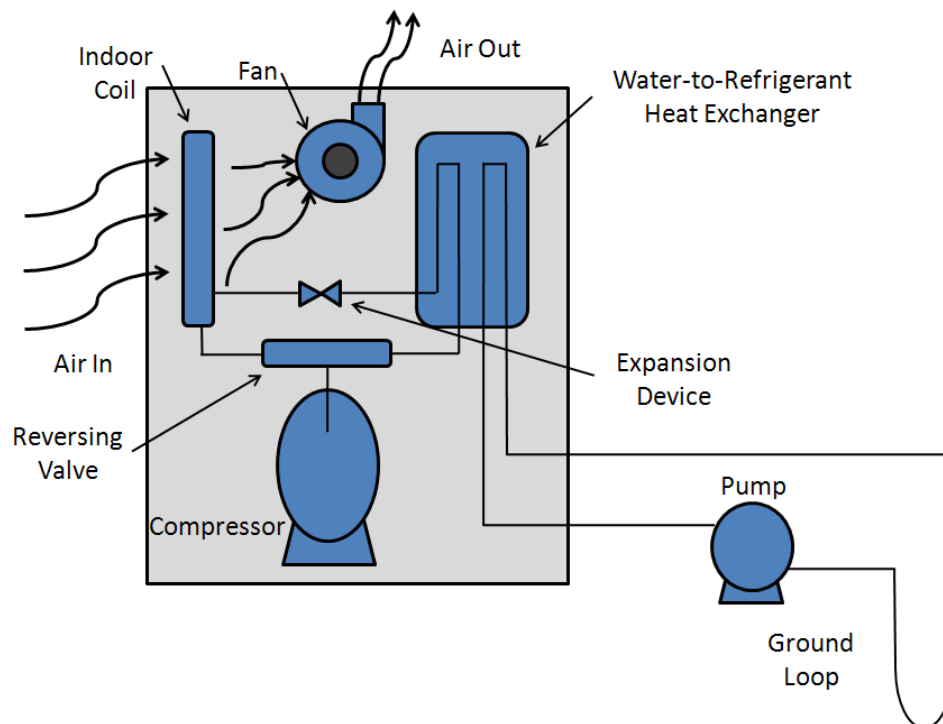


Figure 2 – Water-to-Air Heat Pump Schematic

3.4 Dedicated Outdoor Air System (DOAS)

With a DOAS system, the use of an enthalpy wheel to recover energy with an effectiveness of 50% from the exhaust air is required by ASHRAE Standard 90.1. However, an enthalpy wheel with effectiveness greater than 50% will be utilized.

The use of energy recovery in this system is important because it allows preconditioning of the air with the use of no additional energy. In the summer, warm ventilation air is pre-cooled/dehumidified by the

enthalpy wheel. During winter operation, cold ventilation air is pre-heated/humidified by the enthalpy wheel.

The outdoor air for the DOAS system is ducted within close proximity of the heat pump return air inlet so that the outdoor air and return air mix as they enter the heat pump.

3.5 Benefits of Proposed System

The primary benefit available from the selection of a GSHP system is the significantly reduction in annual energy consumption of the Alumni Center. The difficulty in implementing a GSHP design is overcoming the increased capital costs of such a system. If properly designed and optimized this type of system will be able to overcome the increased capital cost in just a few short years by the large reduction in annual energy costs.

Additional benefits of a GSHP system is the maintenance and replacement costs. Annual maintenance costs for a unitary heat pump are lower than VAV boxes and have an equivalent expected lifetime. The ground loop piping, once installed, is expected to last approximately 50 years and requires only minimal annual maintenance to keep in prime working condition. Additionally, by using a dedicated outdoor air system in parallel with the GSHP system there is a significant reduction in rooftop air-conditioner size. This means that when the dedicated outdoor air-handling units need to be replaced, they will be significantly less expensive than replacing the AHU's that are currently used to condition the building.

3.6 Systems to be Replaced

The GSHP and Dedicated Outdoor Air systems will be used to replace the existing systems that are serving the 1st, 2nd and 3rd floor office spaces (AHU's and VAV terminal units) as well as the 4 AHU's that condition the Grand Ballroom and surrounding Loggia. Unitary water-to-air heat pumps will replace each VAV terminal unit and a dedicated outdoor air-handling unit will replace each existing direct expansion AHU.

The two AHU's serving the kitchen space will not be modified because they utilize very different design criteria, are relatively small, one only provides heating and they're replacement would provide little to no energy savings. Additionally, the exclusion of these AHU's helps to balance the annual heating and cooling loads on the GSHP system, which is critical for long-term satisfactory performance of the ground-loop system.

4.0 Building Load Analysis

4.1 Assumptions

Trane Trace 700 was utilized to estimate the design heating and cooling loads for the Alumni Center. Information to construct the building model was gathered from design documents from both the architect and mechanical engineer. A summary of the basic assumptions used to create the building model are included below.

Zoning

Zoning of the unitary heat pumps followed the same zoning that was utilized for the original VAV design for the most part. In several cases, two or three smaller VAV boxes were consolidated into one heat pump.

Outdoor Air Ventilation Rates

All ventilation rates are taken from the mechanical equipment schedules in the mechanical design documents as prior work has shown that the calculations performed by the design engineer were correct.

Lights and Electrical Equipment Loads and Schedules

The lighting load and electrical equipment loads for the Alumni Center were input on a W/ft² basis. The lighting load was based on the calculation performed for Technical Report I using the Whole Building Method of ASHRAE Standard 90.1. Electrical equipment loads were also input on a W/ft² basis based on recommendations from the design engineer. Table 9 provides a summary of the lighting and electrical equipment loads used for the design load estimation.

Table 9 – Lighting and Equipment Loads

	Entire Building	Offices	Hallways	Restrooms	Banquet Hall	All Others
Load (W/sq ft)	1.0	1.5	0.5	0.5	0.75	1.5

The utilization schedules for the lighting and equipment loads are based on typical low-rise office buildings. The schedules show the percentage of maximum use at each hour of the day. Tables 10 and 11 summarize the utilization schedules for the equipment and lighting loads.

Table 10 – Equipment Load Schedule

	Equipment
12 am - 7 am	5.0
7 am - 8 am	80.0
8 am -10 am	90.0
10 am - 12 pm	95.0
12 pm - 2 pm	80.0
2 pm - 4 pm	90.0
4 pm - 5 pm	95.0
5 pm - 6 pm	80.0
6 pm - 7 pm	70.0
7 pm - 8 pm	60.0
8 pm - 9 pm	40.0
9 pm - 10 pm	30.0
10 pm - 12 am	20.0

Table 11 – Lighting Load Schedule

	Lights
12 am - 6 am	0.0
6 am - 7 am	10.0
7 am - 8 am	50.0
8 am - 5 pm	100.0
5 pm - 6 pm	50.0
6 pm -7 pm	10.0
7 pm - 12 am	0.0

Design Indoor and Outdoor Air Conditions

The design indoor air conditions were specified by the designer and the outdoor air conditions for the Alumni Center were obtained from the ASHRAE Handbook of Fundamentals 2005 and are noted in Table 12.

Table 12 – Indoor and Outdoor Design Conditions

Summer Design Dry Bulb Temp	90°F
Summer Design Wet Bulb Temp	75°F
Winter Design Dry Bulb Temp	10°F
Indoor Cooling Dry Bulb Temp	75°F
Indoor Heating Dry Bulb Temp	70°F
Indoor Relative Humidity	50%

Occupancy Load and Schedule

The occupancy load is typically based on moderate office activity providing a sensible load of 250 BTU/hr and a latent load of 200 BTU/hr. Other occupancy loads are used based on the use of each space. The occupancy schedule is based on a typical low-rise office building as summarized in Table 13.

Table 13 – Occupancy Load Schedule

	People
12 am - 7 am	0.0
7 am - 8 am	30.0
8 am - 5 pm	100.0
5 pm - 6 pm	30.0
6 pm - 7 pm	1.0
7 pm - 12 am	0.0

Infiltration

As a newly constructed building the Alumni Center was assumed to have tight construction for the purpose of this design load estimation. With tight construction the infiltration rate was set at 0.3 air changes per hour.

Energy Recovery Device

Each dedicated outdoor air handling unit includes a total energy wheel with an effectiveness of 64%.

Additional Design Load Assumptions

Additional assumptions including wall constructions and typical rooms are available in Appendix 2.

4.2 Results

Table 14 summarizes which Outdoor Air Units are replacing which packaged rooftop AHU's from the original VAV design. Table 15 through Table 19 summarizes the loads on each zone of the building. The tables include the total sensible load, latent load, zone heating and ventilation heating loads as well as the total CFM.

Table 14 – New Equipment Designations

VAV AHU Designation	New DOAS Designation
AHU-1	DOAU-1
AHU-2	DOAU-2
AHU-3	DOAU-3
AHU-4	DOAU-4
AHU-5	DOAU-5
AHU-6	DOAU-6
AHU-7	DOAU-7

Table 15 – Dedicated Outdoor Air Unit 1 Loads

Zone	Sensible Load (MBH)	Latent Load (MBH)	Zone Heating Load (MBH)	Ventilation Heating Load (MBH)	CFM
1	37.6	13.82	19.7	1.7	1308
2a	25.3	11.25	10.5	0.133	930
2b	25.3	11.25	10.5	0.133	930
2c	25.3	11.25	10.5	0.133	930
3	21.7	8.62	9.3	0.3	760
4	20.6	8.38	8.9	0.3	619

Table 16 – Dedicated Outdoor Air Unit 2 Loads

Zone	Sensible Load (MBH)	Latent Load (MBH)	Zone Heating Load (MBH)	Ventilation Heating Load (MBH)	CFM
1	19	8.02	16.4	0.5	777
2	46.9	38.6	41.5	4.7	1669
3	25.5	22.18	18.1	3.9	691
4	20.4	18.27	16.5	2.4	661
5	13.5	6.22	10.1	0	589
6	14.4	10.01	12.8	1	542
7	19.3	18.27	16.3	2.5	627
8	15.7	3.25	11.9	0.1	660
9	17.6	12.31	15.1	1.3	630
10	46.2	28.95	37.9	2.8	1618
11	11.9	7.85	9.9	0.7	428

Table 17 – Dedicated Outdoor Air Unit 3 Loads

Zone	Sensible Load (MBH)	Latent Load (MBH)	Zone Heating Load (MBH)	Ventilation Heating Load (MBH)	CFM
1	34.3	5.7	33.5	0	1080
2	50	30.25	59.3	2.7	1391
3	24.2	11.4	28.6	1	790
4	42.9	11.65	54.4	0	843

Table 18 – Dedicated Outdoor Air Units 4, 5 and 6 Loads

Zone	Sensible Load (MBH)	Latent Load (MBH)	Zone Heating Load (MBH)	Ventilation Heating Load (MBH)	CFM
1	35.4	46.25	62.85	8.05	1290
2	35.4	46.25	62.85	8.05	1290

Table 19 – Dedicated Outdoor Air Unit 7 Loads

Zone	Sensible Load (MBH)	Latent Load (MBH)	Zone Heating Load (MBH)	Ventilation Heating Load (MBH)	CFM
1	41	33.4	38.7	0.037	1549
2	41	33.4	38.7	0.037	1549
3	41	33.4	38.7	0.037	1549

4.3 Heat Pump Selection

Supply Water Temperature

The first step in being able to select the required heat pumps was to determine Using Figure 17 in Chapter 32 of the 2007 ASHRAE Handbook-HVAC Applications it was determined that the average ground temperature in Morgantown, WV is approximately 55° F. Following advice, also in Chapter 32 of the same book, the design supply water temperatures were set to 45° F in heating and 75° F in cooling.

Heat Pump Type, Placement and Selection Procedure

All heat pumps chosen for this project are Aquazone models made by the Carrier Corporation. All heat pumps that were selected to replace VAV boxes were selected to be horizontal units that will be located above the ceiling. The heat pumps that were selected to serve the Grand Ballroom will be vertical units and will be located in the supply closets surrounding the ballroom.

Each individual heat pump was chosen to meet the sensible loads of the spaces that it serves. This is because each Dedicated Outdoor Air Unit will be selected to meet the latent loads of all the spaces it serves. The heat pumps were chosen to maximize the EER of the entire system.

Table 20 lists the type, number and cost (including installation and required piping) of the selected heat pumps along with their average EER of the units chosen. These heat pumps utilize R-410a, so they will comply with refrigerant phase-outs.

Table 20 – Unitary Heat Pump Selection

Aquazone Model	Number of Units	Average EER	Total Cost
50PSH024	11	17	\$77,275
50PTH038	5	15.85	\$42,000
50PTH049	7	18.1	\$76,825
50PTH064	7	18	\$83,825

Total Heat Pump Cost	\$279,925
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4.4 Dedicated Outdoor Air Unit Selection

Each of the dedicated outdoor air units selected for this design are 100% outdoor air units from Carrier Corporation that use R-410a refrigerant for direct expansion cooling and are equipped with electric heat for when the total energy wheel cannot significantly preheat the air. The units were selected to meet the latent load of the spaces that they serve. Table 21 lists the units selected and their costs figures including installation.

Table 21 – Dedicated Outdoor Air Unit Selection

Unit Designation	Carrier Model Number	Cost
DOAU-1	62DA14	\$16,847
DOAU-2	62DA20	\$20,582
DOAU-3	62DA07	\$13,650
DOAU-4	62DA14	\$17,121
DOAU-5	62DA15	\$17,121
DOAU-6	62DA16	\$17,121
DOAU-7	62DA09	\$15,875

Total AHU Cost	\$118,317
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4.5 Energy Recovery

The inclusion of a total energy wheel in each of the outdoor air units greatly reduces the required heating and cooling loads on the coils in the outdoor air units and the heat pumps. Each of the seven outdoor air units is equipped with a total energy wheel that has the effectiveness shown in Figure 3 while Table 22 shows the significant temperature changes encountered by using the total energy wheel in each of the outdoor air units.

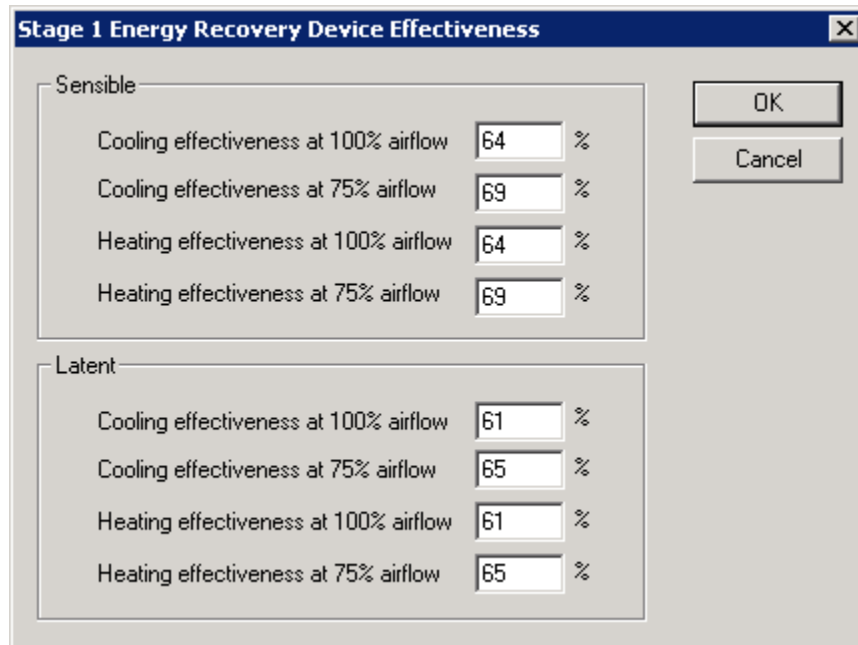


Figure 3 – Total Energy Wheel Effectiveness

Table 22 – Total Energy Wheel Temperatures

	DOAU-1		DOAU-2		DOAU-3		DOAU-4,5,6		DOAU-7	
	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
Design Outdoor Temp	87	10	88	10	89	10	88	10	84	10
Exhaust Temp	70.8	65.6	63.9	60.3	70.5	63.1	77.8	65.5	75.3	67.8
SA Temp after TEW	74.7	45.6	74.7	47.8	74.7	43.1	81.7	49.2	70.2	59.3

It is important to look at the number in the “SA Temp after TEW” row. This row shows the temperature of the air after passing through the Total Energy Wheel and before it reaches the heating or cooling coil in the outdoor air unit. The design supply air temperature in cooling is set to approximately 48-52° F in order to meet the latent load requirements. Therefore, reducing the incident air temperature on the cooling coil by approximately 14° F with the use of the Total Energy Wheel allows for significant energy savings in cooling mode.

In heating mode there are additional energy savings by increasing the incident air temperature on the heating coil from 10° F to approximately 45° F. It is evident from these results that the use of the Total Energy Wheel, while increasing capital cost, has a very significant impact on the energy usage of the building. The capital cost for the energy wheel is included in the cost of the dedicated outdoor air handling units. Energy savings from the use of the energy wheel are summarized in the energy modeling section of this report.

4.6 Ductwork and Insulation Reduction

Compared to the as-designed mechanical system utilizing a VAV system, the redesigned mechanical system will be able to use less ductwork. Using R.S. Means Mechanical Cost Data-2008 it was determined that the average multi-zone rooftop uses 185 lbs of sheet metal ductwork and 104 SF of insulation per ton of cooling. Because a significant amount of cooling is removed from the dedicated outdoor air units and placed on the unitary heat pumps the amount of sheet metal and duct insulation can be reduced.

The design currently implemented in the Alumni Center need to move approximately 202 tons of cooled air through the VAV system. The designer of this system estimated that the cost for ductwork and insulation for this design would amount to \$117,450 and \$73,080 respectively. In the new DOAS system the main duct runs through the building are smaller because only 57 tons of cooled air is being distributed and only limited ductwork is needed from each of the heat pumps to the conditioned spaces. In this new design sheet metal costs are reduced to \$109,000 at a price of \$10.30 per lb of sheet metal. And insulation costs are reduced to \$61,950 at a cost of \$10.50 per SF of insulation.

The total savings from the reduction of ductwork and insulation amounts to \$19,580.

5.0 Annual Energy Usage

Trane Trace 700 was utilized to estimate the annual energy usage for the Alumni Center. Information to construct the building model was gathered from design documents from both the architect and mechanical engineer. This section summarizes the energy models analyzed for this project.

5.1 Designs Analyzed

LEED Baseline Model

A baseline energy model was built in compliance with Appendix G of ASHRAE Standard 90.1 to compare to the energy models was built to match the other designs. The baseline energy model uses direct expansion cooling and natural gas fired boilers to provide hot water to the heating coils.

Original Design

An energy model depicting the original mechanical design of the project is included in this study. The original design for the project included a central plant that included several air-cooled chillers with a water/glycol mix for the chilled water coils of each AHU and a central boiler system that provided hot water to the heating coils of each AHU and the reheat coils in each VAV box. This energy model is included to meet the MAE thesis requirements of incorporating the content of master's level courses into the thesis project. This energy model draws from both AE 557 (Central Cooling Systems) and AE 558 (Central Heating Systems).

As-Designed

The design implemented for this project including direct expansion AHU's with gas heat is included to compare with all other designs

Re-Design

The redesigned mechanical system with unitary water-to-air ground source heat pumps and dedicated outdoor air system is modeled and compared directly to the as-designed case to determine possible energy savings and to the LEED baseline case to determine if LEED credits are available for reduction in energy costs

5.2 Assumptions

All of the assumptions made in Section 4 of this report are relevant to the energy models analyzed in this section. A summary of the additional basic assumptions used to create the building energy models are included below.

Equipment Efficiencies

All equipment was modeled with the efficiencies and EER's as specified in the design documents, ASHRAE Standard 90.1 Appendix G or Section 4 of this report.

Supply and Return Fan Types and Energy Use

All supply and return fan types were taken from the equipment schedules on the design documents and their energy use is based on the Horsepower listed on the same schedule. For the re-designed mechanical systems the same fan types were used in each dedicated outdoor air handling unit that replaced and existing AHU. Fan motor mechanical efficiency was assumed to be 75% for all fans.

Domestic Hot Water Demand

There are two gas-fired water heaters in the Alumni Center. One serves the normal domestic hot water loads of the restrooms while the other serves the hot water needs of the commercial kitchen. The energy use information for the water heaters was obtained from the plumbing design documents and they follow the schedules in Tables 23 and 24. This information was static in all energy models.

Table 23 – Domestic Hot Water Load Schedule

	Domestic Hot Water
12 am - 8 am	0.0
8 am - 10 am	55.0
10 am - 11 am	50.0
11 am - 12 pm	55.0
12 pm - 1 pm	90.0
1 pm - 2 pm	60.0
2 pm - 3 pm	80.0
3 pm - 4 pm	70.0
4 pm - 5 pm	75.0
5 pm - 7 pm	30.0
7 pm - 8 pm	50.0
8 pm - 9 pm	5.0
9 pm - 12 am	0.0

Table 24 – Kitchen Hot Water Load Schedule

	Kitchen Hot Water
12 am - 8 am	5.0
8 am - 11 am	70.0
11 am - 2 pm	60.0
2 pm - 5 pm	40.0
5 pm - 11 pm	80.0
11 pm - 12 pm	20.0

Electric Rates

The West Virginia University receives their electricity from a subsidiary of Allegheny Power. They are charged based on the General Service Rate Schedule D. The rate structure is comprised as follows:

Customer Charge: \$0 per month

Demand Charge: \$11.46 per kilowatt per month for the first 500 kilowatts and \$10.25 per kilowatt per month above 500 kilowatts

Energy Charge: \$0.02327 per kilowatt-hour

Natural Gas Rates

Natural gas is delivered to the site by Dominion Peoples. They are charged based on Rate CS-S for small commercial buildings. The rate structure is comprised as follows:

Customer Charge: \$18.38 per month
 First 5 MCF: \$14.9672 per MCF
 Next 5 MCF: \$14.4283 per MCF
 Next 20 MCF: \$13.9821 per MCF
 Over 30 MCF: \$13.7310 per MCF

5.3 Annual Energy Cost and Consumption Results

The results of the energy models follow in a logical order. The most expensive design on an annual basis is the LEED baseline condition which uses low efficiency equipment. The as-designed case and the original design followed the LEED baseline condition in annual energy costs. The re-designed mechanical system was a significant improvement on all other cases as shown in Figures 4 and 5. Table 25 summarizes the annual energy cost savings of each design.

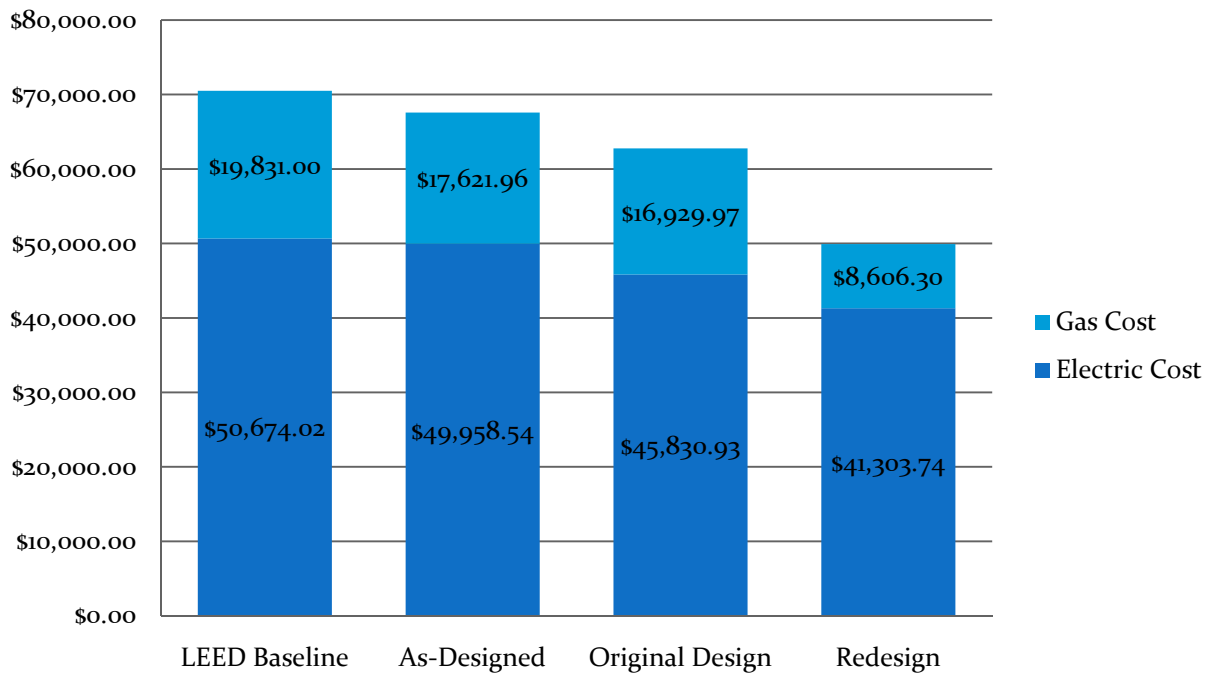


Figure 4 – Annual Energy Costs (\$)

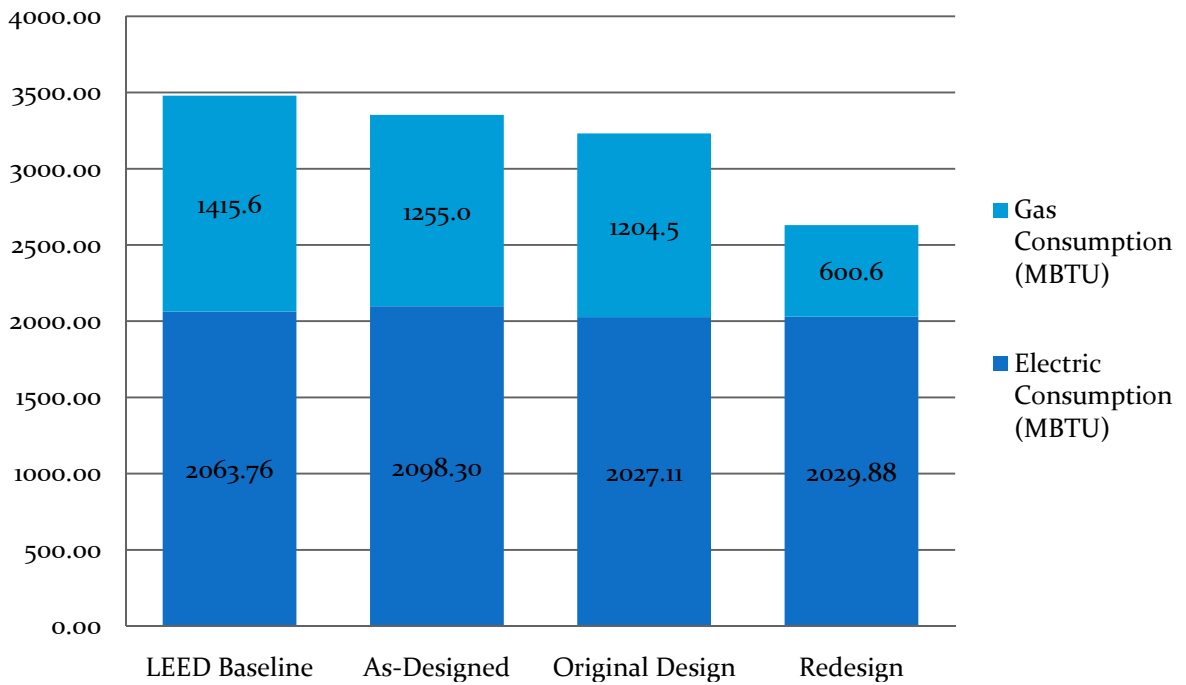


Figure 5 – Annual Energy Consumption (MBH)

Table 25 – Annual Energy Cost Savings

	Savings Over LEED Baseline (\$ and %)	Savings Over Original Design (\$ and %)	Savings Over As-Designed (\$ and %)
As-Designed	\$2,924 (4.15%)	(-) \$4,820 (-7.68%)	\$0 (0%)
Original Design	\$7,744 (10.98%)	\$0 (0%)	\$4,820 (7.13%)
Redesign	\$20,595 (29.21%)	\$12,851 (20.48%)	\$17,670 (26.15%)

It is evident from these energy modeling results that the re-designed mechanical system provides the best energy performance of the 4 systems at an annual energy cost of \$49,910. The GSHP/DOAS system saves almost 30% in energy costs annually when compared to the LEED baseline system and 26% annually in energy costs when compared to the design that was actually implemented.

The redesigned system uses a comparable amount of electricity as the other three designs, at approximately 2000 MBH annually; however, the energy consumption comes at less on-peak hours and therefore result in lower annual electricity costs of \$41,303 compared to \$45,830-\$50,674 for the other designs. Additionally, the redesigned mechanical system uses about 50% less natural gas than any of the other three designs. This is because the only equipment in the new mechanical design that utilizes natural gas is the domestic and kitchen hot water boilers. All other natural gas equipment has been eliminated and that results in significant energy savings.

5.4 LEED Implications

The Alumni Center project was never envisioned as a LEED certified project and therefore no serious strives were made toward meeting any LEED criteria in the original design. However, with the GSHP/DOAS system the Alumni Center would be eligible for LEED credits for Credit 1 in the Energy and Atmosphere category. Since the redesign saves 29% annually over the LEED baseline design the Alumni Center project would be eligible for 6 LEED Credits. With additional credits available for using R-410a in the heat pumps and dedicated outdoor air units the project would already be 25% toward gaining LEED Certified status. This may be the starting point for the owner to realize that they can obtain a LEED accredited building and may encourage them to invest in other opportunities that will allow them to gain the additional credits needed to gain LEED Certified status.

5.5 Greenhouse Gas Emissions

The implementation of the GSHP system will significantly reduce emission levels of gasses that are believed to be influencing global warming such as Carbon Dioxide (CO₂), Sulfur Dioxide (SO₂), and Nitrous Oxides (NO_x). Table 26 summarizes the annual greenhouse gas emissions of all four designs analyzed.

Table 26 – Annual Greenhouse Gas Emissions

System	CO2 (lbm/year)	SO2 (gm/year)	NOX (gm/year)
LEED Baseline	4564213	28997	13026
As-Designed	4525440	28751	12916
Original Design	4366988	27744	12463
Redesign	3994208	25376	11400

The results of this greenhouse gas emissions study shows that the redesigned mechanical system will save 12% in CO₂, SO₂, and NO_x emissions annually over the currently implemented design. This is a tremendous reduction that will have a largely positive impact on the environment.

6.0 Ground Loop Sizing

6.1 Sizing Method

The method described in Chapter 32 of the 2007 ASHRAE Handbook-HVAC Applications for the sizing of vertical ground loops was followed in order to properly determine the total length of vertical ground loop piping necessary for the Alumni Center project. The equations in the ASHRAE handbook include expressions for three different pulses of heat in order to account for long-term temperature variations of the soil. Equations (1) and (2) are provided to determine the required length to meet the cooling and heating loads of the building respectfully. The longer length of the two solutions is the length that the system should be designed for.

$$(1) L_c = \frac{q_c R_a + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_m + R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

$$(2) L_h = \frac{q_h R_a + (q_{lh} - 3.41 W_h)(R_b + PLF_m R_m + R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

The variables and units for equations (1) and (2) are assigned as:

F_{sc} = short circuit heat loss factor

L_c = required bore length for cooling, ft

L_h = require bore length for heating, ft

PLF_m = part load factor during design factor

q_a = net annual average heat transfer to the ground, BTU/h

q_{lc} = building design cooling block load, BTU/h

q_{lh} = building design heating block load, BTU/h

R_{ga} = effective thermal resistance of ground (annual pulse), h-ft²-°F/BTU

R_{gd} = effective thermal resistance of ground (daily pulse), h-ft²-°F/BTU

R_{gm} = effective thermal resistance of ground (monthly pulse), h-ft²-°F/BTU

R_b = thermal resistance of pipe, h-ft²-°F/BTU

t_g = undisturbed ground temperature, °F

t_p = temperature penalty for interference of adjacent bores, °F

t_{wi} = liquid temperature at heat pump inlet, °F

t_{wo} = liquid temperature at heat pump outlet, °F

W_c = power input at design cooling load, W

W_h = power input at design heating load, W

6.2 Assumptions

In order to use the sizing method described above, several assumptions needed to be made to define the variables in the equations. The following assumptions were made.

Part Load Factor

Because actual building performance data is not available for this project no part load factors are known. In this case the worst case scenario was assumed and a part load factor of 1.0 was applied to the variable PLF_m .

Thermal Resistance of Pipe

To determine the thermal resistance of the pipe it was assumed that the Polyethylene U-tube ground loops would be 1" in diameter and placed in a 6" borehole with bore fill conductivity of 1.0 BTU/ h-ft²-°F. With these assumptions made the thermal resistance of the pipe (R_b) was determined to be 0.1 h-ft²-°F/BTU

Heat Pump Inlet/Outlet Water Temperature

The heat pump inlet water temperatures in heating and cooling are described in Section 4.3 of this report. A 10°F ΔT was used to determine the heat pump outlet water temperatures.

Power Input at Design Heating/Cooling Load

To account for the heat added to the ground loop water from the circulation pumps, a reasonable assumption of the equivalent of one 20 HP pump worth of heat was added to ground loop water. This equates to a W_c and W_h of 14,914 BTU/h.

Other Variables

Following the procedure laid out in Chapter 32 of the HVAC Application Handbook all of the other variables were determined. Their determination included intermediate calculations as well as reading values from graphs. It is assumed that the intermediate calculations and graph readings are within a reasonable amount of error of the correct solutions.

6.3 Results

After entering equations (1) and (2) into Engineering Equation Solver (EES) with all of the appropriate variables defined results were calculated for the required borehole length to meet the heating and cooling loads. Tables 27 and 28 summarize those results.

Table 27 – Required Borehole Length Results for Heating

Entering Water Temp (°F)	Exiting Water Temp (°F)	Heating Load (MBH)	Total Borehole Length (ft)
45	35	945	25852

Table 28 – Required Borehole Length Results for Cooling

Entering Water Temp (°F)	Exiting Water Temp (°F)	Cooling Load (MBH)	Total Borehole Length (ft)
75	85	892.8	19858

As is evident from these two tables, the heating load is dominant in the building and therefore requires a longer borehole length. The total required borehole length is 25,852 ft. In the construction breadth section of this report an extensive optimization study will be performed to determine the best combination of number of boreholes vs. length of each borehole. The results of that optimization study show that 115 boreholes at a depth of 225 ft each will minimize the impact on capital cost and construction schedule.

To reduce the need for large diameter piping among other reasons, the ground loop field will be divided into 23 sets of 5 boreholes each. Figure 6 shows the planned borehole field layout. In addition to the required 25,852 ft of vertical piping run-out piping will be installed to reach from the building's mechanical room to each of the vertical well fields. This piping will be buried at a shallow depth below the surface that will not interfere with other utilities crossing the site. Each set of boreholes will be set up in a reverse return fashion so as to equalize the pressure drop across all sets of boreholes.

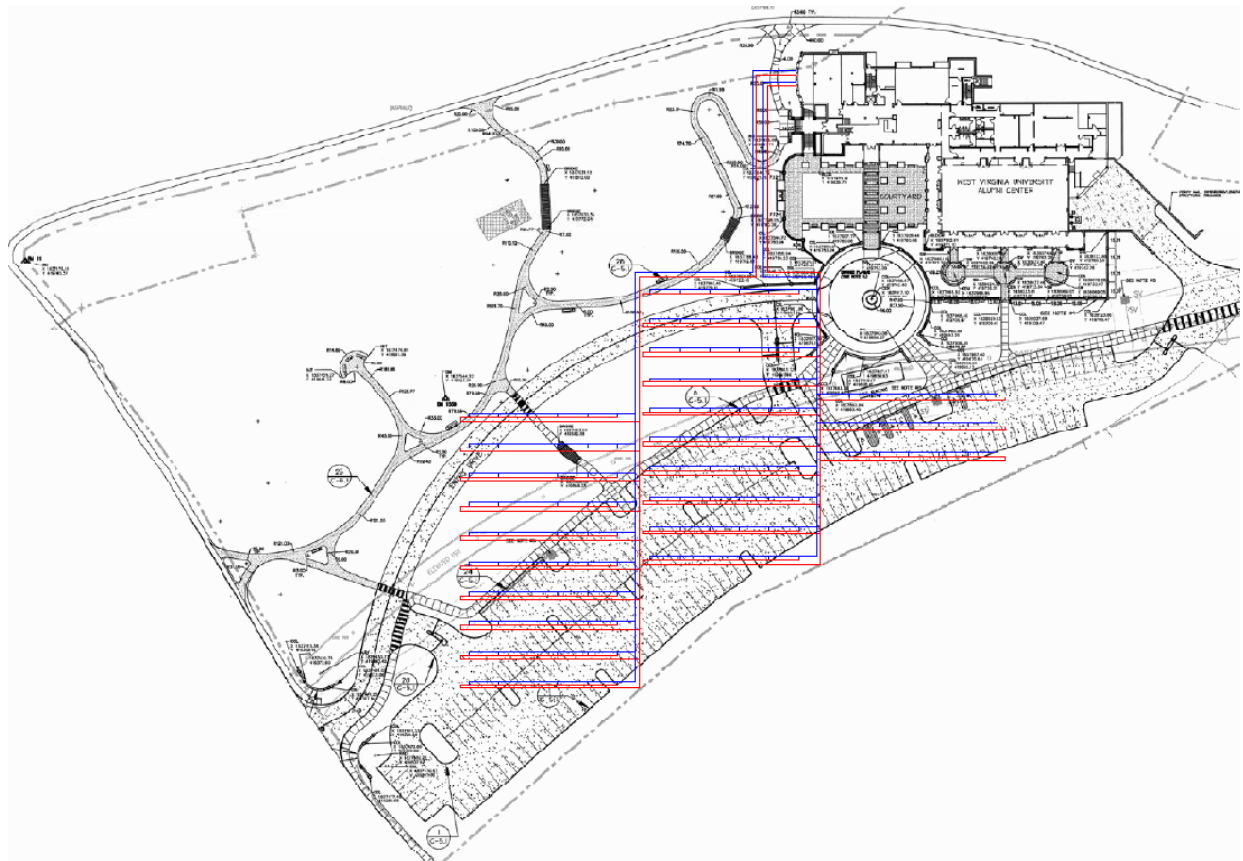


Figure 6 – Borehole Field Layout

7.0 Construction Management Breadth

7.1 Borehole Construction Goals

The implementation of a GSHP system has immediate and direct impacts on the construction cost and schedule. The goal of the construction of the boreholes is to meet the requirements of the mechanical design with the lowest capital cost while not significantly impeding the construction schedule. If not planned correctly, the construction of the vertical borehole field can become extremely expensive and time consuming. High construction costs and extended construction times are realized when the optimal combination of all equipment, materials and man-hours is not utilized. So the two goals of this construction breadth study are to determine the optimal number/length of boreholes and ensuring that the construction sequence for the boreholes will fit in well with the existing construction schedule.

7.2 Equipment and Material Assumptions

Ground Loop Piping

As stated in the assumptions for calculating the required borehole length the ground loop piping has been sized at 1" diameter. This piping is made of High Density Polyethylene (HDPE) and is priced at \$1.32 per linear foot.

HDPE piping will need to be fused together at 40 ft intervals at a cost of \$20 per weld and \$50 per day rental of a fusion unit according to R.S. Means Mechanical Cost Data-2008.

Borehole Driller

Depending on the depth of the borehole, different drill rigs will need to be used. Listed here are the depth of borehole, weekly rental cost and daily output taken from R.S. Means Mechanical Cost Data-2008.

- Drilling deeper than 325 feet: \$16,000/wk rental, 900 ft/day
- Drilling between 225 and 325 feet: \$14,000/wk rental, 1200 ft/day
- Drilling less than 225 feet: \$11,500/wk rental, 1800 ft/day

Borehole Grouting

Grouting of the boreholes is performed at a fixed price for all combinations of length/number of boreholes as it is dependant only on total length of boreholes. The fixed cost of borehole grouting is \$5,780.

Miscellaneous Site Costs

Additional site costs from the purge and testing of the system plus additional unforeseen conditions is set based on the number of boreholes and increases linearly with the number of boreholes.

7.3 Optimization Study Results

The assumptions made in Section 7.2 of this report were incorporated into a Microsoft Excel spreadsheet to determine the optimal outcome of all possible combinations of number and depth of boreholes. The spreadsheet can be seen in Appendix 3. In Figure 7 the red circle shows that the most optimal combination is to implement 115 boreholes at a cost of \$143,096. 115 boreholes at a depth of 225 feet each will meet the requirement of 25,852 total feet of ground loop piping.

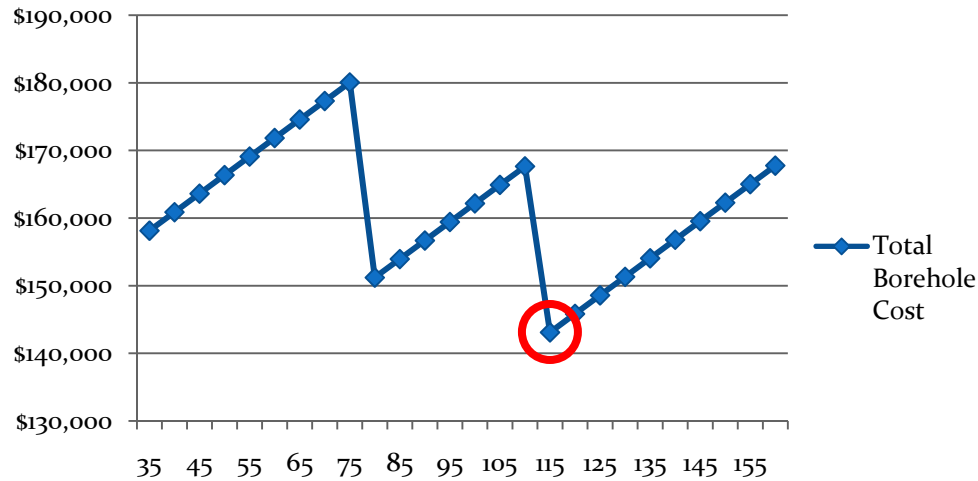


Figure 7 – Number of Boreholes vs. Cost

The large jumps in price show a shift from one drill rig to another, which turned out to be the deciding factor in the optimization study. Using a drill rig that could drill more feet per day is beneficial, especially when attempting to fit the borehole field construction into the existing construction schedule.

An additional way to determine the optimal combination of borehole length/depth/cost is to utilize a three-dimensional plot. The results of the Excel spreadsheet were exported to Engineering Equation Solver (EES) to construct a three-dimensional plot. Figure 8 shows the results of the three-dimensional plot. On the X-axis is the borehole length; on the Y-axis is the number of boreholes. The color gradient, the third dimension, shows the overall cost of each combination of borehole number and length. Red shows high cost and moving through orange, yellow and green gives lower cost with the lowest cost coming at the dark blue portion of the figure. The plot turns dark blue at the intersection of $L_b=225$ and $N_b=115$ at a cost of \$143,096.

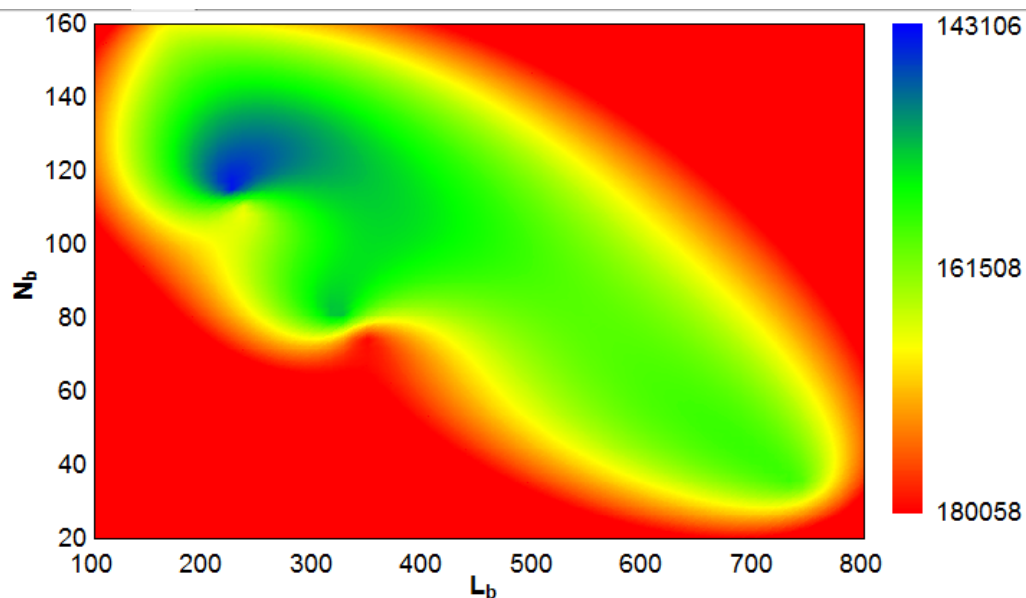


Figure 8 – Three-Dimensional Borehole Optimization

7.4 Construction Schedule Impact

To ensure that the implementation of the GSHP/DOAS design does not add significant cost to the project the impact on the construction schedule must be evaluated. The simplified existing construction schedule is shown in Appendix 4. Site preparation was scheduled to begin on June 20, 2007 with Substantial Completion on August 1, 2008. The goal is to fit the necessary construction activities into the time period allotted for them. The new construction activities and approximate durations (according to R.S. Means Site Work Cost Data-2008 and Mechanical Cost Data-2008) that must be incorporated into the existing schedule are:

- Test Bore Construction and Testing – 3 weeks
- Site Grading and Sediment Control – 4 weeks
- Borehole Drilling – 4 weeks (at previously optimized number/depth)
- Ground Loop Piping and Grouting – 2 weeks
- Interior Piping and Equipment Installation – 12 weeks
- Heat Pump Connections – 5 weeks
- Flush and Test Ground Loops – 2 weeks
- Testing and Air Balancing – 2 weeks
- Plumbing Fit-out – 12 weeks

At the beginning of construction the only major activity is the structural erection of the building. Structural erection begins in mid-July 2007 and continues until early January 2008. Since the borehole field is located away from the structure it is possible to perform the first 4 new activities during the structural erection of the building as shown in Appendix 5.

The current construction schedule has plumbing and mechanical fit-out scheduled from February 2008 through mid-August 2008. In this period of time the Interior Piping and Equipment Installation, Heat Pump Connections, Flushing and Testing of Ground Loops, Testing and Air Balancing and Plumbing Fit-out can all be accomplished as outlined in Appendix 5.

The most daunting task on coordinating the new construction activities with the existing construction schedule was finding the time to drill the boreholes. It is convenient that the borehole field is not located directly adjacent to the building. This allowed the borehole drilling to be conducted at the same time as structural erection and allows the entire project to stay on the existing construction schedule.

All of the interior mechanical and plumbing fit-out work fits easily into the existing timetable for those activities and construction can maintain the pace sought after by the general contractor. Overall, the construction duration is not affected and the only additional costs to the project come from the cost to do the work and not from extending the construction schedule.

8.0 Electrical Breadth

8.1 Electrical Redesign Goals

The removal of the packaged VAV rooftop systems in the Alumni Center and its replacement with the ground source heat pump and dedicated outdoor air systems changes the loads on the electrical distribution network in the building. There is a main distribution switchboard for the mechanical equipment that feeds multiple panels with mechanical equipment connections. With the removal of the packaged VAV rooftop system the VAV box loads can be removed from the panels along with all of the rooftop AHU's. However, all of the new heat pump loads and dedicated outdoor air unit loads must then be added to the panels. The goal of this electrical breadth investigation is to determine the new loads connected to the main mechanical equipment switchboards with sizing of new feeders to each panel and sizing of new breakers. The monetary impact of these changes will be included in the results.

8.2 Assumptions

Demand Factors

Demand factors were used to accurately size the electrical equipment (breakers and feeders). The following demand factors were assumed:

- Lighting: 1
- Receptacles: 0.5
- Motors: 0.3
- Miscellaneous: 1
- Kitchen: 0.66
- Data: 0.5
- A/C: 1

Phase Balancing

All electrical panel loads were assigned to closely balance the loads across all three phases. All phases are within 2.5% of each other on all panels that were affected by the redesign

Voltage

All existing VAV boxes and AHU's that were removed were 480V, 3-Phase models. With this in mind, all new dedicated outdoor air units and heat pumps were selected to match that voltage.

8.3 Equipment Added/Removed

Tables 29-31 summarize the equipment that was removed from each panel, their associated breakers and wires and show the equipment that was added and their associated breakers and wires. Existing panel schedules are available in Appendix 6 and new panel schedules are available in Appendix 7.

Table 29 – Panel HPG Added/Removed Loads

Equipment Removed	# Poles	CB Size	# Sets	Wire Qty/Set	Conductor Size	Ground Size	Conduit Size
AHU-3	3	70	1	3	#4	#8	1-1/4"
AHU-4	3	70	1	3	#4	#8	1-1/4"
AHU-5	3	70	1	3	#4	#8	1-1/4"
AHU-6	3	70	1	3	#4	#8	1-1/4"
AHU-7	3	70	1	3	#4	#8	1-1/4"
VVB-008A	3	20	1	3	#10	#10	3/4"
Equipment Added	# Poles	CB Size	# Sets	Wire Qty/Set	Conductor Size	Ground Size	Conduit Size
DOAHU-3	3	90	1	3	#2	#8	1-1/4"
DOAHU-4	3	90	1	3	#2	#8	1-1/4"
DOAHU-5	3	90	1	3	#2	#8	1-1/4"
DOAHU-6	3	90	1	3	#2	#8	1-1/4"
DOAHU-7	3	110	1	3	#1	#8	1-1/2"
Spare	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 30 – Panel HMR Added/Removed Loads

Equipment Removed	# Poles	CB Size	# Sets	Wire Qty/Set	Conductor Size	Ground Size	Conduit Size
AHU-1	3	90	1	3	#2	#8	1-1/4"
WB-005	3	20	1	3	#10	#10	3/4"
WB-011A	3	20	1	3	#10	#10	3/4"
WB-004B	3	20	1	3	#10	#10	3/4"
WB-003A/B	3	20	1	3	#10	#10	3/4"
WB-004A	3	20	1	3	#10	#10	3/4"
WB-103,106	3	20	1	3	#10	#10	3/4"
WB-003B,115	3	20	1	3	#10	#10	3/4"
WB-002	3	20	1	3	#10	#10	3/4"
WB-110,116	3	20	1	3	#10	#10	3/4"
WB-111,112	3	20	1	3	#10	#10	3/4"
WB-102	3	20	1	3	#10	#10	3/4"
Equipment Added	# Poles	CB Size	# Sets	Wire Qty/Set	Conductor Size	Ground Size	Conduit Size
DOAHU-1	3	90	1	3	#2	#8	1-1/4"
HP-003	3	20	1	3	#10	#10	3/4"
HP-004A/B/C	3	20	1	3	#10	#10	3/4"
HP-011A/B,002	3	20	1	3	#10	#10	3/4"
HP-102,103	3	20	1	3	#10	#10	3/4"
HP-106/110,111,112	3	20	1	3	#10	#10	3/4"
HP-030A/B	3	20	1	3	#10	#10	3/4"
HP-030C/D	3	20	1	3	#10	#10	3/4"
HP-032A/B,034	3	20	1	3	#10	#10	3/4"
HP-030E/F	3	20	1	3	#10	#10	3/4"

Table 31 – Panel HMR₁ Added/Removed Loads

Equipment Removed	# Poles	CB Size	# Sets	Wire Qty/Set	Conductor Size	Ground Size	Conduit Size
WB-203A/B	3	20	1	3	#10	#10	3/4"
WB-209A/B/C	3	20	1	3	#10	#10	3/4"
WB-210,216	3	20	1	3	#10	#10	3/4"
WB-201,226	3	20	1	3	#10	#10	3/4"
WB-218	3	20	1	3	#10	#10	3/4"
WB-208	3	20	1	3	#10	#10	3/4"
Equipment Added	# Poles	CB Size	# Sets	Wire Qty/Set	Conductor Size	Ground Size	Conduit Size
HP-115,116,201	3	20	1	3	#10	#10	3/4"
HP-203,205	3	20	1	3	#10	#10	3/4"
HP-226,208/209	3	20	1	3	#10	#10	3/4"
HP-209A,210/216	3	20	1	3	#10	#10	3/4"
Spare	3	20	1	3	#10	#10	3/4"
HP-218	3	20	1	3	#10	#10	3/4"

8.4 Electrical Cost Results

The changes to the electrical distribution system are minimal. Five AHU’s have increased conductor sizes and breaker sizes. Other equipment has either been eliminated or has changed conduit sizes. Tables 32-34 summarize the additional electrical equipment costs. Table 32 shows the additional costs for conductors, with negative length indicating that wiring was removed to be replaced with a different size. Table 33 shows the cost change for conduit, with negative length again indicating that conduit was removed to be replaced with a different size. Table 34 summarizes the additional cost for the resized breakers. A negative quantity means that breakers were removed to be replaced with a new size. The total additional electrical cost is -\$392.49. This means that the changes to the air-side mechanical system save almost \$400 on electrical costs.

Table 32 – Conductor and Ground Wire Cost Adjustment

Conductor/Ground Size	Cost Per 100 Linear Ft	FT Wire	Cost
#2	\$122.50	1032	\$1,264.20
#1	\$195.00	258	\$503.10
#4	\$97.50	-1290	-\$1,257.75
#10	\$46.00	-289	-\$132.94

Total Conductor Cost:	\$376.61
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Table 33 – Conduit Cost Adjustment

Conduit Size	Cost Per 100 Linear Ft	FT Wire	Cost
3/4"	\$4.35	-72	-\$3.13
1-1/4"	\$5.75	-258	-\$14.84
1-1/2"	\$6.30	258	\$16.25

Total Conduit Cost:	-\$1.71
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Table 34 – Breaker Cost Adjustment

Breaker Size	Cost per	#	Cost
90A/3P	\$535.00	4	\$2,140.00
70A/3P	\$511.00	-5	-\$2,555.00
110A/3P	\$555.00	1	\$555.00
20A/3P	\$454.00	-2	-\$908.00

Total Conduit Cost:	-\$768.00
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9.0 Overall Cost Analysis

Through the redesign of the Alumni Center project there have been costs added and costs subtracted from the project total cost. In order to determine whether the project redesign is a success, a life-cycle cost comparison between the current design and the redesigned projects must be conducted. A typical 20- year life-cycle cost comparison was conducted to determine the benefits of the redesign. For the redesign to be considered a success the payback period of investing in the redesign must be below seven years. Many owners consider seven years the payback limit for accepting a design alternative.

9.1 Assumptions

The following assumptions were used to calculate the life-cycle cost of both the currently implemented mechanical design and the GSHP/DOAS redesign.

Mechanical Equipment Cost

The total capital cost for the mechanical system that is currently implemented is based on the estimate put together by the design engineer. The total cost is \$1,420,000.

The capital cost of the redesigned mechanical system uses the estimate for the currently implemented design and modifies it based on equipment that was removed, replaced or added; changes in sheet metal cost; changes in required ductwork insulation; and added construction cost of the borehole field. The total cost for the redesigned system is \$1,511,000. This amounts to a capital cost increase of 7%.

Complete estimates are available in Appendix 8 (existing) and 9 (redesign).

Future Cost Items

Future cost items such as equipment replacement; preventive maintenance and annual inspection are included in the cost analysis. The following future cost items were assumed for the currently implemented design:

- AHU-1 has annual costs of \$215 with expected replacement at year 10 at a cost of \$30,375
- AHU-2 has annual costs of \$465 with expected replacement at year 10 at a cost of \$48,750
- AHU-3 has annual costs of \$215 with expected replacement at year 10 at a cost of \$24,600
- AHU-4, AHU-5 and AHU-6 have annual costs of \$215 with expected replacement at year 10 at a cost of \$22,050 each
- AHU-7 has annual costs of \$215 with expected replacement at year 10 at a cost of \$18,000
- VAV boxes have an annual cost of \$66 per box with expected replacement in year 19 at a cost of \$875 per box

The following future cost items were assumed for the redesigned system:

- DOAHU-1,2,3,4,5,6,7 have an annual cost of \$125 with expected replacement at year 10 at a cost of \$12,231 each
- Heat pumps have an annual cost of \$30 with expected replacement at year 19 at a cost of \$5207 per heat pump

All future cost items are brought back to Present Values utilizing an expected inflation rate of approximately 2% annually.

Energy Costs

Energy costs as calculated for Section 5 of this report are used in the life-cycle cost analysis. The currently implemented design has an annual energy cost of \$67,580 while the redesigned system has an annual energy cost of \$49,910.

9.2 Life-Cycle Cost Results

After taking into account all of the cost items for these two designs over a 20 year life-cycle the results show that the redesigned system would be a success. As shown in Table 35, the redesigned system saves \$380,400 over the span of 20 years at an average of \$19,220 per year. At that pace it will only take 4.99 years to payback the additional \$91,000 needed to construct the redesigned system.

Table 35 – 20-Year Life-Cycle Cost Comparison

System	Capital Cost	Maintenance and Replacement	Energy Costs	Total Present Value Cost	Savings	Simple Payback
As-Designed	\$1,420,000	\$218,000	\$1,351,600	\$2,989,600	-	N/A
Redesign	\$1,515,000	\$96,000	\$998,200	\$2,609,200	\$380,400	4.99

10.0 Summary and Recommendations

While the low construction cost, minimal space requirements and low maintenance cost create a positive feeling for the current design, these factors alone do not provide the entire picture of the system. The AHU's that were specified by the design engineer are available in both R-22 and R-410a models. To reduce the first cost, the mechanical contractor chose to install the R-22 version of the AHU's. Starting in 2020, R-22 will no longer be produced or imported in accordance with the Montreal Protocol because it is harmful to the ozone layer and may cause global warming. That deadline is only 12 years away, and the expected life of a rooftop AHU is approximately 15-20 years.

This is not to say that the current mechanical system is inadequate or fails to meet the needs of the building. The design engineers were faced with the difficult task of providing a comfortable environment for the building occupants on a small budget. The engineers provided a carefully designed system that meets all of the design requirements for the building. Since the decision for the mechanical system was based on a first-cost only basis, due to fund-raising limitations, the design team provided the best system for the most appropriate price.

However, the implementation of the ground source heat pump and dedicated outdoor air systems is strongly recommended as an alternative to the current design. This recommendation is based on the analysis described in this report that demonstrated that the redesigned mechanical system has many benefits.

The first and most obvious benefit of implementing the redesigned mechanical system is the reduced annual energy costs. Because the Alumni Center is owner occupied, a reduction in annual energy costs equates to more funds available for alumni events. An annual energy cost reduction of \$17,670 over the current design would allow the Alumni Association to provide many more services to their members.

Going along with the reduction in annual energy cost is a reduction in annual green house gas emissions. The GSHP/DOAS redesign reduces greenhouse gas emissions by 12% over the current design and such a significant reduction would be something for the Alumni Association to be proud of.

While the capital cost of the redesigned mechanical system is approximately 7% greater than the current design, the benefits of the redesign outweigh the increased initial cost. The significant reduction in annual energy costs, coupled with reductions in annual maintenance and replacement costs and reductions in electrical system costs equate to a 20-year life-cycle savings of \$380,400. These life-cycle savings allow for a simple payback period of 5 years. Many owners use a floating limit on simple payback periods of approximately 7 years to determine whether to implement a design alternative. With a payback period of 5 years, the redesigned mechanical system should appear beneficial to most owners.

Because the Alumni Association's funding is limited to the amount that they can receive in donations from their members, a 7% increase in capital cost is substantial. In order to raise the additional funds needed to meet the construction cost the Alumni Association could advertise to their members that they were

investing in a sustainable technology that would allow the Association to provide more services to the members in the long run by reducing annual costs. By widely publicizing their interest in sustainable heating and cooling measures the Association may be able to have the additional funding needed to meet the 7% capital cost increase donated.

As long as the Alumni Association can meet the fund-raising goal required to implement the redesigned mechanical system, it is strongly believed that it could be implemented successfully.

11.0 Credits and Acknowledgements

I would like to express my gratitude to those that helped me during the process of completing this year long study on the West Virginia University Alumni Center. The following people helped me tremendously:

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Appendix 1-Existing Equipment Summary

	Total CFM	% OA	Supply Fan Data		Cooling Coil		Condenset Fans		Gas Furnace		Exhaust/Return		Phase/Volt		
			Total SP	Fan I/P	Fan VFD	TOT MBH	SENS MBH	QTY	Fan I/P	Input MBH	Output MBH	CFM		I/P	VTD
AHU-1	8550	25	3.97	15	Yes	306	235	3	0.75	270	218.7	8150	7.5	Yes	3//80V
AHU-2	1/1900	35	1.28	2(15)	Yes	62/1	153	1	0.75	780	632	1/1900	15	Yes	3//80V
AHU-3	4725	25	3.24	7.5	Yes	171	130	2	0.75	270	218.7	4725	2(5)	Yes	3//480V
AHU-4	5000	50	2.85	7.5	No	224	157	2	0.75	390	315.9	5000	3	No	3//480V
AHU-5	5000	50	2.85	7.5	No	224	157	2	0.75	390	315.9	5000	3	No	3//480V
AHU-6	5000	50	2.85	7.5	No	224	157	2	0.75	390	315.9	5000	3	No	3//480V
AHU-7	5455	100	3.16	7.5	No	305	197	4	0.75	780	631.8	5455	5	Yes	3//480V
AHU-8	8620	100	2.5	15	No	347	269	4	0.75	940	750	10000	7.5	No	3//480V
AHU-9	10000	20	3.53	15	No	347	269	4	0.75	540	437	10000	7.5	No	3//480V

Appendix 2 – Additional Design Load Assumptions

Typical Wall Construction

Alternative	Alternative 1		
Description	WVU-Alum		
Construction...		U-factor Btu/h-ft ² -°F	
Slab	6" LW Concrete		0.156986
Roof	4" LW Conc		0.033
Wall	Face brick, 2.42" Ins		0.059
Partition	0.75" Gyp Frame		0.387955
Glass type...		U-factor Btu/h-ft ² -°F	Shading coeff
Window	Single Clear 1/4"	0.45	0.8
Skylight	Single Clear 1/4"	0.95	0.95
Height...			
Wall	9	ft	
Fir to flr	12	ft	
Plenum	3	ft	

Typical Lobby

Alternative 1			
Room description 003-Lobby			
Templates...			
Room	Default	People... Activity	Hotel/Motel Lobby
Internal	Lobby	Density	60 sq ft/person
Airflow	Default	Schedule	People - Office
Tstat	Default	Sensible	250 Btu/h
Constr	WVU-Alum	Latent	200 Btu/h
Lights... Type	Recessed fluorescent, not vented, 80% load to space		
Heat gain	1	W/sq ft	Schedule Lights - Office
Miscellaneous loads...			
Misc Load 1	Tag	Misc Load 1	Type None
	Energy	0.5 W/sq ft	Schedule Misc - Low rise office
	Energy meter	Electricity	

Typical Banquet Hall

Alternative 1
 Room description: 030A-Grand Hall 1

Templates...

Room: Default | People... Activity: Restaurant | Schedule: People - Office
 Internal: Grand Hall | Density: 143 | People | Sensible: 275 Btu/h
 Airflow: Default | Latent: 275 Btu/h
 Tstat: Default
 Constr: WVU-Alum | Lights... Type: Recessed fluorescent, not vented, 80% load to space
 Heat gain: 1 | W/sq ft | Schedule: Lights - Office

Miscellaneous loads...

Misc Load 1	Tag: Misc Load 1	Type: None
	Energy: 0.75 W/sq ft	Schedule: Misc - Low rise office
	Energy meter: Electricity	

Typical Meeting Room

Alternative 1
 Room description: 110-Meeting

Templates...

Room: Default | People... Activity: Conference Room | Schedule: People - Office
 Internal: Conference Room | Density: 24 | People | Sensible: 245 Btu/h
 Airflow: Default | Latent: 155 Btu/h
 Tstat: Default
 Constr: WVU-Alum | Lights... Type: Recessed fluorescent, not vented, 80% load to space
 Heat gain: 1 | W/sq ft | Schedule: Lights - Office

Miscellaneous loads...

Misc Load 1	Tag: Misc Load 1	Type: None
Misc Load 2	Energy: 1.5 W/sq ft	Schedule: Misc - Low rise office
	Energy meter: Electricity	

Typical Office

Alternative 1
 Room description: 217-Assistant Director

Templates...

Room: Default | People... Activity: General Office Space | Schedule: People - Office
 Internal: Offices | Density: 1 | People | Sensible: 250 Btu/h
 Airflow: Default | Latent: 200 Btu/h
 Tstat: Default
 Constr: WVU-Alum | Lights... Type: Recessed fluorescent, not vented, 80% load to space
 Heat gain: 1 | W/sq ft | Schedule: Lights - Office

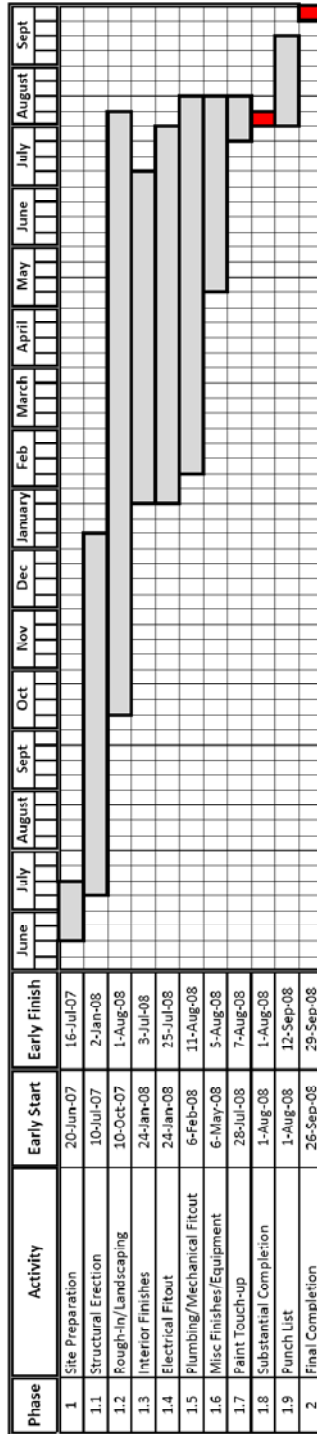
Miscellaneous loads...

Misc Load 1	Tag: Misc Load 1	Type: None
	Energy: 1.5 W/sq ft	Schedule: Misc - Low rise office
	Energy meter: Electricity	

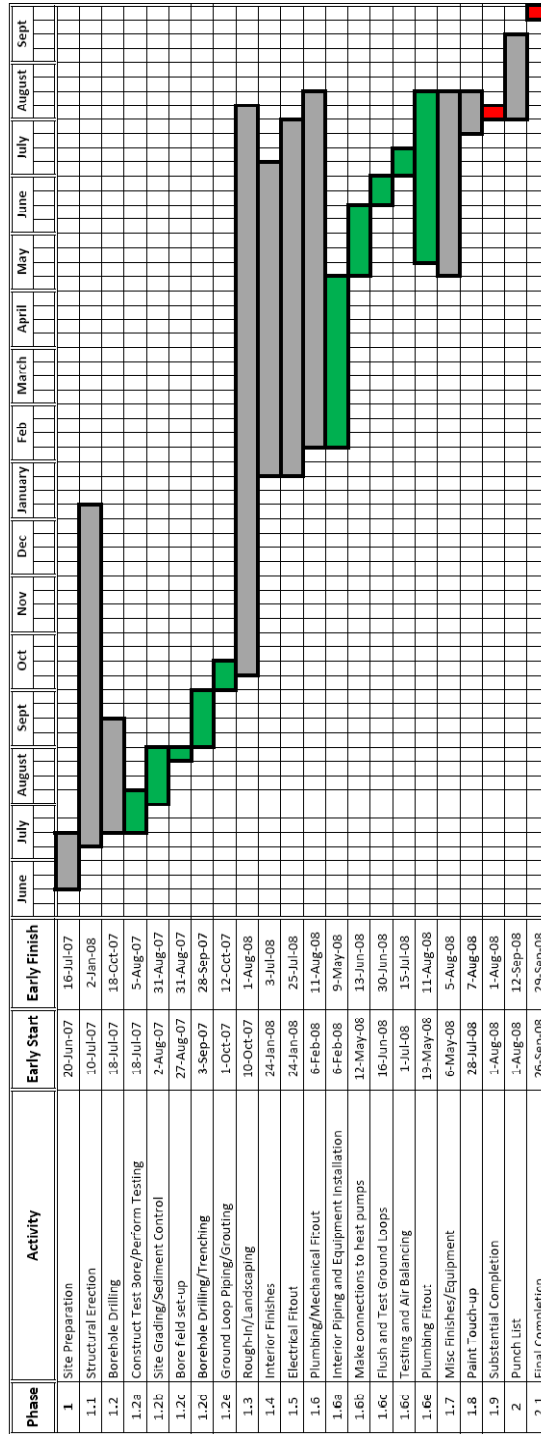
Appendix 3 – Borehole Construction Optimization

Total Length	Length per Bore	# Boreholes	Drilling Cost	Pipe Cost	Grouting Cost	Misc Site Cost	Total Cost
25852	739	35	\$98,011	\$34,345	\$5,780	\$20,000	\$158,136
25852	646	40	\$98,881	\$35,715	\$5,780	\$20,500	\$160,876
25852	574	45	\$99,751	\$37,085	\$5,780	\$21,000	\$163,616
25852	517	50	\$100,622	\$38,455	\$5,780	\$21,500	\$166,357
25852	470	55	\$101,492	\$39,825	\$5,780	\$22,000	\$169,097
25852	431	60	\$102,362	\$41,195	\$5,780	\$22,500	\$171,837
25852	398	65	\$103,233	\$42,565	\$5,780	\$23,000	\$174,578
25852	369	70	\$104,103	\$43,935	\$5,780	\$23,500	\$177,318
25852	345	75	\$104,973	\$45,305	\$5,780	\$24,000	\$180,058
25852	323	80	\$74,247	\$46,675	\$5,780	\$24,500	\$151,202
25852	304	85	\$75,117	\$48,045	\$5,780	\$25,000	\$153,942
25852	287	90	\$75,987	\$49,415	\$5,780	\$25,500	\$156,683
25852	272	95	\$76,858	\$50,785	\$5,780	\$26,000	\$159,423
25852	259	100	\$77,728	\$52,155	\$5,780	\$26,500	\$162,163
25852	246	105	\$78,598	\$53,525	\$5,780	\$27,000	\$164,904
25852	235	110	\$79,469	\$54,895	\$5,780	\$27,500	\$167,644
25852	225	115	\$53,051	\$56,265	\$5,780	\$28,000	\$143,096
25852	215	120	\$53,921	\$57,635	\$5,780	\$28,500	\$145,836
25852	207	125	\$54,792	\$59,005	\$5,780	\$29,000	\$148,577
25852	199	130	\$55,662	\$60,375	\$5,780	\$29,500	\$151,317
25852	191	135	\$56,532	\$61,745	\$5,780	\$30,000	\$154,057
25852	185	140	\$57,403	\$63,115	\$5,780	\$30,500	\$156,798
25852	178	145	\$58,273	\$64,485	\$5,780	\$31,000	\$159,538
25852	172	150	\$59,143	\$65,855	\$5,780	\$31,500	\$162,278
25852	167	155	\$60,014	\$67,225	\$5,780	\$32,000	\$165,019
25852	162	160	\$60,884	\$68,595	\$5,780	\$32,500	\$167,759

Appendix 4 – Existing Construction Schedule



Appendix 5 – Construction Schedule with New Activities



Appendix 6 – Existing Panel Schedules

PANEL HPG					
MAIN <u>400</u> MCB		VOLTAGE <u>480 /277V</u>		MOUNTING <u>SURFACE</u>	
BUSING <u>400</u> AMPS		<u>3-Ph 4-W</u>		LOCATION <u>ELEC 009</u>	
SCR 65,000 AIC				FED FROM <u>HMDS</u>	
NO	DESCRIPTION	CB/P	CB/P	DESCRIPTION	NO
1	BOLLARD LIGHTING	20/1	20/1	PARKING LOT LIGHTING	2
3	ENTRY DRIVE	20/1	20/1	SITE LIGHTING	4
5	COURTYARD LIGHTING	20/1	20/1	COURTYARD LIGHTING	6
7	GARDEN AREA LIGHTING	20/1	20/1	TURN AROUND LIGHTING	8
9	SIDE WALK LIGHTING	20/1	20/1	TREE/LANDSCAPE LIGHTING	10
11	STAIRS/TERRACE LIGHTING	20/1	20/1	PARKING LOT LIGHTING	12
13	PARKING LOT LIGHTING	20/1	20/1	SIGN LIGHTING	14
15	SPARE	20/1	20/1	COURTYARD LIGHTING	16
17	COURTYARD LIGHTING	20/1	20/1	SPARE	18
19	COURTYARD LIGHTING	20/1	50/3	LOADING DOCK	20
21	SPARE	20/1			22
23	SPARE	20/1			24
25					26
27	AHU-7	70/3	15/3	EF-2	28
29					30
31					32
33	AHU-3	70/3	70/3	AHU-4	34
35					36
37					38
39	AHU-5	70/3	70/3	AHU-6	40
41					42
43					44
45	KEF-1	15/3	15/3	KEF-3	46
47					48
49					50
51	KEF-4	15/3	20/3	SPARE	52
53					54
55	SPACE	-	-	SPACE	56
57	SPACE	-	-	SPACE	58
59	SPACE	-	-	SPACE	60
83	SPACE	-	-	SPACE	84

PANEL HMR					
MAIN <u>800</u> MLO		VOLTAGE <u>480 /277V</u>		MOUNTING <u>SURFACE</u>	
BUSING <u>800</u> AMPS		<u>3-Ph 4-W</u>		LOCATION <u>ELEC 009</u>	
SCR 65,000 AIC				FED FROM <u>HMDS</u>	
NO	DESCRIPTION	CB/P	CB/P	DESCRIPTION	NO
1	FT-2	20/1	20/1	FT-2	2
3	FT-2	20/1	20/1	FT-2	4
5	FT-2	20/1	20/1	FT-2	6
7	FT-2	20/1	20/1	RCP-2	8
9			20/1	RCP-1	10
11	CUH-2	20/3	20/1	RCP-1	12
13			20/1	SPARE	14
15					16
17	CUH-2	20/3	20/3	VVB-005, CUH-1	18
19					20
21					22
23	HUH-1	20/3	20/3	VVB-011A	24
25					26
27					28
29	VVB-004B	20/3	20/3	VVB-003A, 003B	30
31					32
33					34
35	VVB-004A	20/3	20/3	HUH-2	36
37					38
39	SPARE	20/1	20/1	SPARE	40
41	SPARE	20/1	20/1	SPARE	42
43					44
45	AHU-1	90/3	20/3	HUH-2	46
47					48
49					50
51	AHU-8	45/3	20/3	HUH-1	52
53					54
55					56
57	SPARE	20/3	20/3	CUH-2	58
59					60
61					62
63	VVB-103,106	20/3	50/3	CUH-3	64
65					66
67					68
69	VVB-003B, 115	20/3	20/3	VVB-002	70
71					72
73					74
75	VVB-110,116	20/3	20/3	CUH-5	76
77					78
79					80
81	VVB-111,112	20/3	20/3	VVB-102	82
83					84

PANEL HMR1						
MAIN <u>100</u> MLO		VOLTAGE <u>480 /277V</u>		MOUNTING <u>SURFACE</u>		
BUSING <u>100</u> AMPS		<u>3-Ph 4-W</u>		LOCATION <u>1ST FLR ELC</u>		
SCR 10,000 AIC				FED FROM <u>HMDS</u>		
NO	DESCRIPTION	CB/P	CB/P	DESCRIPTION	NO	
1					2	
3	VVB-203A,203B	20/3	20/3	VVB-209A,B,C	4	
5					6	
7					8	
9	VVB-210,216	20/3	20/3	VVB-201,226	10	
11					12	
13					14	
15	VVB-218	20/3	20/3	VB-208	16	
17					18	
19					20	
21	CUH	20/3	20/3	SPARE	22	
23					24	

Appendix 7 – Redesigned Panel Schedules

PANEL HPG						
MAIN 400 MCB		VOLTAGE 480 /277V		MOUNTING SURFACE		
BUSING 400 AMPS		3-Ph 4-W		LOCATION ELEC 009		
SCR 65,000 AIC				FED FROM HMDS		
NO	DESCRIPTION	CB/P	CB/P	DESCRIPTION	NO	
1	BOLLARD LIGHTING	20/1	20/1	PARKING LOT LIGHTING	2	
3	ENTRY DRIVE	20/1	20/1	SITE LIGHTING	4	
5	COURTYARD LIGHTING	20/1	20/1	COURTYARD LIGHTING	6	
7	GARDEN AREA LIGHTING	20/1	20/1	TURN AROUND LIGHTING	8	
9	SIDE WALK LIGHTING	20/1	20/1	TREE/LANDSCAPE LIGHTING	10	
11	STAIRS/TERRACE LIGHTING	20/1	20/1	PARKING LOT LIGHTING	12	
13	PARKING LOT LIGHTING	20/1	20/1	SIGN LIGHTING	14	
15	SPARE	20/1	20/1	COURTYARD LIGHTING	16	
17	COURTYARD LIGHTING	20/1	20/1	SPARE	18	
19	COURTYARD LIGHTING	20/1			20	
21	SPARE	20/1	50/3	LOADING DOCK	22	
23	SPARE	20/1			24	
25					26	
27	DOAHU-7	110/3	15/3	EF-2	28	
29					30	
31					32	
33	DOAHU-3	90/3	90/3	DOAHJ-4	34	
35					36	
37					38	
39	DOAHU-5	90/3	90/3	DOAHJ-6	40	
41					42	
43					44	
45	Spare	-	-	Spare	46	
47					48	
49					50	
51	Spare	-	-	Spare	52	
53					54	
55			-	SPACE	56	
57	Spare	-	-	SPACE	58	
59			-	SPACE	60	
83	SPACE	-	-	SPACE	84	

PANEL HMR						
MAIN 800 MLO		VOLTAGE 480 /277V		MOUNTING SURFACE		
BUSING 800 AMPS		3-Ph 4-W		LOCATION ELEC 009		
SCR 65,000 AIC				FED FROM HMDS		
NO	DESCRIPTION	CB/P	CB/P	DESCRIPTION	NO	
1	FT-2	20/1	20/1	FT-2	2	
3	FT-2	20/1	20/1	FT-2	4	
5	FT-2	20/1	20/1	FT-2	6	
7	FT-2	20/1	20/1	RCP-2	8	
9			20/1	RCP-1	10	
11	CUH-2	20/3	20/1	RCP-1	12	
13			20/1	SPARE	14	
15					16	
17	CUH-2	20/3	20/3	HP-003	18	
19					20	
21					22	
23	HUH-1	20/3	20/3		24	
25					26	
27					28	
29	HP-004A/B/C	20/3	20/3	HP-011A/B,002	30	
31					32	
33					34	
35	Spare	20/3	20/3	HUH-2	36	
37					38	
39	SPARE	20/1	20/1	SPARE	40	
41	SPARE	20/1	20/1	SPARE	42	
43					44	
45	DOAHU-1	90/3	20/3	HUH-2	46	
47					48	
49					50	
51	AHU-8	45/3	20/3	HUH-1	52	
53					54	
55					56	
57	SPARE	20/3	20/3	CUH-2	58	
59					60	
61					62	
63	HP-102,103	20/3	50/3	CUH-3	64	
65					66	
67					68	
69	HP-106/110,111,112	20/3	20/3	HP-030A,030B	70	
71					72	
73					74	
75	HP-030C,030D	20/3	20/3	CUH-5	76	
77					78	
79					80	
81	HP-032A,032B,034	20/3	20/3	HP-030E, 030F	82	
83					84	

PANEL HMR1						
MAIN 100 MLO		VOLTAGE 480 /277V		MOUNTING SURFACE		
BUSING 100 AMPS		3-Ph 4-W		LOCATION 1ST FLR ELC		
SCR 10,000 AIC				FED FROM HMDS		
NO	DESCRIPTION	CB/P	CB/P	DESCRIPTION	NO	
1					2	
3	HP-115,116,201	20/3	20/3	HP-203/205	4	
5					6	
7					8	
9	HP-226,208/209	20/3	20/3	HP-209A,210/216	10	
11					12	
13					14	
15	Spare	20/3	20/3	HP-218	16	
17					18	
19					20	
21	CUH	20/3	20/3	SPARE	22	
23					24	

Appendix 8 – Existing Mechanical Cost Estimate

ITEM	DESCRIPTION	QTY	UNIT	MATERIAL COST		LABOR COST		LINE TOTAL
				PER UNIT	TOTAL	PER UNIT	TOTAL	
1	AHU-1 (7000 CFM)	1	EA	15,750.00	15,750.00	4,500.00	4,500.00	20,250.00
2	AHU-2 (12000 CFM)	1	EA	27,000.00	27,000.00	5,500.00	5,500.00	32,500.00
3	AHU-3 (7000 CFM)	1	EA	11,900.00	11,900.00	4,500.00	4,500.00	16,400.00
4	AHU-4 (6000 CFM)	1	EA	10,200.00	10,200.00	4,500.00	4,500.00	14,700.00
5	AHU-5 (6000 CFM)	1	EA	10,200.00	10,200.00	4,500.00	4,500.00	14,700.00
6	AHU-6 (6000 CFM)	1	EA	10,200.00	10,200.00	4,500.00	4,500.00	14,700.00
7	AHU-7 (4000 CFM)	1	EA	8,000.00	8,000.00	4,000.00	4,000.00	12,000.00
8	AHU-8 (8620 CFM)	1	EA	13,500.00	13,500.00	5,000.00	5,000.00	18,500.00
10	AHU-9 (4000 CFM)	1	EA	8,000.00	8,000.00	4,000.00	4,000.00	12,000.00
11	Add. Equip. Cost	1	EA					353,500.00
12	5" VVB	2	EA	675.00	1,350.00	200.00	400.00	1,750.00
13	Variable Volume Box	30	EA	1,000.00	30,000.00	230.00	6,900.00	36,900.00
14	Fan Powered Box	8	EA	1,400.00	11,200.00	300.00	2,400.00	13,600.00
15	Split Systems	3	EA	2,800.00	8,400.00	1,000.00	3,000.00	11,400.00
16	Kitchen Exhaust Fan (KEF)	2	EA	2,500.00	5,000.00	425.00	850.00	5,850.00
17	Kitchen Hood Exhaust Fan (KHE)	3	EA	2,500.00	7,500.00	425.00	1,275.00	8,775.00
18	In-line Fans	3	EA	1,250.00	3,750.00	425.00	1,275.00	5,025.00
19	Power Roof Ventilators (PRV)	3	EA	1,000.00	3,000.00	425.00	1,275.00	4,275.00
20	Radiant Ceiling Panel (RCP)	300	LF	30.00	9,000.00	22.00	6,600.00	15,600.00
21	Cabinet Unit Heaters (CUH)	3	EA	800.00	2,400.00	300.00	900.00	3,300.00
22	Horizontal Unit Heaters (HUH)	9	EA	450.00	4,050.00	250.00	2,250.00	6,300.00
23	Chilled Water Piping	1200	LF	19.50	23,400.00	27.00	32,400.00	55,800.00
24	Chilled Water Piping Insulation	1200	LF	2.95	3,540.00	6.00	7,200.00	10,740.00
25	Hot Water Piping	53000	SF	0.55	29,150.00	0.50	26,500.00	55,650.00
26	Hot Water Piping Insulation	53000	SF	0.20	10,600.00	0.15	7,950.00	18,550.00
27	Ductwork	53000	SF	1.50	79,500.00	0.75	39,750.00	119,250.00
28	Ductwork Insulation	53000	SF	1.00	53,000.00	0.40	21,200.00	74,200.00
29	Hot Water Piping Accessories	1	LS	5,000.00	5,000.00	6,000.00	6,000.00	11,000.00
30	Chilled Water Piping Accessories	1	LS	3,900.00	3,900.00	5,000.00	5,000.00	8,900.00
31	Testing and Balancing	1	LS			45,000.00	45,000.00	45,000.00
32	Controls	1	LS	80,000.00	80,000.00	42,000.00	42,000.00	122,000.00
	Sub-total				488,490.00		301,125.00	1,143,115.00
	Overhead - 10%							114,311.50
	Profit - 10%							114,311.50
	Sub-total							1,371,738.00
	Contingency - 3.5%							48,010.83
	Grand Total							1,419,748.83

Appendix 8 – Redesigned Mechanical Cost Estimate

ITEM	DESCRIPTION	QTY	UNIT	MATERIAL COST		LABOR COST		LINE TOTAL
				PER UNIT	TOTAL	PER UNIT	TOTAL	
1	AHU-8 (8620 CFM)	1	EA	13,500.00	13,500.00	5,000.00	5,000.00	18,500.00
2	AHU-9 (4000 CFM)	1	EA	8,000.00	8,000.00	4,000.00	4,000.00	12,000.00
Redesign	Added Equipment	1						629,918.00
3	Split Systems	3	EA	2,800.00	8,400.00	1,000.00	3,000.00	11,400.00
4	Kitchen Exhaust Fan (KEF)	2	EA	2,500.00	5,000.00	425.00	850.00	5,850.00
5	Kitchen Hood Exhaust Fan (KHE)	3	EA	2,500.00	7,500.00	425.00	1,275.00	8,775.00
6	In-line Fans	3	EA	1,250.00	3,750.00	425.00	1,275.00	5,025.00
7	Power Roof Ventilators (PRV)	3	EA	1,000.00	3,000.00	425.00	1,275.00	4,275.00
8	Radiant Ceiling Panel (RCP)	300	LF	30.00	9,000.00	22.00	6,600.00	15,600.00
9	Cabinet Unit Heaters (CUH)	3	EA	800.00	2,400.00	300.00	900.00	3,300.00
10	Horizontal Unit Heaters (HUH)	9	EA	450.00	4,050.00	250.00	2,250.00	6,300.00
11	Chilled Water Piping	1200	LF	19.50	23,400.00	27.00	32,400.00	55,800.00
12	Chilled Water Piping Insulation	1200	LF	2.95	3,540.00	6.00	7,200.00	10,740.00
13	Hot Water Piping	53000	SF	0.55	29,150.00	0.50	26,500.00	55,650.00
14	Hot Water Piping Insulation	53000	SF	0.20	10,600.00	0.15	7,950.00	18,550.00
15	Ductwork	53000	SF					109,000.00
16	Ductwork Insulation	53000	SF					61,950.00
17	Hot Water Piping Accessories	1	LS	5,000.00	5,000.00	6,000.00	6,000.00	11,000.00
18	Chilled Water Piping Accessories	1	LS	3,900.00	3,900.00	5,000.00	5,000.00	8,900.00
19	Testing and Balancing	1	LS			45,000.00	45,000.00	45,000.00
20	Controls	1	LS	80,000.00	80,000.00	42,000.00	42,000.00	122,000.00
	Sub-total				220,190.00		198,475.00	1,219,533.00
	Overhead - 10%							121,953.30
	Profit - 10%							121,953.30
	Sub-total							1,463,439.60
	Contingency - 3.5%							51,220.39
	Grand Total							1,514,659.99