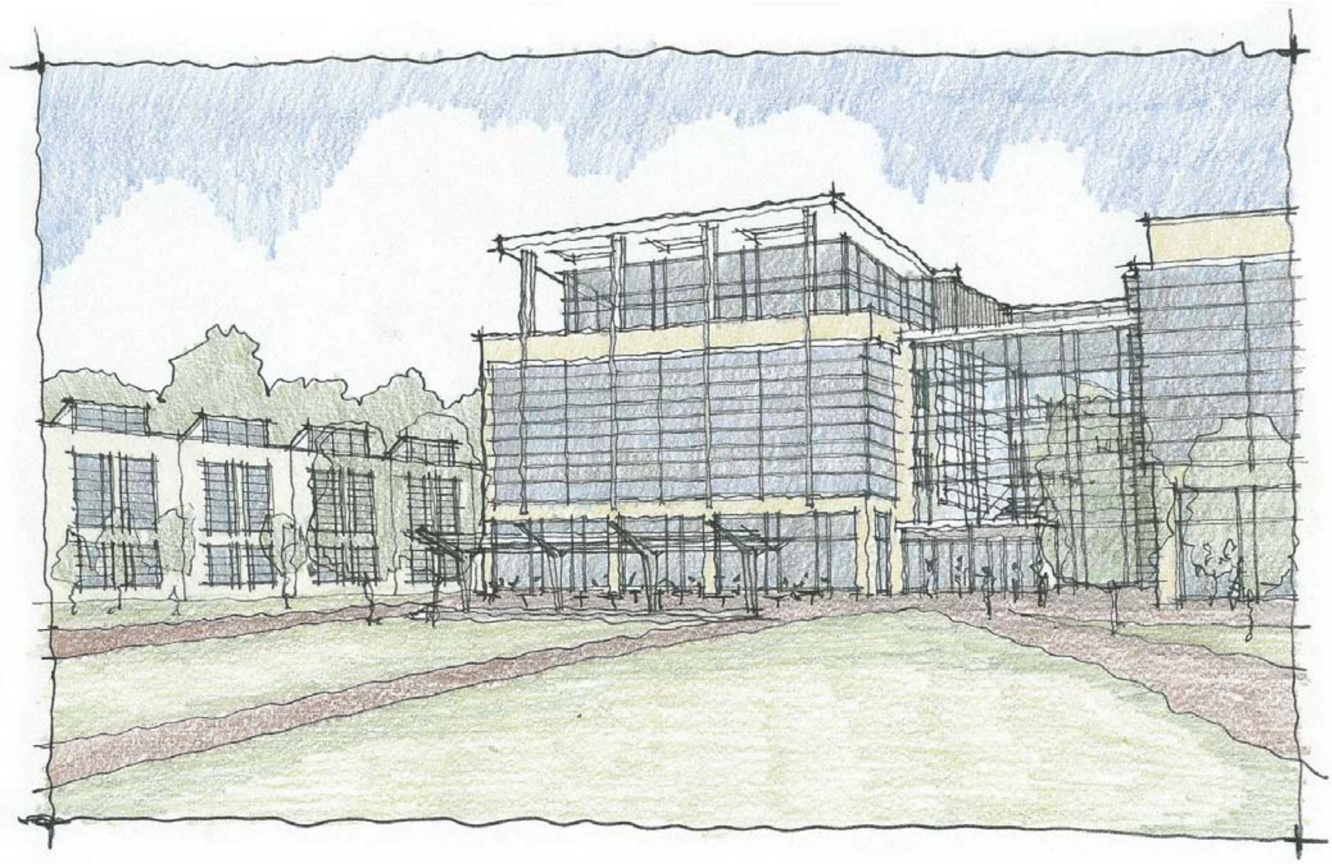
THE PENNSYLVANIA STATE UNIVERSITY
ARCHITECTURAL ENGINEERING
SENIOR THESIS REPORT



STUDENT SERVICES BUILDING
HOWARD COMMUNITY COLLEGE
COLUMBIA, MD

Jason P. Fair
Mechanical Option

Spring 2006

Faculty Advisor: Dr. William Bahnfleth

STUDENT SERVICES BUILDING

HOWARD COMMUNITY COLLEGE
COLUMBIA, MD

Jason P. Fair—Mechanical Option
Sponsored by Mueller Associates Inc.
http://www.arche.psu.edu/thesis/eportfolio/current/portfolios/jpf161

Project Team
Owner: Howard Community College
Architect: Design Collective, Inc.
Construction Manager: Riparius Construction, Inc.
MEP Engineer: Mueller Associates Inc.
Structural Engineer: Smislova, Kehnemui & Associates
Civil Engineer: Patton Harris Rust & Associates
Geo Tech Engineer: Froehling & Robertson, Inc.

Construction
- Dates of Construction: June 2005 to Dec. 2006
- Actual Cost Data: $24,650,467
- Project Delivery Method: Design-Bid-Build

Structural System
- Foundation shallow spread footings for columns
- Continuous strip footings for perimeter walls
- 5" thick slab-on-grade with 6x6 wwf reinforcement
- Intermediate floors 3-1/4" lightweight concrete over 3", 20 gage composite metal deck
- Decking on W18x35 beams bolted to W24x55 girders
- Roof 3", 22gage metal deck over steel beams

Lighting
- General lighting typical 4ft T8 lamps, compact fluorescent lamps, and electronic ballasts
- Automatic controls for atrium space allow for natural lighting
- Emergency lighting and exit signage supplied from emergency panelboards
- Exterior lighting metal halide
- Control of exterior lighting is provided by photo-cell and time clock

Architecture
- Size: 101,405 sqft
- Stories: 4 floors and basement MER
- Western end of Quadrangle
- 3 story central atrium space with grand staircase
- 4th floor dining room with roof terrace

Electrical System
- Campus 13.2kV distribution system
- Two medium voltage feeders extended from switchgear
- Building voltage distribution 480Y/277 volts
- Power distribution systems have 20% min spare capacity
- Panel boards have 20% min space for future breakers.
- Emergency power supplied by an outside diesel generator

Mechanical System
- Chilled and condenser water provided by stand-alone chilled water plant
- Chilled water plant connected to plant in mechanical room of the adjacent Visual Arts Building
- Redundancy allows for continuous operation of select loads during plant failure or maintenance
- Two dual fuel (natural gas & oil) 3000MBH boilers
- 180°F hot water supply and 150°F return
- Six AHU's ducted to air terminal units to service each zone

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Acknowledgements:

First and most importantly I would like to thank my God, Lord and Savior Jesus Christ. Without His guidance, provision, grace, mercy, healing, and strength, I would have never been able to achieve anything.

I would like to thank the faculty of the Architectural Engineering Department for providing me with a superior education here at Penn State University which will enable me to become a leader in the Architectural Engineering field. A few of the faculty members who have had a substantial impact on my career as a student are Professor Moses Ling, Dr. William Bahnfleth, and the famous Dr. Jae-Weon Jeong better known as JJ. Many thanks also go to my classmates who have helped me through these many years here at Penn State. Without their friendship, patience, and assistance on numerous homework assignments and projects, my college career would have been much more difficult.

Many industry professionals were of great assistance to my senior thesis. A big thanks goes to Mueller Associates for providing me with a summer internship, and all of the design and construction documents used for my senior thesis, especially Darren Anderson for answering my many questions. I would also like to thank Tom Sloan of Riparius Construction and Rachel Voigtland from Carrier.

Finally I would also like to thank my family. My parents have always stuck together even when times were hard. All of my six siblings have helped support me and encourage me during my college career. Without all of their love and support I don't think I would have finished. Last but certainly not least I would like to thank my wife Jessica. She is my motivation and encouragement and hope for the future. She has given me the final push and desire I needed to finish strong in my college career.

Executive Summary:

This senior thesis is based upon analysis and research performed over the fall and spring semesters. It is based upon the original mechanical systems design of Mueller Associates. Their design was used as the base case for my mechanical analysis of the building. The entire building was simulated using Trane's TRACE 700 energy simulation program. Once the building was entered the program was run with the original configuration of air handling units connected to VAV boxes all supported by a chilled water plant and heating water plant. Next the simulation was run using zone mounted heat pumps connected to a runaround loop. The heating and cooling loads from this simulation were then entered into RETScreen International's Ground-Source Heat Pump Project Model to obtain the amount of the geothermal heat exchange piping required to meet these loads. This program was run in two configurations, one to meet the cooling needs and the other to meet the heating needs. Ultimately the heating demand loop field was chosen in conjunction with a cooling tower. This hybrid system provides the energy savings of the geothermal system for the majority of the year and utilizes the cooling capacity of the cooling tower during peak loads.

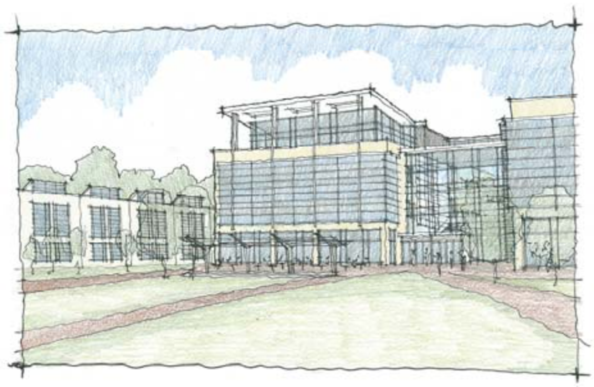
Through a construction management analysis this hybrid system provided a lower present value and did not have any major impact on the constructability of the building. Major equipment and system components were the basis for the first cost analysis. Energy consumption based upon the TRACE simulation provided a life cycle cost. These two financial analyses were then entered into the Engineering Economic Analysis by Carrier to provide a present worth value for both systems. Through my analysis it was determined that the proposed geothermal system had a present value that was $840,640.00 lower than the base case. Through my site and schedule evaluation it was determined that the proposed geothermal system would not have a negative impact on the constructability of the building project.

Project Background

General Description:

The Student Services Building on the Howard Community College campus is located at 10901 Little Patuxent Parkway Columbia, Md 21044. This latest addition to the campus will house the Student Support Services and will have a business type occupancy. The 101,405 sqft building is distributed over 4 floors and is supported by a basement mechanical equipment room for a total of 5 levels.

Architecture:



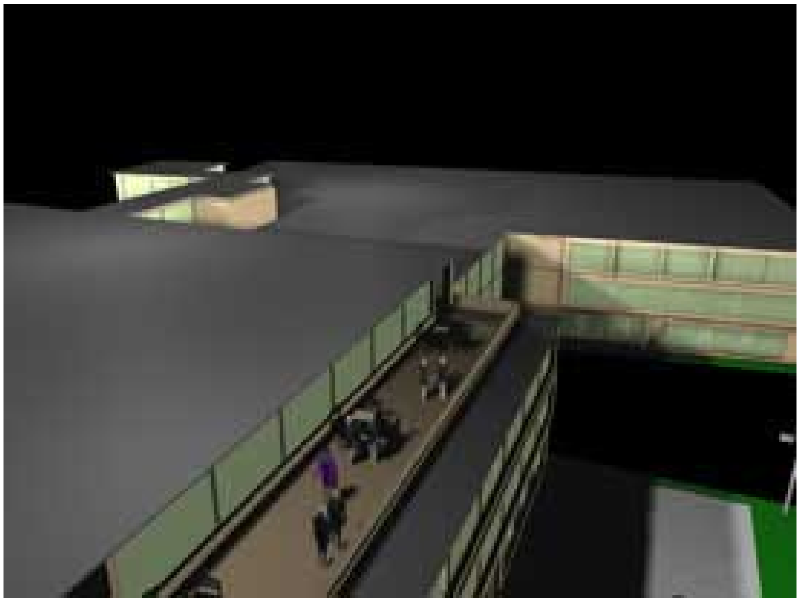
The Student Services Building (SSB) at Howard Community College is the third building that will make up the academic quadrangle. The first building in this quadrangle to the northeast of the Student Services Building is the Instructional Laboratory Building, which was completed in 2003. The next building to the south of the SSB is the Visual Arts Building, which is currently under construction. Having the Student Services Building on the western end of the quadrangle encloses the space but also allows for a more inviting main entrance from this side of the campus. The quadrangle is the first area one will enter after exiting from the parking lot. The materiality of the Student Services Building is similar to that of the Lab and Arts buildings. Also by breaking up the façade with large 0central atrium spaces, the buildings surrounding the quadrangle become less dominate and develop into a warmer and more welcoming backdrop.

After walking through the quadrangle one will enter the SSB at the lower level, your gaze looks upward to the vast atrium space and ceremonial stair case which connects to the upper lobby. Other features of the lower level are the welcome center, campus security, book store, and the main dining facility.

The second floor offers a lobby directly off of the parking lot. Additional services adjacent to this lobby are the records and registration department, admissions and advising department, financial aid department, and the finance department.

The third floor houses the test center and academic support, and the counseling and career services. This floor gives a completely different perspective of the atrium space observed at the entrances.

The features of the fourth floor truly cater to the needs and hungers of the students. There is a large and a small private dining room located on this floor which is supported by the lower level dining facilities via elevators and a service corridor. The main feature of this floor is the large dining room which opens out to a roof terrace where one can obtain a bird's eye view of the quadrangle.



Project Team:

Owner:	Howard Community College www.howardcc.edu
C M:	Riparius Construction, Inc. www.ripariusconstruction.com
Architect:	Design Collective, Inc. www.designcollective.com
MEP	Mueller Associates, Inc. www.muellerassoc.com
Structural	Smislova, Kehnemui & Associates www.skaengineers.com
Civil	Patton Harris Rust & Associates www.phra.com
Geo Tech	Froehling & Robertson, Inc. www.fandr.com
Consultants:	Birchfield Jacobs Foodsystems www.birchfieldjacobs.com

Engineered Systems Overview:

- **Electrical:**

Primary electrical service for the building is provided from the campus 13.2kV distribution system. Two medium voltage feeders are extended from the switchgear serving the Arts & Humanities Building to a switchgear serving the Student services building. The switchgear is equipped to energize the building from either feeder. A single medium voltage feeder will run from the switchgear to the to a secondary unit substation in the main electrical room located in the basement. The building voltage distribution will be 480Y/277 volts. Power distribution systems will have 20% minimum spare capacity and panel boards will have minimum 20% space for future circuit breakers. Duplex receptacles are be 20 amp 120 volt heavy-duty type. Emergency power is supplied by an outside diesel generator. All emergency systems and legally required systems are supported by the generator.

- **Lighting:**

In general, lighting throughout the building is fluorescent using typical 4ft T8 lamps, compact fluorescent lamps, and electronic ballasts. Power connections are provided for display lighting in the bookstore. Controls are provided in the atrium space to automatically adjust lighting levels to allow for natural light. Emergency lighting and exit signage are supplied from unswitched branch circuits in the emergency panelboards. Exterior lighting is metal halide to illuminate building entrances, walkways, and the parking lot. Control of exterior lighting is provided by a photocell and a time clock.

- **Structural:**

The foundation is comprised of shallow spread footings and continuous strip footings. Slab-on-grade will be 5” thick, reinforced with 6x6 welded wire mesh and placed over vapor barrier and gravel. The second and third floors are 3-1/4” lightweight concrete over 3”, 20 gage composite metal deck. The deck is typically supported by W18x35 beams bolted to W24x55 girders. Columns are typically W10 wide flanges with wind moment connections. The fourth floor north section is typically W16x26 beams bolted to W21x44 girders. The south section is typically W18x35 beams connected to W24 wide girders. Roof construction is comprised of 3”, 22gage metal deck over steel beams.

- **Plumbing:**

  A 6” service main extends from the existing 8” campus main into the basement mechanical room. Domestic hot water is supplied at a temperature of 110°F to the toilet rooms and at 140°F to the kitchen. All domestic water pipes are copper with lead free solder joints, and will be insulated. New plumbing fixtures are low flow water conserving type.

- **Fire Protection:**

  The fire detection and alarm system complies with the American with Disabilities Act Accessibility Guidelines and National Fire Protection Association (NFPA) 72. Alarm initiation devices include manual pull stations, smoke and heat detectors, duct smoke detectors. A smoke evacuation system required in the atrium space will exhaust the atrium at a rate of approximately 150,000 – 200,000 cfm. Entrance doors will automatically open to make up the exhausted air. A dedicated 6” fire main is provided in the basement mechanical equipment room. Except for the telecommunications room the building will be equipped with an automatic wet pipe sprinkler system.

- **Telecommunications:**

  The cabling and equipment for the telecommunications systems adheres to EIA/TIA-569 the standard for spaces and pathways, and EIA/TIA-607 grounding and bonding requirements for telecommunications.

Existing Mechanical Systems

The overall design goal for the mechanical systems is energy conservation throughout the life of the building. Therefore, not only is ASHRAE Standard 90.1 adhered to, but additional energy conservation techniques were also incorporated into the design. Occupancy sensors, light level sensors, and variable speed pumps and fans are just a few of the energy saving design features.

The mechanical system is set up in a primary/secondary chilled water loop configuration. The primary loop connects the pumps to the chillers to maintain a constant flow through the chillers located in the mechanical room. The chilled and condenser water is provided by a stand-alone chilled water plant since campus chilled water service is not available. This plant is located in the basement level mechanical room and linked to the chilled water plant in the basement mechanical room of the adjacent Arts Building. This allows for select loads in each building to remain uninterrupted in the event of a failure of one plant. The secondary loop connects to the rest of the building including the air-handling units and air terminal units.

Since campus steam is not available, there is a heating water system located in the basement mechanical room and operates year round to meet the required heating loads. This hot water system is also set up in a primary/secondary configuration. The primary loop connects two 3100MBH boilers to their pumps in the mechanical room. Each dual fuel boiler is able to operate on natural gas and No.2 oil. The heated water is supplied to the secondary loop for building distribution at 200°F and returned at 160°F.

Six air handling units are utilized to meet the required building loads and ventilation requirements. The heating and cooling coils are connected to the secondary loops of the hot water and chilled water systems. The air handling units are ducted with high pressure duct to variable air volume boxes (VAV) which service each locally controlled zone through low pressure duct. Supplemental fin tube radiant heaters are also used around the perimeter walls to maintain thermal comfort near the windows during cold winter months.

Design Objectives

1. HVAC equipment (chillers, boilers, cooling towers, and service water heaters) was selected in accordance with minimum equipment efficiency requirements of ASHRAE Standard 90.1
2. A 5^{o}F minimum deadband is maintained between each zone's heating and cooling control setpoints to prohibit concurrent operation of heating and cooling systems
3. Perimeter radiation controls for each zone are sequenced with cooling controls to preclude simultaneous heating and cooling
4. HVAC systems automatically shut down during unoccupied hours subject to building high and low temperature limits
5. Air handling systems will utilize optimum start and economizer control programs and low leakage dampers
6. A supply air isolation damper and occupancy over-ride switch is utilized at each floor served from a centralized air handling system
7. CO_2 controls are utilized to reduce ventilation air in systems serving high occupancy spaces (serving, dining, and bookstore) during periods of reduced occupancy
8. Duct insulation R values and pipe insulation thickness was selected in accordance with minimum requirements of ASHRAE Standard 90.1
9. Ducts are sealed to reduce leakage per the requirements of ASHRAE Standard 90.1
10. HVAC systems will be tested, balanced and commissioned
11. Variable air flow air handling systems with variable frequency drive fans are utilized. Zone design flow rates are reduced to maximum 30% or 4cfm/ft^2 where reheat is utilized to ensure adequate ventilation and control building humidity
12. Variable water flow heating and chilled water systems with variable frequency pump drives are utilized
13. Fan static pressure and discharge air temperature reset controls are utilized on central air handling systems to minimize energy during periods of reduced load
14. Cooling tower fans utilize variable frequency fan drives.
15. Occupancy sensors are utilized to control lights within the atrium
16. Day lighting controls are utilized to control lights within the atrium
17. Water saving plumbing fixtures are utilized to reduce water consumption

Design Conditions

OUTDOOR AND INDOOR DESIGN CONDITIONS:

Outdoor design conditions are based on weather data typical for Baltimore, Md. This data is based upon standard weather data used by Mueller Associates which has been adjusted by the senior engineers who have practiced in Baltimore for the past several decades. Indoor design data is also based up on Mueller senior engineer experience.

OUTDOOR AND INDOOR DESIGN CONDITIONS		
DESCRIPTION	DESIGN CRITERIA	
	COOLING SEASON	HEATING SEASON
Outdoor Design	93^oF_{DB} / 75^oF_{WB}	0^oF_{DB}
Indoor Design - General	75^oF_{DB}+-1^oF / $50\%_{RH}$+- 10%	70^oF_{DB}+-1^oF
Indoor Design - Kitchen	85^oF_{DB}+-2^oF / $50\%_{RH}$+- 10%	70^oF_{DB}+-2^oF
Indoor Design - Mechanical & Electrical rooms	95^oF_{DB}+-5^oF	55^oF_{DB}+-5^oF

Mechanical Equipment

A mix of roof top and indoor air handling units (AHU) were utilized in the design in order to maintain comfort levels in the rooms, and at the same time minimize the distance between the AHU and the rooms that are serviced by that AHU. The AHU's are served by the chiller and boiler for chilled and heating water. The chiller heat is rejected to the atmosphere through the use of a roof top cooling tower sized in accordance with the needs of the chiller.

AIR HANDLING UNITS								
Desig.	Type	Location	Service	Total Airflow (cfm)		Outside Air (cfm)		Max Internal Static Pressure (inWG)
				Max	Min	occupied	unoccupied	
AHU1	Roof Top	Roof North	1st, 2nd, 3rd	36300	13100	6300	6300	3.5
AHU2	Roof Top	Roof South	South wing 2,3	32300	11300	10300	10300	3.5
AHU3	Roof Top	Roof South	South wing 4	11000	7100	6500	1800	3.5
AHU4	Indoor	MER 105	North wing 1	9000	2800	1900	1900	3.4
AHU5	Indoor	Basement MER	South wing 1 dining	15000	8700	7200	7200	3.3
AHU6	Indoor	Basement MER	South wing 1 kitchen	5700	5700	5700	5700	3.2

CHILLER

GENERAL	
DESIGNATION	CH-1
LOCATION	BASEMENT MER
NOMINAL COOLING CAPACITY (TONS)	500
MAX CHILLER INPUT (KW)	271.5
EVAPORATOR PERFORMANCE	
ENTERING CHILLED WATER TEMP (^{o}F)	56
LEAVING CHILLED WATER TEMP (^{o}F)	44
CHILLED WATER FLOW RATE (GPM)	1000
FOULING FACTOR (HR-SQ FT-^{o}F)/BTU	0.0001
MAXIMUM WATER PRESSURE DROP (FT HD)	12.37
NUMBER OF PASSES	2
CONDENSER PERFORMANCE	
ENTERING CONDENSER WATER TEMP (^{o}F)	85
LEAVING CONDENSER WATER TEMP (^{o}F)	95
CONDENSER WATER FLOWRATE (GPM)	1500
FOULING FACTOR (HR-SQ FT-^{o}F)/BTU	0.00025
MAXIMUM WATER PRESSURE DROP (FT HD)	19.78
NUMBER OF PASSES	2
COMPRESSOR PERFORMANCE	
VOLTAGE	460
PHASE	3
FREQUENCY (HZ)	60
FULL LOAD AMPS (FLA)	369.2
MAXIMUM KW/TON	0.54
MAXIMUM NPLV (KW/TON)	0.47

COOLING TOWER

GENERAL	
DESIGNATION	CT-1
LOCATION	ROOF
SERVICE	BLDG CONDENSER WATER
NOMINAL COOLING CAPACITY (TONS)	500
NUMBER OF CELLS	1
BASIN HEATER QUANTITY & CAPACITY (KW)	2 @ 5 KW
PERFORMANCE	
ENTERING WATER TEMP (^{o}F)	95
LEAVING WATER TEMP (^{o}F)	85
AMBIENT AIR WET BULB TEMP (^{o}F)	79
WATER FLOWRATE PER UNIT (GPM)	1500

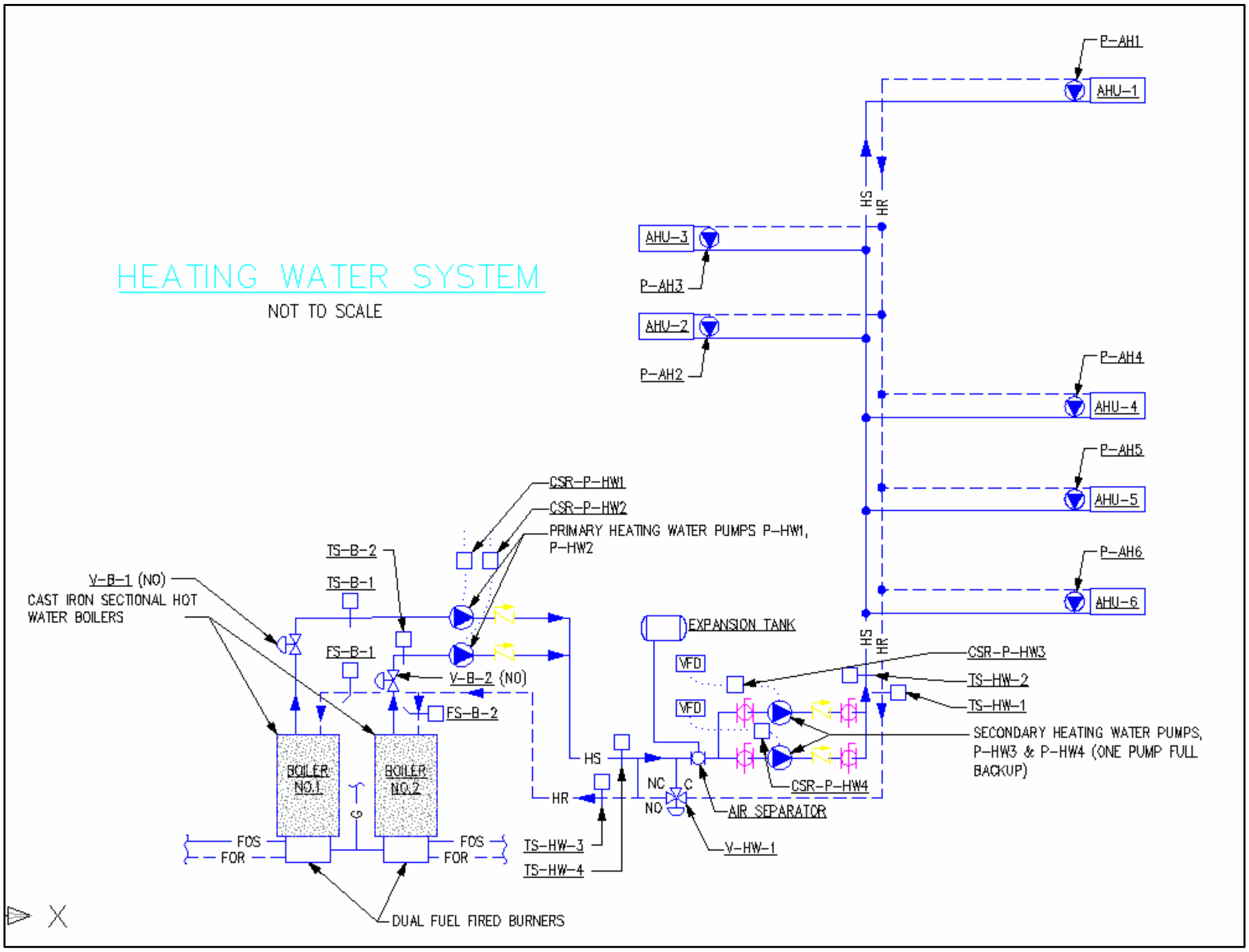
FAN DATA	
FAN TYPE	CENTR
FAN QUANTITY & HORSEPOWER	2 @ 30 HP
FAN CONTROL	VFD
ELECTRICAL	
FULL LOAD AMPS (FLA)	---
VOLTAGE	460
PHASE	3
FREQUENCY (HZ)	60

BOILERS	
GENERAL	
DESIGNATION	B-1 & B-2
LOCATION	BASEMENT MER
SERVICE	BLDG HEATING WATER
TYPE	CAST IRON SECTIONAL
BOILER CAPACITY	
GROSS I-B-R OUTPUT (MBH)	3098
ENTERING WATER TEMP (^oF)	160
LEAVING WATER TEMP (^oF)	200
WATER FLOW RATE (GPM)	155
BURNER	
FUEL TYPE	#2 FUEL OIL / NATURAL GAS
MIN GAS INLET PRESSURE (IN WG)	2
MIN BURNER INPUT CAPACITY	
OIL (GPH)	31.5
GAS (MBH)	3600
ELECTRICAL	
VOLTAGE	460
PHASE	3
FREQUENCY (HZ)	60
BURNER MOTOR HORSEPOWER	2
PHYSICAL	
APPROXIMATE LENGTH (IN)	161"
APPROXIMATE WIDTH (IN)	42"
APPROXIMATE HEIGHT (IN)	66"
FLUE DIAMETER (IN)	16"
OPERATING WEIGHT (LBS)	12467

Controls:

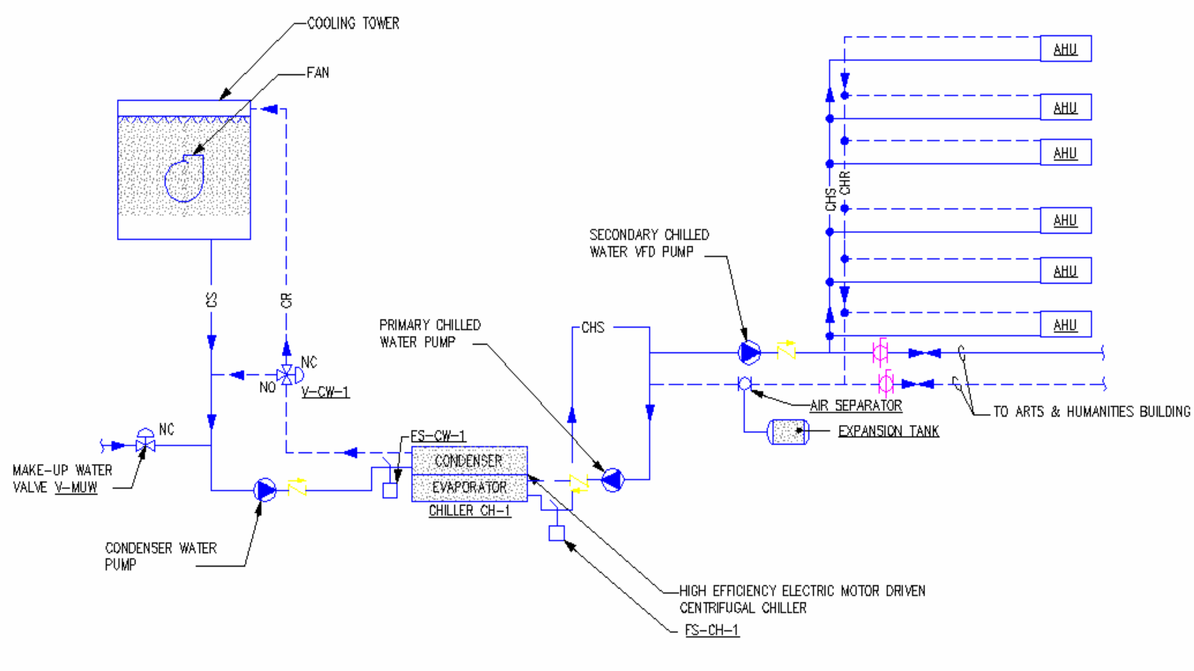
Heating Water System:

Direct Digital Control (DDC) software menus shall allow the operator to select “START-STOP" modes in addition to the operating modes. The menus shall be selectable through the local DDC panel in the mechanical room. All set points shall be variables in the DDC programs and be adjustable by the user through a keyboard interface. Temperature sensors monitor the heating water system temperatures through the DDC system. Current sensor relays (CSR) shall signal the DDC system to provide operating status of each pump and each boiler burner. Internal safety controls (low gas pressure, low water level, low combustion air, etc) shall automatically shutdown a boiler in the event of abnormal conditions. A general alarm will be annunciated through the DDC system if a boiler shuts down.



Chilled Water System:

The chiller system shall be indexed to start or stop by the Direct Digital Control (DDC) System. All setpoints shall be variables in the DDC programs and be adjustable by the user through a keyboard interface. Temperature sensors monitor the primary and secondary chilled water loop temperatures through the DDC system. Temperature sensors also monitor the condenser water loop temperatures. Current sensor relays (CSR) shall signal the DDC system to provide operating status of each pump and each cooling tower fan. Internal safety controls furnished with the chiller (high pressure, high temperature, low oil, low voltage, etc) automatically shutdown the chiller in the event of abnormal conditions. A general alarm will be annunciated through the DDC system if the chiller shuts down. Flow switches, FS-CH-1 and FS-CW-1 shall signal the DDC to provide status of flow conditions through the chiller's evaporator and condenser. Level controller provided by the tower manufacturer shall signal the DDC system to alarm high and low water levels in the cooling tower basin.



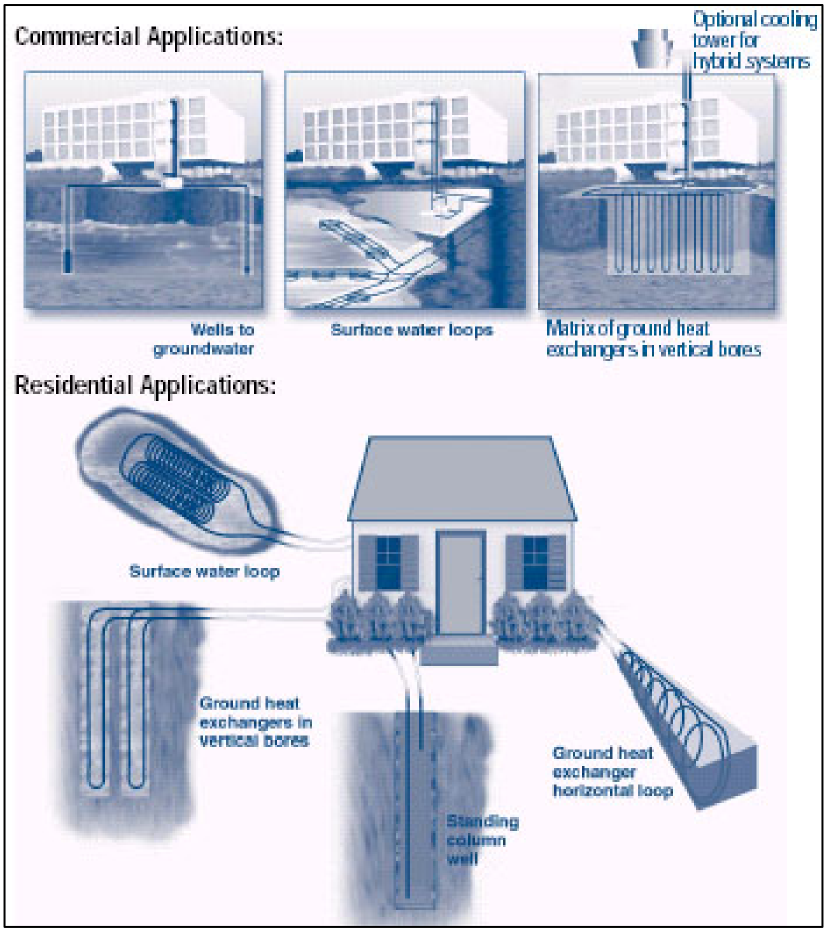
CHILLED AND CONDENSER WATER SYSTEM
NOT TO SCALE

System Commentary

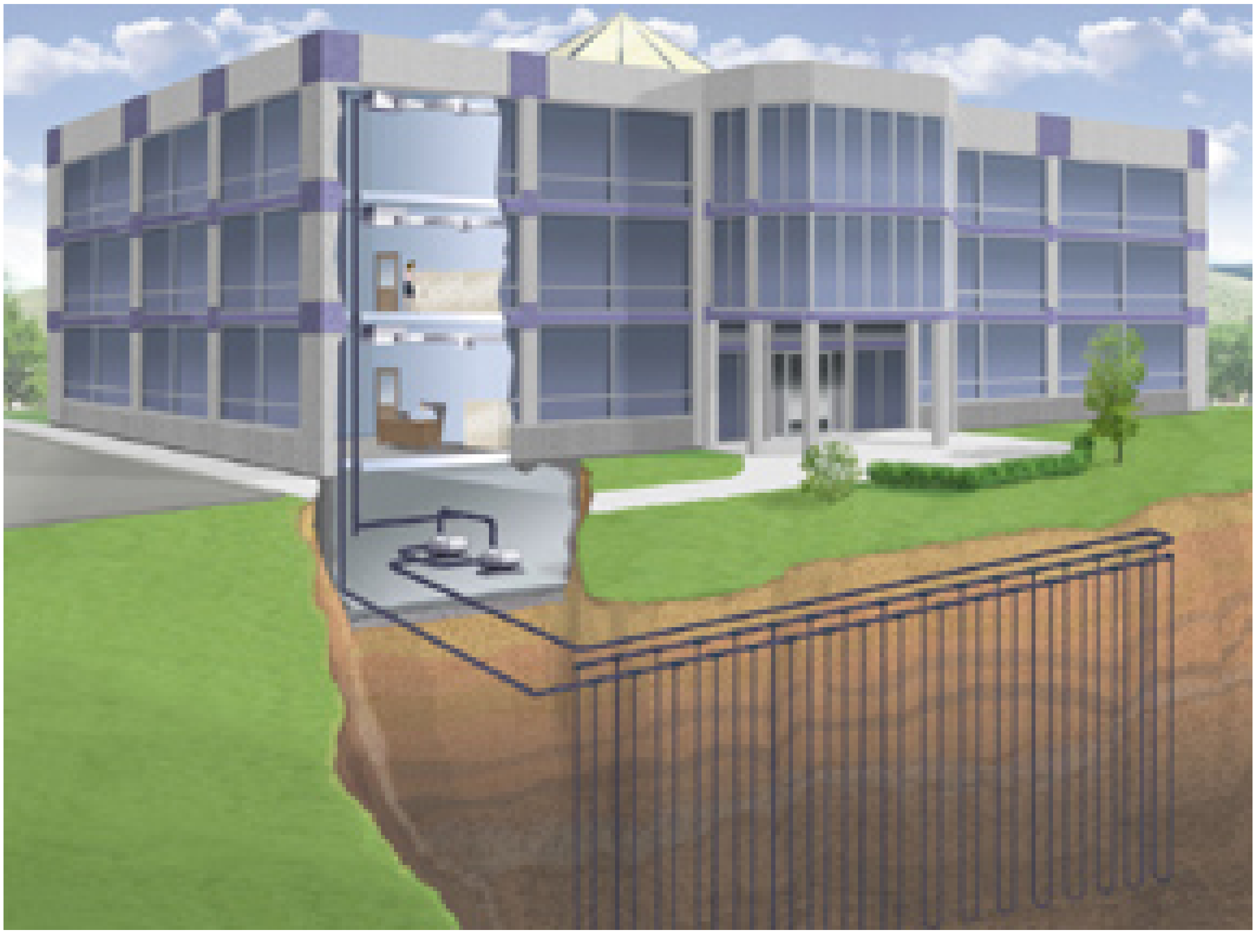
The mechanical system design of the Student Services Building at Howard Community College provided by Mueller Associates is an effective and efficient solution to the environmental requirements of the building. Through the use of energy efficient components, the design team has developed building mechanical systems that will provide many years of efficient operation. The design has sufficiently met the objectives set forth by the owner in the schematic design phase. Use of occupancy sensors, CO_2 sensors, and occupancy schedules ensures that the mechanical systems will operate only when necessary. This prevents expensive continuous operation of systems which would use excess utility fuel. The Direct Digital Control (DDC) System is a good design to maintain efficient operation. However, this will require the need for thorough and complete commissioning of the systems. Once the systems are running properly the facility engineers will be able to quickly identify any malfunctions in the systems and then find the proper solution. The DDC system also allows for the recognition of required maintenance such as changing air filters. The overall design is very comprehensive, and once installed and commissioned properly, will provide the owners with a cost effective and energy saving mechanical system.

Mechanical Depth

The mechanical systems at the Student Services Building are designed to meet several different types of loads and occupancies. The building houses many administrative offices, admissions and testing facilities, kitchen and dining spaces, and retail space for a book store. Due to these diversified load types, the growing cost of fossil fuels, and the push for more green buildings, I decided to investigate a geothermal water source heat pump system to meet the required heating and cooling loads. When looking into geothermal systems a few different options are available. There are three main types of geothermal system configurations. The first type is to drill into the ground for an existing aquifer (underground water source). Once the aquifer is reached, two wells are needed; an extraction well and an injection well. The underground water is extracted and pumped through a heat exchanger to supply heating or cooling to the building then injected back into the aquifer. This type of system has a few drawbacks such as strict regulation from the Environmental Protection Agency; fouling of equipment due to mineral build-up from the ground water; and soil porosity requirements for the injection well. The next type of system requires an open body of water near the building. Coils of heat exchanger piping are floated out into the body of water then sunk. The building heat pumps are then connected to this piping loop and exchange heat with the body of water. This system is relatively easy to install compared to the other systems. The main draw back to this system is that it requires a large volume of water. The temperature of the water can fluctuate

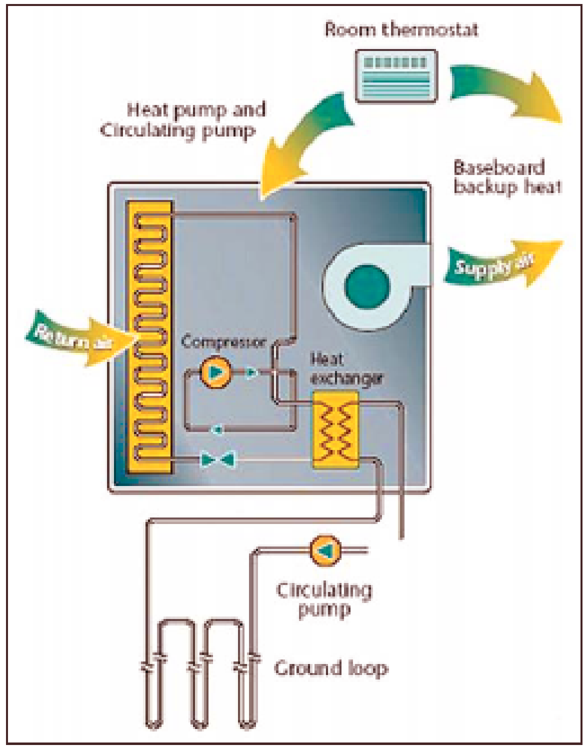


greatly, depending upon climactic conditions and location. The swing in temperature will reduce the efficiency of the heat pumps. The final configuration takes the heat exchanger piping and buries it in the ground. This configuration has two variations horizontal and vertical loop piping. The horizontal setup requires a large land area to bury the piping a few feet below the surface of the ground. This setup is also susceptible to the variations in temperature which occur at the surface of the earth. The vertical setup requires boreholes to be drilled deep into the earth typically 100 ft to 350 ft. The piping is then inserted into these holes in a "U" configuration and

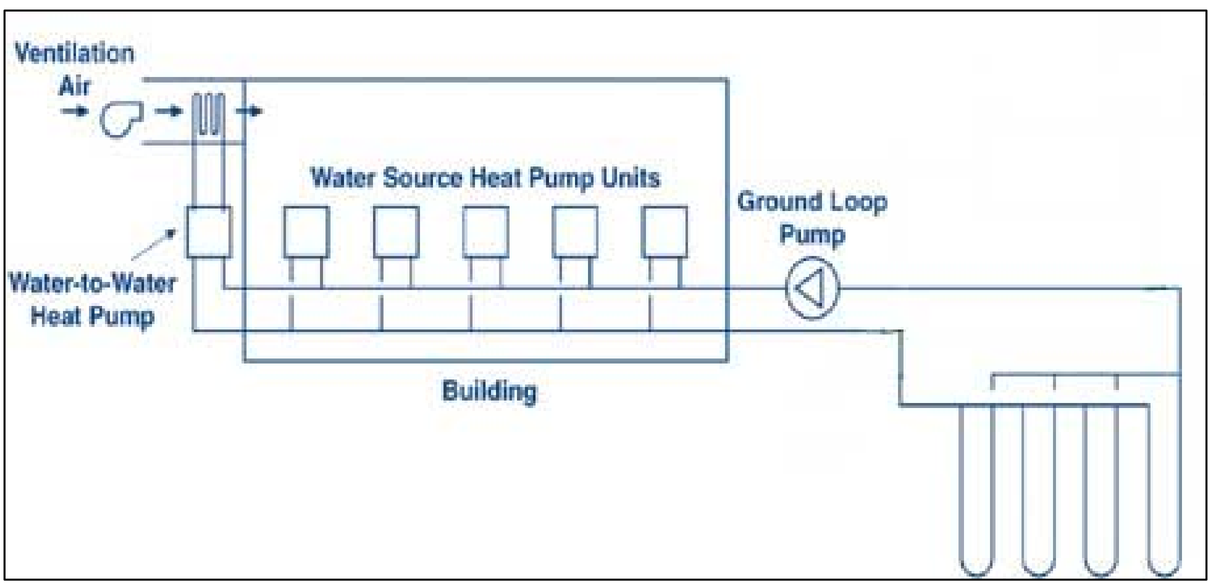


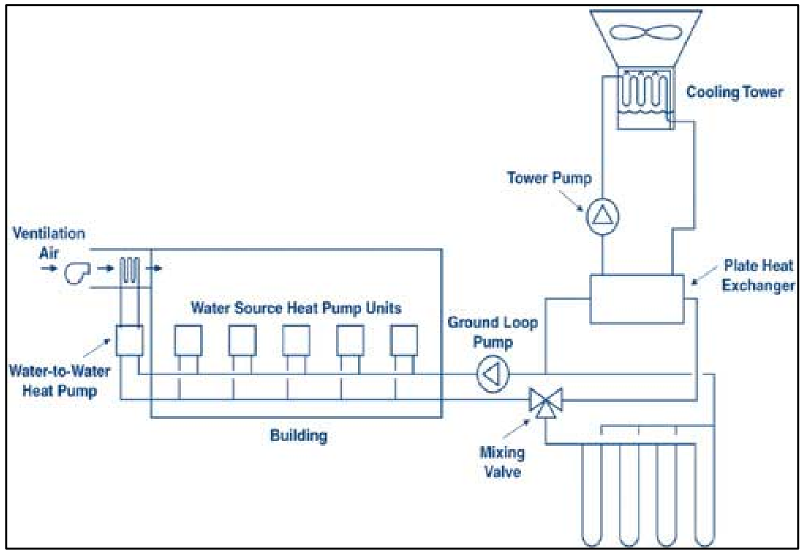
grouted into place. This configuration typically requires many boreholes to be drilled to meet the heating and cooling loads of the building. However, this setup allows for a more constant temperature for the circulating water loop. This allows the heat pumps to operate at the optimum efficiency. This final configuration was the most appealing to me due to the higher efficiencies of the circulation loop, and was the basis for my mechanical depth.

System overview



My proposed system consists of plenum space mounted heat pumps which essentially replace the VAV boxes of the existing design. The heat pumps are all interconnected to a run-around water loop within the building. This will allow for "free" heating within the building during times when interior spaces require cooling and rooms along the exterior of the building require heating. This loop is then connected to a closed ground source loop located in a vertical bore well field. The connection to a water loop in the ground allows the heat pumps to operate at a higher efficiency since the ground temperature is relatively constant. One configuration available is to size the ground loop to meet both the heating and cooling requirements for the building. One problem arises from this configuration, however, the long term heating of the ground due to imbalanced heating and cooling loads.





To facilitate balance between the loads a hybrid system was also considered. This design incorporates a cooling tower and a heat exchanger into the water loop to reject excess heat. This configuration will avoid long term heat build up in the well field. If the ground temperature rises over time due to load imbalance, the efficiency of the heat pumps will diminish and increase operating costs. This is similar to a residential air-to-air heat pump which looses efficiency on the cold winter days and requires electric resistance back-up heat.

In order to maintain proper ventilation requirements for the occupants, two air handling units will service the North and South wings of the building with pre-conditioned ventilation air. Each heat pump will be connected directly to its corresponding AHU through the use of high pressure rated duct work as to reduce the size of the ducts. The heat pumps are then ducted directly to the room diffusers using low pressure duct work to ensure the required NC levels for each space are met. To meet the required heating and cooling needs of each space the heat pumps will mix return air from the plenum space with the ducted ventilation air. The remainder of plenum air, minus some diversity to maintain positive building pressure, will be exhausted back to each air handling unit where it will help precondition the incoming ventilation air.

This building was simulated using the TRACE 700 energy modeling software. Since the building is still under construction, there is no actual energy usage data. Through the use of the construction documents, the original design was entered into TRACE to serve as a standard for comparison to my proposed depth topic. Using the same building data, the systems were changed to water source heat pumps and the loads were recalculated. These required heating and cooling loads were then inputted in to another program, RETScreen International's Ground-Source Heat Pump Project Model, to attain the required length of ground source heat exchanger piping.

Heat Load Modeling

Using the construction documents as a guide, the building was simulated using the TRACE 700 energy modeling program. All available data was inputted into the program. Floor areas of each room were entered. Also the compass orientations of exterior walls in the rooms were entered to account for heat gains imposed by the sun's radiation. Exterior wall area and construction materials, along with fenestration area and the corresponding U-values were entered to calculate building envelope loads. Internal loads such as lighting, people, and office equipment were also entered. Since Howard Community College is a local commuter campus, there are no dorms on site. Therefore, occupancy schedules were assumed to be similar to that of an office building. An example of typical input data for one of the spaces is presented below.

ENTERED VALUES
ROOM BY ROOM
By ae

74 222-FINANCIAL & RECEPTION Zone - 001

GENERAL INFORMATION (Create Rooms - Rooms)

Size...	Floor area	810 ft²	Design...	Cooling DB:	75 °F	
				Heating DB:	70 °F	
Height...	Flr-Flr	14.7 ft		Relative humidity	50 %	
	Plenum	5.7 ft				
			Thermostat...	Clg driftpoint:	90 °F	
Duplicate...	Floor multiplier	1		Htg driftpoint:	55 °F	
	Rooms per zone	1		Clg. Schedule:	Cstat	
				Htg. Schedule:	Hstat	
Is There Carpet?:	YES			Location:	Zone	
Room Mass/avg.	None					
Slab Cnstr Type:	4" LW Concrete					
Acoustical Ceiling Res.	1.786	hr·ft²·°F/Btu				

PEOPLE AND LIGHTS (Create Rooms - Internal Loads)

People...	Activity:	General Office Space	Sensible	250 Btu/h
	Density	10 People	Latent	200 Btu/h
	Schedule	Cooling Only (Design)		
Lighting...	Type:	Recessed fluorescent, not vented, 80% load to space		
	Schedule	Cooling Only (Design)		
	Fixture Type	RECFL-NV		
	%Load to RA	20 %		
	Lighting Amount	1.8 W/sq ft		
	Ballast Factor	1.0		

AIRFLOW INFORMATION (Create Rooms - Airflows)

Ventilation...	General Office Space	Main Supply...		Vav Minimum...	
Cooling	20 cfm/person	Cooling	To be calculated	Rate	% Clg Airflow
Heating	20 cfm/person	Heating	To be calculated	Schedule	Available (100%)
Schedule	Available (100%)				
Infiltration...	None	Aux Supply...		Room Exhaust...	
Cooling	0 air changes/hr	Cooling	To be calculated	Rate	0.00 air changes/hr
Heating	0 air changes/hr	Heating	To be calculated	Schedule	
Schedule	Available (100%)				

ROOM COMPONENTS (Create Rooms - Roofs, Walls, Partn/Floors, Misc Loads)

No	Description	Area/ Amount	Dir	Tilt	Const Type/ Schedule	U Val	Alpha	Grnd Refl	Glass Type	Glass Area	Glass U Val	Glass Shad	External Shading	Adj Temp/ Internal Shading	Pct Sen/ Cool Tmp	Pct Rm/ Heat Tmp	Pct Ret/ Perm Len	Rad Frc/ Loss Coef
1	SOUTH	270 ft²	180	0	Face Brick, 6" LW Conc blk, 3" Ins	0.060	0.90	1.00	Double Coated 1/4"	139	0.29	0.44	Overhang - None	None				
2	EAST	9 ft²	0	0	Face Brick, 6" LW Conc blk, 3" Ins	0.060	0.90	1.00					Overhang - None	None				
1	Misc Load 1	0.50 W/sq ft			Cooling Only (Design)										0	0	0	0.00

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 1 Entered Values Room information page 74 of 238

The weather data used for this simulation was a function of the TRACE 700 program. The weather station closest to the building is located in Baltimore, MD. The following design temperatures were used as the basis for this simulation. These programmed values are: a summer dry bulb temperature of 91°F, a summer wet bulb temperature of 77°F, and a winter dry bulb temperature of 13°F.

Entered Values

TRACE® 700 version 4.1

By ae

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC
Location: Howard County, MD
Building Owner: Howard Community College
Program User: Jason Fair
Company: PSU AE
Comments:

Cooling Design Period:	January Thru December		
Peak Hour Override:	0	Location:	Baltimore, Maryland
Daylight Savings Period:			
Summer Period:		Summer Design Dry Bulb:	91.00 °F
		Summer Design Wet Bulb:	77.00 °F
Cooling Methodology:	TETD-TA1	Winter Design Dry Bulb:	13.00 °F
Heating Methodology:	UATD		
Ventilation Methodology:	OADB	Summer Clearness Number:	0.85
		Winter Clearness Number:	0.85
Room Circ Rate:	Medium	Summer Ground Reflectance:	0.20
Wall Load To Plenum:	YES	Winter Ground Reflectance:	0.20
Building Orientation:	0		

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1
Entered Values Project Information Alternative - 3

Once the room and weather data were entered, the building systems and plants were entered. For the base case, the original design was used which consisted of six air handling units connected to a chiller and cooling tower for chilled water, and connected to the boilers for the heating water requirements. Shown below are the inputs for AHU #1 followed by the cooling and heating plants.

SYSTEM ENTERED VALUES

By ae

AHU-1 (Atrium & North Offices)
Variable Volume Reheat (30% Min Flow Default)

Design Air Temp	Max		Min	
Cooling supply	55	°F	55	°F
Leaving Cooling coil		°F		°F
Heating supply		°F		°F
Leaving preheat coil		°F		°F

Supply Duct Temperature Diff:	0	°F
Reheat Temperature Diff:	0	°F
Design Humidity Ratio Diff:		grains
Min Room Relative Humidity:		%

Diversity	
People	100.00
Lights	100.00
Misc loads	30.00

Optional Ventilation

Cooling SADB:		°F	Available (100%)
Heating SADB:		°F	Available (100%)

Economizer

Type		Dry Bulb	Available (100%)	
"On" Point:	55	°F	Max Percent OA:	100

Evaporative Cooling

Type:	None		
Direct efficiency	0	%	Available (100%)
Indirect efficiency	0	%	Available (100%)

Exhaust-Air Heat Recovery

Stage 1 Type:	None (default)		% Eff.
Exh-side deck	Outdoor & Rm Exh Mix	Available (100%)	
Stage 2 Type:	None (default)		% Eff.
Exh-side deck	Outdoor & Rm Exh Mix	Available (100%)	

Discriminator control Schedule	Off (0%)
Night Purge Schedule	Off (0%)
Optimum Start Schedule	Off (0%)
Optimum Stop Schedule	Off (0%)

Duty Cycling - "On" Period Schedule	Off (0%)
Duty Cycling - Pattern length (minutes)	
Duty Cycling - Maximum "off" time (minutes)	

Coil	Capacity	Schedule
Main cooling	100	% of Design Cooling Capacity
Auxiliary cooling		
Main heating	100	% of Design Capacity
Auxiliary heating		
Preheat	100	% of Design Capacity
Reheat	100	% of Design Capacity
Humidification	100	% of Design Capacity

Advanced Options

Cooling Coil Sizing Method:	Block	Supply Fan Motor Location:	Supply
Cooling Coil Location:	System	Return Fan Motor Location:	Return
Ventilation Deck Location:	Return/Outdoor Deck	Supply Fan Cofiguration:	Draw Thru
System ventilation flag	SUM	Supply Fan Sizing:	Block
Supply Duct Location:	RETAIR		
Return Air Path:	PLENUM	Fan Mechanical efficiency :	75 %
Block Cooling Airflow:			

Fan	Type	Static Press.	Full Load Energy Rate	Schedule	Efficiency	Demand Limit
Primary	Eq4280 - AF Centrifugal var freq drv	6.0	0.00022 kW/Cfm-in wg	Cooling Only (Design)	90	
Secondary	None	0.0	0.00000 kW/Cfm	Cooling Only (Design)	85	
Return	Eq4280 - AF Centrifugal var freq drv	1.5	0.00022 kW/Cfm-in wg	Cooling Only (Design)	90	
System Exhaust	None	0.0	0.00000 kW/Cfm	Cooling Only (Design)	90	
Room Exhaust	None	0.0	0.00000 kW/Cfm	Cooling Only (Design)	85	
Optional ventilation	None	0.0	0.00000 kW/Cfm	Cooling Only (Design)	90	
Auxiliary	None	0.0	0.00000 kW/Cfm	Cooling Only (Design)	85	

AHU-2 (South Offices)
Variable Volume Reheat (30% Min Flow Default)

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 1 Entered Values Systems page 1 of 6

ENTERED VALUES
PLANTS
By ae

Cooling Plant **Cooling plant - 001**

Sizing Method	Peak
Heat Rejection type	None
Secondary Dist. Pump	Default water pump
Secondary Pump Cons.	0 Ft Water
Thermal Storage type	None
Thermal Storage Capacity	0 ton-hr Off (0 %)

Equipment tag **Water-cooled chiller - 001** Cooling Type: 3-Stage Centrifugal Cooling plant - 001

Operating Mode	Capacity	Energy Rate	Pumps	Type	Full Load Consumption
Cooling		0.5200 kW/ton	Chilled water	Eq5001 - Cnst vol chill water pump	125.00 Ft Water
Heat Recovery			Condenser water	Eq5010 - Cnst vol cnd water pump	80.00 Ft Water
Tank Charging			Ht. rec. or Aux cond.	None	125.00 Ft Water
Tank Chrg & Ht. Rec					

				Dmd. limit priority	
				Sequencing type	Single
Heat Rejection Type	Eq5100 - Cooling tower	Max Chil. Water Reset	0 °F	Energy Source	
Thermal Storage Type	None	Load Shed. Econ	no	Reject Cond Heat	Cooling plant
T-Storage Capacity	0 ton-hr	Evap. Precooling	no	Cond. Heat to plant	
T-Storage Schedule	Storage	Free Cooling type	None	Equip Schedule	Available (100 %)

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 1 Entered Values Plants page 1 of 2

ENTERED VALUES
PLANTS
By ae

Heating Plant Heating plant - 002

Sizing Method	Peak
Cogeneration type	None
Secondary Dist. Pump	Default water pump
Thermal Storage type	None
Thermal Storage Capacity	0 ton-hr

Equipment tag **Boiler - 001** Heating Type: Oil Fired Hot Water Boiler Heating plant - 002

Heating Capacity	3,100.0 Mbh	Thermal Storage Type	None
Energy Rate	83.30 % Effic.	T-Storage Capacity	0 ton-hr
		T-Storage Schedule	Storage
Hot Water Pump type	Eq5020 - Heating water circ pump	Equipment Schedule	Available (100%)
Hot Water Pump Cons.	0.00 Ft Water	Demand Limit Priority	

Equipment tag **Boiler - 002** Heating Type: Oil Fired Hot Water Boiler Heating plant - 002

Heating Capacity	3,100.0 Mbh	Thermal Storage Type	None
Energy Rate	83.30 % Effic.	T-Storage Capacity	0 ton-hr
		T-Storage Schedule	Storage
Hot Water Pump type	Eq5020 - Heating water circ pump	Equipment Schedule	Available (100%)
Hot Water Pump Cons.	0.00 Ft Water	Demand Limit Priority	

Base Utilities

Plant	Type	Hourly Demand	Demand Limit Priority	Schedule
Stand-alone	None	0.00 kW	-1	Off (0%)

Miscellaneous accessories

Plant	Equipment tag	Type	Energy	Schedule
Heating plant - 002	All	Eq5504 - Boiler controls	2.00 kW	People - ASHRAE 90.1 (A)

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 1 Entered Values Plants page 2 of 2

Energy Modeling Results

Once the building data was entered a yearly energy simulation was ran to determine the energy usage by each system. My proposed design did reduce the yearly energy consumption by 52,504,300 Btu per year. This is a substantial energy savings over the period of a year. With the continuously rising cost of energy, this system has the potential to bring substantial savings to the building owner.

ENERGY CONSUMPTION SUMMARY

By ae

	Elect Cons. (kWh)	Oil Cons. (therms)	Water Cons. (1000 gals)	Percent of Total Energy	Total Source Energy* (kBtu/yr)
Primary heating					
Primary heating	28,090.5	10,498.5		11.5 %	13,927.5
Primary cooling					
Cooling Compressor	478,092.9			16.3 %	48,956.8
Tower/Cond Fans	136,499.6		3,563.5	4.7 %	13,977.6
Condenser Pump	99,999.2			3.4 %	10,239.9
Other CLG Accessories	1,038.0			0.0 %	106.3
Cooling Subtotal....	715,629.6		3,563.5	24.4 %	73,280.6
Auxiliary					
Supply Fans	544,756.7			18.6 %	55,783.2
Circ Pumps	129,746.3			4.4 %	13,286.1
Base Utilities				0.0 %	0.0
Aux Subtotal....	674,503.0			23.0 %	69,069.3
Lighting					
Lighting	983,156.6			33.6 %	100,675.5
Receptacle					
Receptacles	220,401.6			7.5 %	22,569.2
Heating plant load					
Base Utilities				0.0 %	0.0
Cogeneration					
Cogeneration				0.0 %	0.0
Totals					
Totals**	2,621,781.5	10,498.5	3,563.5	100.0 %	279,522.0

* Note: Resource Utilization factors are included in the Total Source Energy value.
** Note: This report can display a maximum of 6 utilities. If additional utilities are used, they will be included in the total.

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 1 Energy Consumption Summary report page 1

ENERGY CONSUMPTION FROM BASE CASE

ENERGY CONSUMPTION SUMMARY
By ae

	Elect Cons. (kWh)	Gas Cons. (therms)	Percent of Total Energy	Total Source Energy* (kBtu/yr)
Primary heating				
Primary heating	130,905.4	1,228.3	5.8 %	14,697.7
Primary cooling				
Cooling Compressor	789,304.6		27.3 %	80,825.0
Tower/Cond Fans	3,524.1		0.1 %	360.9
Condenser Pump			0.0 %	0.0
Other CLG Accessories	359.9		0.0 %	36.9
Cooling Subtotal....	793,188.6		27.4 %	81,222.7
Auxiliary				
Supply Fans	474,917.6		16.4 %	48,631.7
Circ Pumps			0.0 %	0.0
Base Utilities		8,760.0	8.9 %	9,221.1
Aux Subtotal....	474,917.6	8,760.0	25.3 %	57,852.7
Lighting				
Lighting	983,156.6		34.0 %	100,675.5
Receptacle				
Receptacles	220,401.6		7.6 %	22,569.2
Heating plant load				
Base Utilities			0.0 %	0.0
Cogeneration				
Cogeneration			0.0 %	0.0
Totals				
Totals**	2,602,569.5	9,988.3	100.0 %	277,017.7

* Note: Resource Utilization factors are included in the Total Source Energy value.
** Note: This report can display a maximum of 6 utilities. If additional utilities are used, they will be included in the total.

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 3 Energy Consumption Summary report page 1

ENERGY CONSUMPTION FROM WATER SOURCE HEAT PUMPS

The electrical energy consumed was reduced by 19,212 kWh per year. This equates to about 52.6 kWh per day which will also bring the building owner substantial savings in electric bills, and potentially reduce the demand charges as well. These savings will be evaluated in the Life Cycle Cost analysis in the Construction Management breadth.

As a result of the incorporation of water source heat pumps the peak cooling loads were also reduced. The base system peaked at a capacity of 396 tons of cooling, while the proposed system peaked at 382 tons. This difference of 14 tons of cooling capacity will help reduce equipment costs.

SYSTEM SUMMARY

DESIGN CAPACITY QUANTITIES

By ae

		COOLING				HEATING						
System Description	System Type	Main System Capacity ton	Auxiliary System Capacity ton	Optional Vent Capacity ton	Cooling Totals ton	Main System Capacity Btu/h	Auxiliary System Capacity Btu/h	Preheat Capacity Btu/h	Reheat Capacity Btu/h	Humidification Capacity Btu/h	Optional Vent Capacity Btu/h	Heating Totals Btu/h
AHU-1 (Atrium & North Offices)	Variable Volume Reheat (30% Min Fl	79	0	0	79	-278,640	0	-294,780	-160,253	0	0	-573,420
AHU-2 (South Offices)	Variable Volume Reheat (30% Min Fl	74	0	0	74	-162,089	0	-319,741	-113,735	0	0	-481,830
AHU-3 (Private Dining & Catering)	Variable Volume Reheat (30% Min Fl	23	0	0	23	-87,389	0	-91,956	-40,471	0	0	-179,346
AHU-4 (Bookstore)	Variable Volume Reheat (30% Min Fl	28	0	0	28	-93,995	0	-111,962	-47,866	0	0	-205,956
AHU-5 (Dining Hall Seating & Service)	Variable Volume Reheat (30% Min Fl	71	0	0	71	-103,085	0	-454,747	-68,246	0	0	-557,832
AHU-6 (Kitchen)	Incremental Heat Pump	121	0	0	121	-2,533	0	0	0	0	0	-2,533
Totals		396	0	0	396	-727,731	0	-1,273,186	-430,571	0	0	-2,000,917

*** The building peaked at hour 15 month 7 with a capacity of 396 tons.**

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 1 Design Capacity Quantities report page 1

COOLING CAPACITY OF BASE CASE

SYSTEM SUMMARY

DESIGN CAPACITY QUANTITIES

By ae

		COOLING				HEATING						
System Description	System Type	Main System Capacity ton	Auxiliary System Capacity ton	Optional Vent Capacity ton	Cooling Totals ton	Main System Capacity Btu/h	Auxiliary System Capacity Btu/h	Preheat Capacity Btu/h	Reheat Capacity Btu/h	Humidification Capacity Btu/h	Optional Vent Capacity Btu/h	Heating Totals Btu/h
WSHPs (AHU-1,4)	Water Source Heat Pump	93	0	19	112	-203,842	-145,683	0	0	0	-439,212	-788,737
WSHPs (AHU-2,3,5,6)	Water Source Heat Pump	236	0	43	279	-493,048	0	0	0	0	-990,564	-1,483,612
Totals		329	0	62	391	-696,890	-145,683	0	0	0	-1,429,776	-2,272,349

*** The building peaked at hour 8 month 7 with a capacity of 382 tons.**

Project Name: SSB
Dataset Name: C:\Documents and Settings\jpf161\THESIS\TRACE\HCC_SSB0403061657BAK.TRC

TRACE® 700 v4.1 calculated at 10:27 AM on 04/03/2006
Alternative - 3 Design Capacity Quantities report page 1

COOLING CAPACITY USING WATER SOURCE HEAT PUMPS

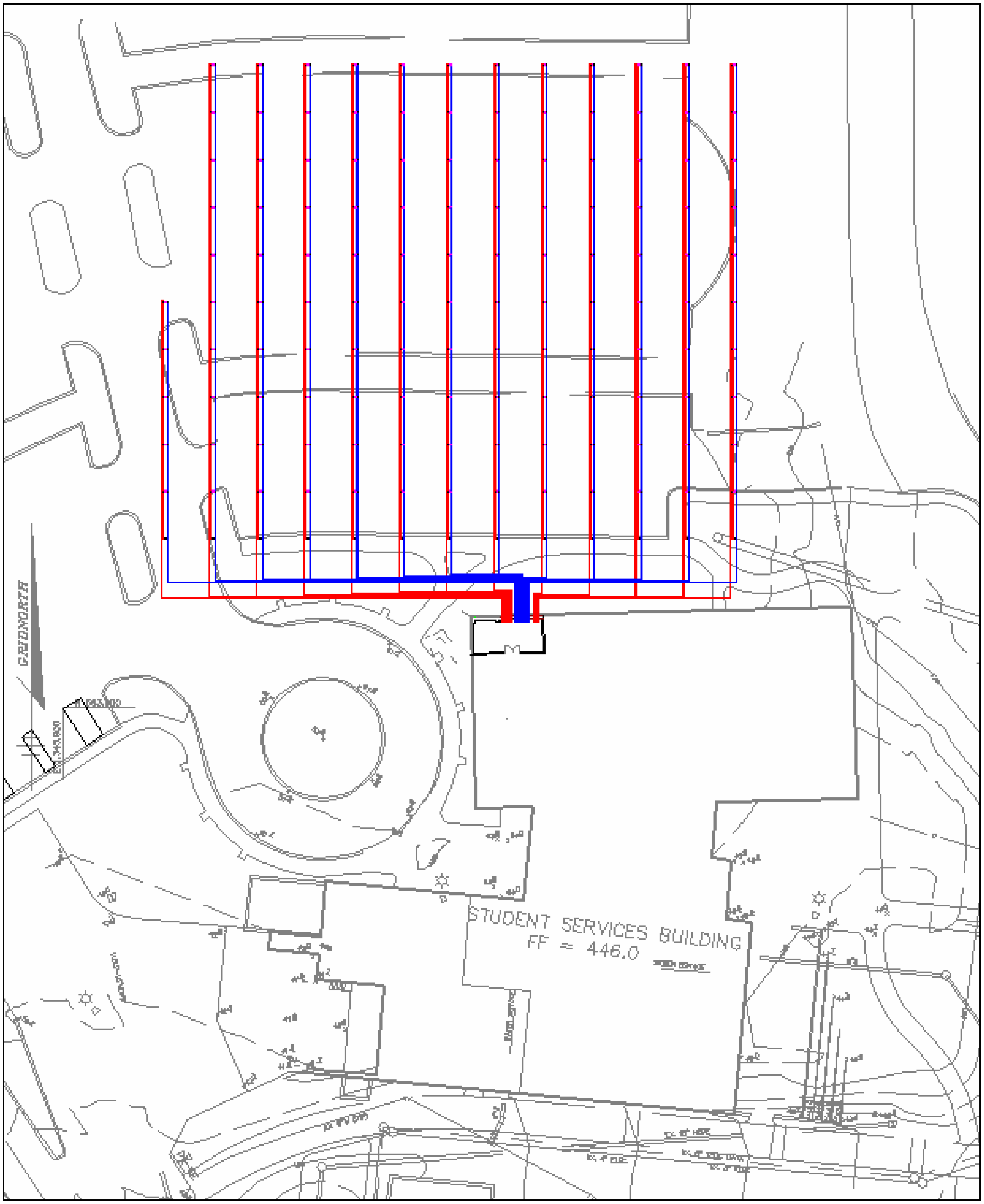
The following loads were computed using TRACE 700 then used as the basis for sizing the amount of heat exchanger piping required.

Design heating load	million Btu/h	2.272
Annual heating energy demand	million Btu	14.7
Design cooling load	ton (cooling)	382.1
Annual cooling energy demand	million Btu	81.2

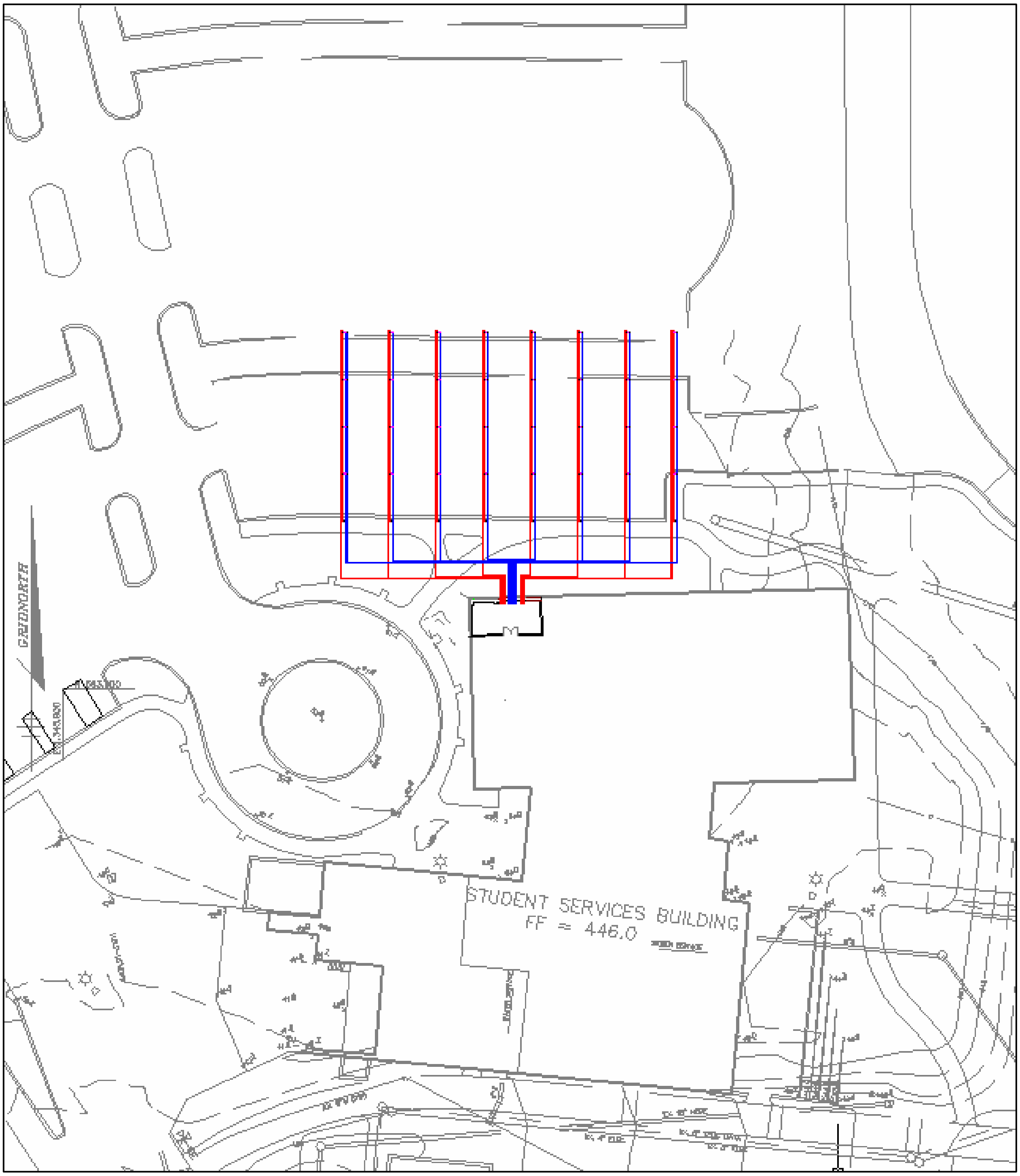
Ground Loop Sizing

After the building loads were calculated in the TRACE 700 energy modeling program, I needed to determine the required length of ground loop heat exchanger piping. The TRACE program does not have this feature in the simulation. Therefore, another program was needed to determine the amount of vertical borehole length. The program I chose to use was the Ground-Source Heat Pump Project Model by RETScreen International. This was a very "user friendly" program which allows the user to input various data to estimate the sizing of the ground loop. The location for the model was once again Baltimore MD which is the closest available data for Howard County Maryland. Heating and cooling design temperatures were adjusted to match what was used in the TRACE program; a summer dry bulb temperature of 91^{o}F and a winter dry bulb temperature of 13^{o}F. The ground was assumed to be comprised of light rock at a temperature of 55^{o}F. Using high efficiency heat pumps with a cooling COP of 5.5 the total length of bore hole required to meet the cooling load was 41,286 feet. This would require the extensive drilling of 138 boreholes at a depth of 300 feet. An area of 48,245 square ft would be required for this option.

To reduce the amount of bore holes required to meet the cooling needs I decided to change to a hybrid system with a cooling tower incorporated into the water loop. The heat exchanger piping length was calculated a second time to meet the required heating loads. This configuration not only reduces the amount of boreholes required, but also balances the heating and cooling loads that are introduced into the ground. If there is an imbalance in the heating and cooling loads, the average ground temperature can increase over time causing reduced efficiency in the heat pumps. When the piping is reduced to meet the heating needs, substantial piping length is conserved. 11,972 feet of piping is required, which equates to 40 boreholes at a 300 foot depth. Spacing the boreholes at the suggested distance of 20 feet on center covers an 11,200 square ft area. The following figures illustrate the difference in areas of the well fields.

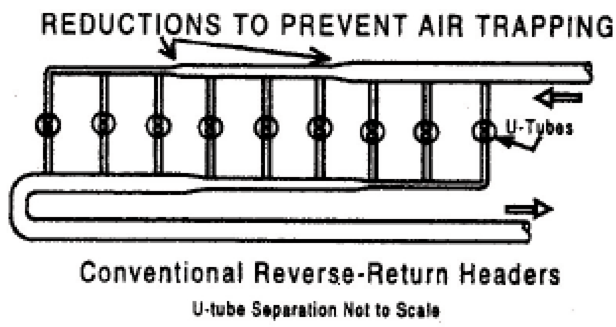


The figure above illustrates the required well field area to meet the entire cooling load of the building. The bore hole spacing is 20 feet on center. The supply and return lines enter the building through an existing mechanical room.

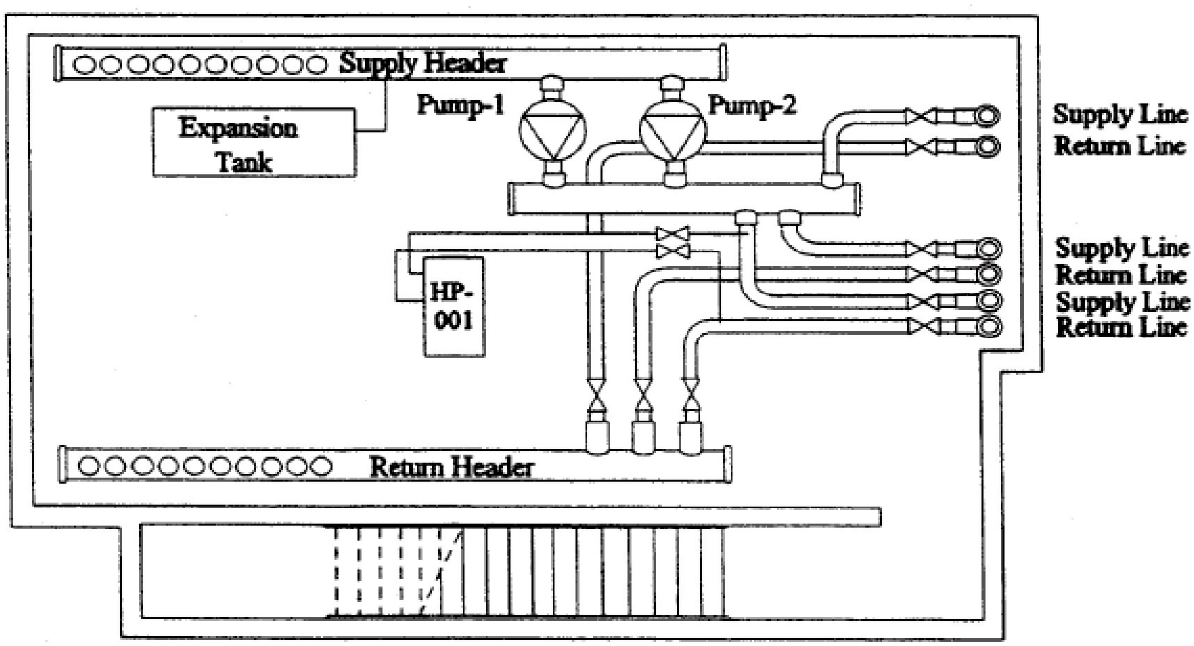


The figure above illustrates the well field area required to meet just the heating loads of the building. Bore hole spacing is maintained at 20 foot centers. In addition to this well field, another 270 tons of cooling capacity is required to meet peak demands. This capacity will be met through the use of a roof mounted cooling tower. Assuming a flow rate of 3gpm per ton of cooling, a plate heat exchanger with a capacity of 810 gpm will be used in conjunction with the cooling tower.

The proposed well field would be located under the existing parking lot at the college.



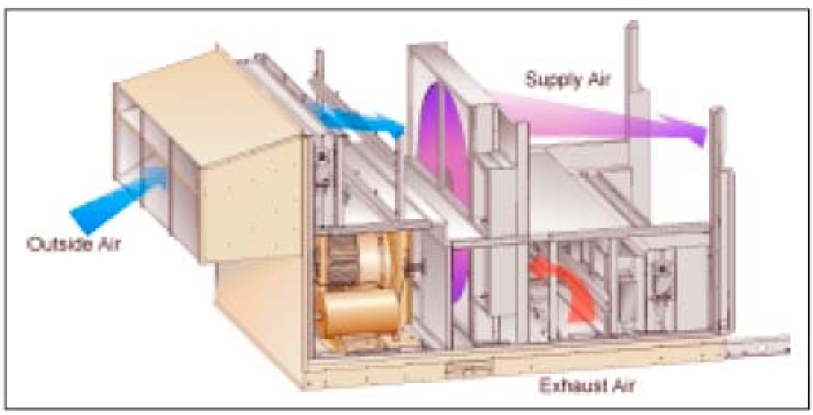
Further discussion of the drilling location is located in the construction management breadth. Construction in this area will reduce the impact on the surrounding green environment. This will also protect the heat exchanger piping run-outs. The vertical heat exchanger piping is set up in a reverse return header configuration. This configuration is inherently self balancing, and allows for even flow through the wells. The supply run is piped out in a large diameter pipe and is gradually reduced as each “U” tube is branched off into its well. The return piping is then increased in diameter as each “U” tube branch is reconnected. The run-out piping is then returned to the building and connected to the building loop. The schematic below illustrates how a typical mechanical room would be set up.



The minimal equipment required to operate a ground source heat pump system allows the mechanical room to be greatly reduced in size. In my proposed mechanical room only a few piping headers, pumps, and a plate heat exchanger will occupy the space. Since no large chillers are to be housed, the mechanical room space can be reclaimed by the occupants providing more rentable space within the building.

Ventilation

Through the addition of heat pumps within the building, the existing air handling units can now be resized. The changes to ASHRAE Standard 62.1 between 2001 and 2004 have allowed for differing ventilation rates within buildings. When calculating ventilation rates using the most recent standard, two factors are accounted for in the final result. Occupancy of the rooms and the floor area of the rooms are the two variables that account for the total ventilation rate for the space. When looking at the existing building zones I decided to downsize from six AHU's to two AHU's. The building layout consists of two main wings separated by an atrium space. Therefore, it was conducive to designate an AHU for each wing. The recalculation of ventilation rates for the building resulted in an AHU for the North wing and atrium with a capacity of 5,000 cfm (cubic feet per minute) and 11,000 cfm for the South wing AHU. To facilitate efficient operation of the heat pumps the outdoor ventilation air needs to be pre-conditioned. This preconditioning is attained through the use of an enthalpy wheel within the AHU. The enthalpy wheel recovers both sensible and latent energy from the exhaust air before it exits the unit and transfers this energy to the incoming outside air. During extreme outside temperatures i.e. the design temperatures, the enthalpy wheel will most likely not be able to handle the entire preheating or precooling load. For this reason, the air handling unit will also be connected to the water loop to provide additional capacity. This air is now preconditioned and ducted directly to the heat pumps where



any additional heating or cooling that is required by the occupant's comfort level can be adjusted by the local thermostat within the zones.

When reevaluating the original design, the total air capacity of the AHU's for the North wing of the building is 45,300 cfm, and the capacity of the AHU's for the South wing is 64,000 cfm. This large volume of air requires large amounts of ductwork to get the conditioned air to the VAV boxes and then to the rooms. Through the proposed design only ventilation air is required to be ducted to the heat pumps not the typical mix of ventilation and return air. This is a minimal amount of air and requires a minimal amount of duct work. This reduced amount of duct work will decrease the cost of materials and installation for the proposed system, and will be discussed in the Construction Management Breath.

Controls

The controls for this hybrid system are critical to the efficiency of the system. Constant monitoring through temperature sensors and flow meters will be required at various points throughout the water loop. These sensors will be connected to a direct digital control system that will constantly record operating data including time of day, water temperature, zone temperatures, zone set temperatures, water loop flow rates. To obtain optimum efficiency of the system several iterations of set points will likely be required. The water loop should have a maximum set temperature where once this temperature is reached the cooling tower will turn on to reject excess heat. Also using thermometers to measure outside air wet bulb temperatures, the control system can turn on the cooling tower to operate during times of maximum efficiency. Data from this system should be kept and analyzed frequently. It is critical to have good records of the heating and cooling requirements of the building. These loads need to be balanced within the ground loop system to ensure no yearly net gain or loss of heat in the ground. An increase or decrease in the ground temperatures will cause a loss in the efficiency of the heat pumps. With over one hundred fifty heat pumps in the building, it is very important that they run at optimum efficiency. With the constant changes in technology and new equipment, computer controls are required for today's building systems. These systems require constant monitoring and continuous commissioning.

Conclusions

I feel the proposed design is a good overall solution to the building requirements, and is a pleasing solution for the many parties involved. The occupants should remain happy with individual zone controls throughout the building to maintain comfort within each room. With the reduction in energy consumption, the building owner will be pleased by the reduced utility bills. Reduced energy consumption by the building means that less fossil fuels will be burned to meet the needs of the building; therefore reducing the amount of green house gases being released into the atmosphere. By reducing the amount of mechanical equipment in the building, the required maintenance is also reduced. The installation of high quality heat exchanger piping in the ground, and the use of high efficiency heat pumps will provide many years of trouble free operation. Through use of good controls and proper maintenance, the building systems will run efficiently and provide considerable cost savings throughout its life cycle.

Breadth Topic

Construction Management

The use of a geothermal heat pump system will affect cost and construction time of the Student Services Building. As part of my breadth analysis I will analyze the constructability of this option. The use of a geothermal system will require extensive drilling and/or site excavation in order to install the required ground source water loop. The additional site work required will be compared to the existing time table to see if any major milestones are delayed in the critical path of the schedule. The required time, additional labor, and materials will be estimated to provide a first cost and lifecycle cost financial analysis.

Initial Cost Evaluation

To evaluate the cost of the proposed geothermal system only major equipment and material costs were evaluated many resources were utilized. The main resource was the cost analysis worksheet of the Ground-Source Heat Pump Project Model by RETScreen International. This work sheet is for a feasibility study of the geothermal proposal. Some cost factors are functions of the worksheet and others were gathered from sources such as various industry contacts and RS Means. Data sources are listed in the appendix.

The reduced amount of air has reduced the air handling equipment and the amount of required duct work. Due to time constraints I did not resize all of the duct work required for the new ventilation rates. For an estimate of the required cost of the proposed duct work, I determined the fraction of designed supply air vs. proposed supply air. I then applied this same fraction to the original cost data obtained from the mechanical subcontractor. Cost data for the various sized heat pumps was obtained from a sales engineer for Carrier. Cooling tower and plate heat exchanger cost data was obtained from 2005 RS Means Building Construction Cost Data. To meet the demands for domestic hot water, it is possible to incorporate a desuperheater into the geothermal water loop. This piece of equipment is essentially takes the waste heat from the compressor motor on a heat pump and adds it to the domestic water. Since the building houses food service equipment, there is a large requirement for domestic hot water supplied at high temperatures suitable for sanitation. Due to this high demand for hot water and high temperature limitations of the desuperheaters, I decided that the existing boilers would remain and not be replaced by a desuperheater connected to the ground source loop heat pumps. Therefore the boilers have not been included in the scope of this cost evaluation. For the proposed heat exchanger well field a cost of $17.00 per foot, which includes drilling, loop installation, bore grouting and lateral pipe into the building, essentially covers installation of all exterior components of the geothermal system.

Equipment & Material Initial Costs

Description	Geo Thermal cost	As Designed cost
Heat Exchange Fluid	$ 1,677.00	$ -
Circulation Pumps	$ 19,227.00	$ 25,462.00
Air Handling Units	$ 110,000.00	$ 738,167.00
VAV boxes	$ -	$ 41,000.00
Water Source Heat Pumps	$ 331,145.00	$ -
Drilling & Grout	$ 203,524.00	$ -
Ground loop piping	$ 24,887.00	$ -
Fittings and Valves	$ 16,008.00	$ -
Building HVAC Piping	$ 901,500.00	$ 655,500.00
Chiller	$ -	$ 250,000.00
Cooling tower	$ 29,200.00	$ 44,700.00
Plate heat exchanger	$ 47,300.00	$ -
Sheet metal	$ 132,755.00	$ 879,400.00
Totals	$ 1,817,223.00	$ 2,634,229.00

In my estimation, the proposed geothermal system will provide a first cost savings of $816,000. This is mainly due to the substantial cost savings provided by reduced air handling equipment cost and sheet metal cost

Life Cycle Cost

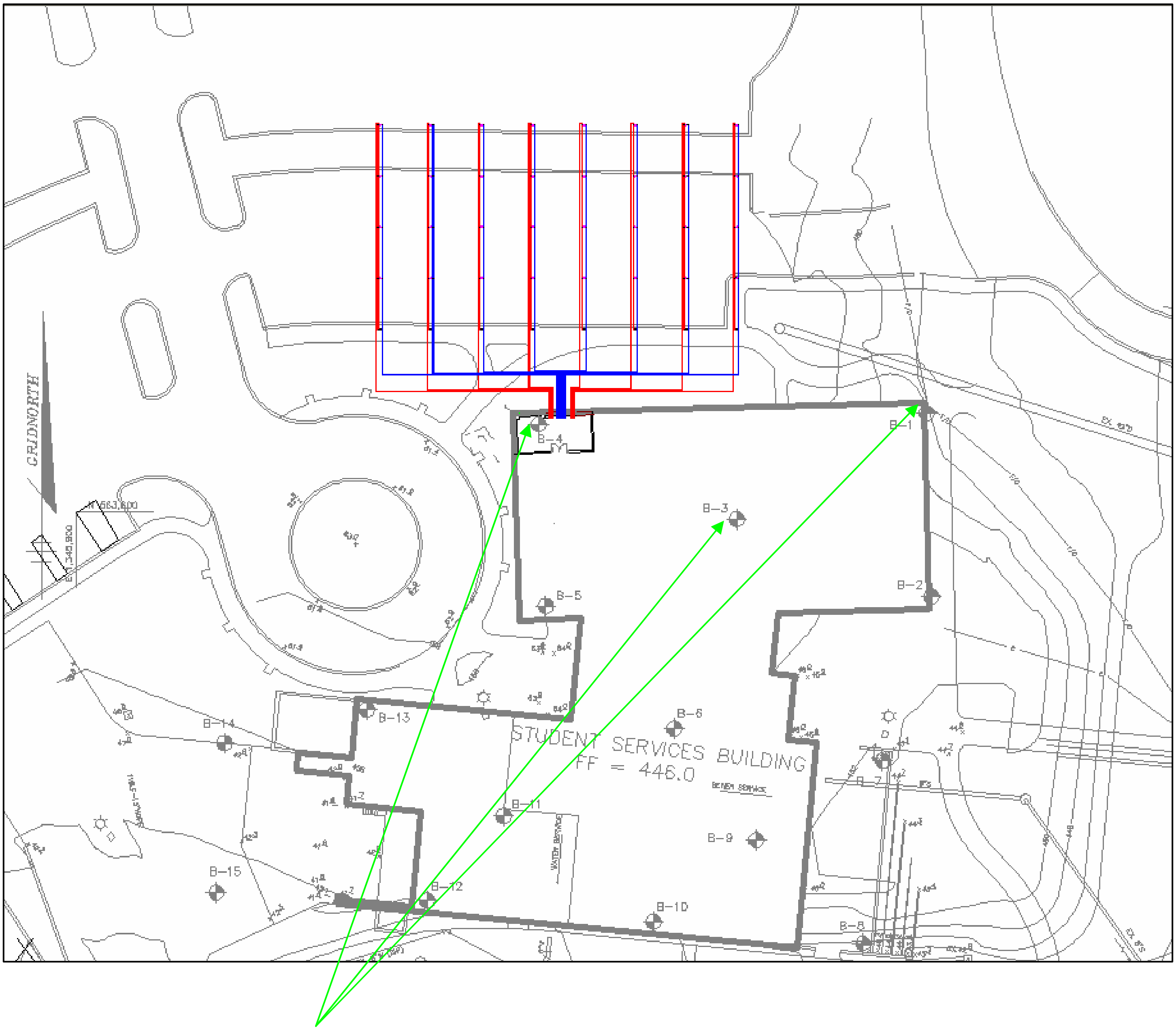
The life cycle cost for the proposed system was performed using Engineering Economic Analysis software from Carrier. When considering economic factors and energy cost data, it is impossible to provide guaranteed results. The volatility in the energy market causes constantly changing prices; therefore prediction of future costs is a guesstimate at best. The following data was used to provide a 20 year life cycle estimate of the proposed system versus the base system. The discount rate was obtained from the current interest rate of 4.5% on a 20 year treasury bill. The escalation rate was determined from the average 2005 inflation rate of 3.4% obtained from http://inflationdata.com. Energy prices for electricity and natural gas were obtained from 2004 utility rates for Howard Community College. Energy consumption for the geothermal system and the base case was based on output data obtained from the TRACE 700 program. The complete results from the 20 year Life Cycle Cost Analysis are listed in the appendix. As a result of lower first costs and operating costs of the proposed geothermal system; it was determined that the present worth of this system is $840,638 less than the base case, Therefore; in my opinion the proposed system is a good alternative to the base case.

Constructability

When reviewing the schedule and site plans, several events were taken into consideration to determine where and when the site drilling could occur. The main consideration was possible interference with site work that was being performed around the building.

Site Considerations

To the south of the Student Services building is the new Arts Building. There is limited amount of space between the buildings and this is also where the main utilities (water, sewer, and electricity) connect to the building. To the west of the Student Services Building is a road connecting to the southern part of campus. This location was not chosen due to the impact of closing the access road in order to drill. The east side of the Student Services Building is the main entrance into the quad area which is surrounded by the adjacent buildings. Again, drilling in this area would not be advised, because students and faculty need access to the adjacent Instructional Lab, Administration building, and the Arts Building. The final location for the well field was chosen to be on the north side of the building. This location would only affect the parking lot for a short period of time and minimize construction intrusion into the center of campus. This side of the building also has a mechanical equipment room which is well below grade so piping can easily be connected directly into this room.

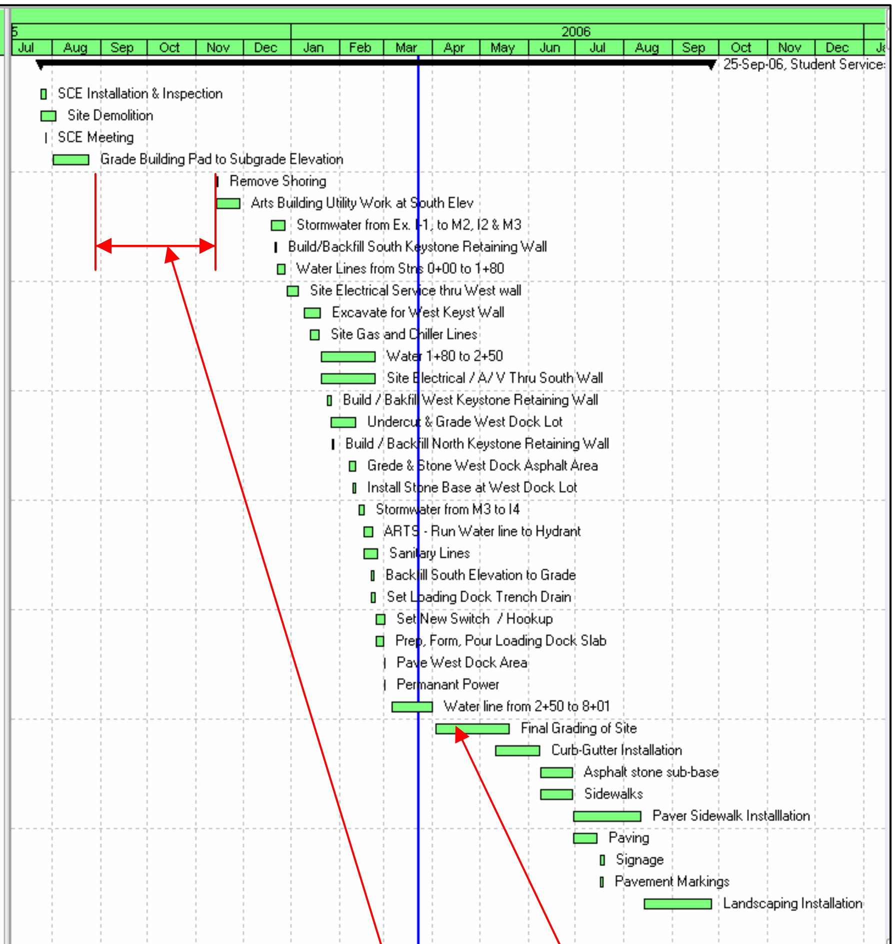


Test bores in the above locations were sampled to a mean depth of 40 feet. The resulting soil samples at the 40 foot depth produced moist very dense silty sand with mica. Assuming that this type of soil continues to the required depth of 300 feet, drilling should not be extra difficult for the subcontractor. From the results of test bores B-1, B-3, and B4 performed by Froehling & Robertson Inc., and other site influences it was determined that the best location for the well field would be on the north side of the building.

Scheduling Impact

Based upon a case study by CETCO, average drilling rates are 700 feet per day. Applying this rate to my proposed well field, the drilling contractor should be able to drill at least 2 bore holes per day. With a relaxed 5 day work week schedule, the drilling operation should be completed in 4 weeks, assuming no unforeseen circumstances.

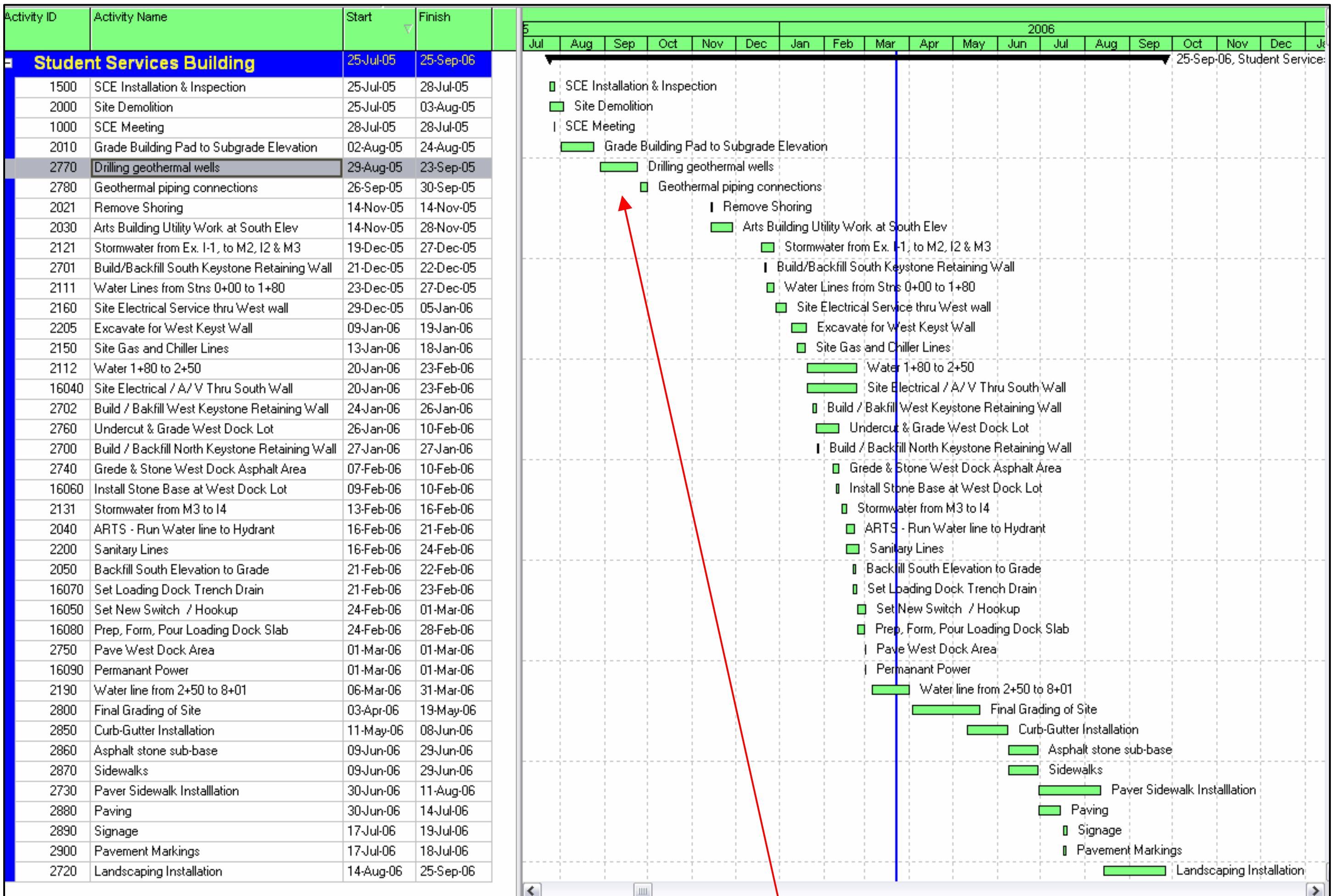
Activity ID	Activity Name	Start	Finish
	Student Services Building	25-Jul-05	25-Sep-06
1500	SCE Installation & Inspection	25-Jul-05	28-Jul-05
2000	Site Demolition	25-Jul-05	03-Aug-05
1000	SCE Meeting	28-Jul-05	28-Jul-05
2010	Grade Building Pad to Subgrade Elevation	02-Aug-05	24-Aug-05
2021	Remove Shoring	14-Nov-05	14-Nov-05
2030	Arts Building Utility Work at South Elev	14-Nov-05	28-Nov-05
2121	Stormwater from Ex. I-1, to M2, I2 & M3	19-Dec-05	27-Dec-05
2701	Build/Backfill South Keystone Retaining Wall	21-Dec-05	22-Dec-05
2111	Water Lines from Stns 0+00 to 1+80	23-Dec-05	27-Dec-05
2160	Site Electrical Service thru West wall	29-Dec-05	05-Jan-06
2205	Excavate for West Keyst Wall	09-Jan-06	19-Jan-06
2150	Site Gas and Chiller Lines	13-Jan-06	18-Jan-06
2112	Water 1+80 to 2+50	20-Jan-06	23-Feb-06
16040	Site Electrical / A/ V Thru South Wall	20-Jan-06	23-Feb-06
2702	Build / Bakfill West Keystone Retaining Wall	24-Jan-06	26-Jan-06
2760	Undercut & Grade West Dock Lot	26-Jan-06	10-Feb-06
2700	Build / Backfill North Keystone Retaining Wall	27-Jan-06	27-Jan-06
2740	Grede & Stone West Dock Asphalt Area	07-Feb-06	10-Feb-06
16060	Install Stone Base at West Dock Lot	09-Feb-06	10-Feb-06
2131	Stormwater from M3 to I4	13-Feb-06	16-Feb-06
2040	ARTS - Run Water line to Hydrant	16-Feb-06	21-Feb-06
2200	Sanitary Lines	16-Feb-06	24-Feb-06
2050	Backfill South Elevation to Grade	21-Feb-06	22-Feb-06
16070	Set Loading Dock Trench Drain	21-Feb-06	23-Feb-06
16050	Set New Switch / Hookup	24-Feb-06	01-Mar-06
16080	Prep, Form, Pour Loading Dock Slab	24-Feb-06	28-Feb-06
2750	Pave West Dock Area	01-Mar-06	01-Mar-06
16090	Permanant Power	01-Mar-06	01-Mar-06
2190	Water line from 2+50 to 8+01	06-Mar-06	31-Mar-06
2800	Final Grading of Site	03-Apr-06	19-May-06
2850	Curb-Gutter Installation	11-May-06	08-Jun-06
2860	Asphalt stone sub-base	09-Jun-06	29-Jun-06
2870	Sidewalks	09-Jun-06	29-Jun-06
2730	Paver Sidewalk Installlation	30-Jun-06	11-Aug-06
2880	Paving	30-Jun-06	14-Jul-06
2890	Signage	17-Jul-06	19-Jul-06
2900	Pavement Markings	17-Jul-06	18-Jul-06
2720	Landscaping Installation	14-Aug-06	25-Sep-06



Existing Site Work Construction Schedule

Potential window of opportunity for well field drilling and piping installation

All drilling, piping installation, and connections to the building must be completed before the final grading of the site.



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2000	Site Demolition	25-Jul-05	03-Aug-05
1000	SCE Meeting	28-Jul-05	28-Jul-05
2010	Grade Building Pad to Subgrade Elevation	02-Aug-05	24-Aug-05
2770	Drilling geothermal wells	29-Aug-05	23-Sep-05
2780	Geothermal piping connections	26-Sep-05	30-Sep-05
2021	Remove Shoring	14-Nov-05	14-Nov-05
2030	Arts Building Utility Work at South Elev	14-Nov-05	28-Nov-05
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2890	Signage	17-Jul-06	19-Jul-06
2900	Pavement Markings	17-Jul-06	18-Jul-06
2720	Landscaping Installation	14-Aug-06	25-Sep-06

Proposed Site Work Construction Schedule

Proposed geothermal well field installation

Allowing an extra week for final piping connections and demobilization, my total estimated time frame for the geothermal heat exchanger field is just five weeks.

Conclusions

Through the cost and constructability analysis of the proposed geothermal system, I feel that it is a very feasible alternative. First cost savings over the existing system and lower operating costs of the geothermal system make it a very viable option for the building. The location of the well field will have minimal impact on the campus being located under the parking lot. Through the use of a hybrid geothermal system first costs have been reduced, and running more energy efficient equipment, substantial savings can be seen for the owner.

Breadth Topic

Lighting & Electrical

With today's growing cost of energy, whenever there is a opportunity for conserving I think it should be seized. While reviewing the lighting power densities I noticed that some large dining rooms seemed to have higher densities. After looking at the lighting schedules, I determined that the higher densities were due to the use of a 50 watt MR-16 halogen lamp in many fixtures throughout the room. With the increase in compact fluorescent technology, it is becoming more feasible to replace incandescent lamps. For my proposed breadth I decided to replace the existing down lights with MR-16 lamps to down lights with 26watt compact fluorescent lamps.

Lamp Comparison

The new down lights are aesthetically pleasing and provide similar light output to the original design. The new down lights still have the same dimming capabilities as the original design. Also the amount of light output is slightly higher. The typical MR-16 lamp will produce 1600 lumens, while a 26W compact fluorescent will provide about 1800 lumens. The quality of light was also considered when making the switch. Comparisons in the Color Rending Index (CRI) and the Correlated Color Temperature (CCT) were made. For the MR-16 lamp the CRI was100 and the CCT was 3000(K). The compact fluorescent provided a CRI of 82 and a CCT of 2700(K). With the listed performances, it was assumed that the proposed compact fluorescent lights would be acceptable for the architect and owner. Please consult the ut sheets provided in the appendix for above stated values.

When calculating the new power density factor the calculation must be made using the ballast watts which was 32 Watts. Below is a table used to calculate the new densities.

FLR	ROOM #	SPACE DESCRIPTION	AREA (sqft)	WATTS PER LAMP	NO OF LAMPS PER FIXTURE	NO OF FIX-TURES	WATTS	POWER DENSITY W/SQFT	Watts saved per room
4th	400	PRIVATE DINING ROOM 1	2988	50	1	63	3150	1.054	
4th	400	PRIVATE DINING ROOM 1 proposed	2988	32	1	63	2016	0.675	1134
4th	401	PRIVATE DINING ROOM 2	1360	50	1	24	1200	0.882	
4th	401	PRIVATE DINING ROOM 2 proposed	1360	32	1	24	768	0.565	432

Conclusion

The proposed lighting change will provide significant energy savings without compromising the quality of light within the space. Assuming the lights are on for an office occupancy schedule from 8am to 6pm on weekdays, and an electricity charge of $.05 per kWh, the proposed lighting change will save $204.36 annually. This may seem like insignificant amount; however it will save about $4,100 over the course of 20 years. In addition to the energy savings, maintenance for the new lamps will also be reduced. The average life for an MR-16 is 4,000 hours, while the average life for the compact fluorescent is 12,000 hours. This cuts the maintenance costs by a factor of 3. No first cost data was determined for this comparison, but I still believe that it would be a wise decision due to the energy savings and maintenance.

Summary

In today's society of constantly increasing fuel cost it is important that any potential energy saving measures be pursued. Typically building owners will only look at first costs. It is my belief that this mindset needs to be changed in order to be able to provide for future generations.

The mechanical system design for the Student Services Building provided by Mueller Associates was in no way flawed. However, I believe that my proposed redesign is also a very feasible option in comparison to the one which is being built. There are always many solutions to the goal of energy savings and I believe that the duty of engineers should be to make building owners aware of these many possible avenues.

This senior thesis has provided me with a good opportunity to explore alternative mechanical designs. As technology increases so do the efficiencies of the equipment. This equipment needs to be utilized to its fullest capabilities. With a limited supply of fossil fuels, I believe that the future lies in renewable energy resources such as the sun and geothermal. Making the most of these free energy sources will ensure prosperity for the future.

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13. http://www.fhp-mfg.com/commercial/geo/geosystems.htm

Appendices

TRACE 700 Modeling Results

Ventilation

RETScreen International Ground Source Heat Pump Project Model

Water Source Heat Pump Cut Sheet

WSHP Performance Data

Water Source Heat Pump Pricing

Drilling Pricing

Mechanical SubContractor Estimate

Life Cycle Cost

Lighting Densities

Fixture and Lamp Cut Sheets