Coppin State University Physical Education Complex – Final Report

Analysis of Geothermal System with Heat Recovery Chiller

Kaylee M Damico

Advisor: Dr. Jelena Srebric

Location: Baltimore, MD

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Executive Summary

The purpose of this report is to analyze a proposed redesign for the Coppin State University Physical Education Complex. Currently the complex utilizes a variable air volume (VAV) system to serve the various spaces in the complex. Highly efficient boilers, chillers and cooling towers help serve the loads of the complex, which are located in the future central utility plant. The plant also has connections and space anticipating the future renovations to the campus.

A mechanical depth was analyzed by redesigning the mechanical systems in two ways. The first addition was a ground source heat pump system for zones A and B of the complex. These two zones were chosen for this system because they are the only areas of the complex that run year round. The second system analyzed was utilizing heat recovery chiller during non-peak load times for the boiler.

With the addition of this equipment the building and construction process would be affected overall. Two depths were investigated to see how this redesign would affect the construction process and the current electrical systems. The site, schedule and installation of these systems were evaluated for the construction breadth. The existing Motor Control Centers were evaluated for the addition of the major equipment being added for the electrical breadth.

Adding both these systems drastically affect the cost and energy savings year round for the complex. An in-depth study of the energy saved, emissions and 30-year life cycle cost was performed in order to see the benefits of adding these systems.

Building Overview and Existing Conditions

Architecture

The new Physical Education Complex at Coppin State University was designed to support the health and human performance academic programs, the indoor and outdoor athletic teams and the West Baltimore community outreach mission of the University. With its varying height changes and expansions surrounding the adjacent field and track, the complex welcomes its guests allowing the balance of brick and glass to complement its features. The Complex houses laboratories, classrooms, faculty and staff offices, dance studio, auxiliary gym, racquetball courts, fitness center, 4,100 seat arena and an eight lane NCAA regulation pool. It also houses a future satellite central utility plant with the associated maintenance and support service shops. Outdoor improvements include an outdoor track, soccer field, softball field, tennis courts, and a new campus entrance.

Sustainability Features

The complex was designed and built to achieve LEED Silver certification, therefore there were multiple sustainable features implemented into the design. Some features were considered through the architecture while others were implemented through the building systems. Examples of these attributes include; overhanging officer on south façade for solar shading, water efficient landscaping and daylighting provided to over 75% of spaces.

Building Enclosure

The building's façade is mainly composed of brick and glass windows. The typical exterior walls are comprised of Concrete Masonry Units (CMU) connected to the face brick. Insulated clear and translucent glass is used with metal paneling to create a curtain wall system. The roofing system includes a composite metal decking with a thermoplastic polyolefin roofing membrane which is supported by several trusses spanning over 150 feet.

Electrical and Lighting System

The main electrical room has all the main switchboards as well as two supporting panelboards. The main switchboard and panelboards run on 3 phase, 4-wire 480/277 volt system while the other panelboards step down to a 208/120 volt system. Distribution panels are spread out throughout the building, primarily found in mechanical rooms and smaller electrical rooms. A generator powers the main electrical room through underground conduits.

The complex uses primarily fluorescent lamps for interior lighting in spaces such as classrooms, hallways and lobbies. The more complex lighting features are in the arena and swimming pool areas. In these areas pendant mounted compact fluorescent lighting fixtures are used to bring the intense amount of light all the way to the floor. Exterior lighting includes mounted step lights around the exterior and additional sporting event lights around the training field.

Structural System

The complex is separated by expansion joints to split it up into 4 separate buildings. One expansion joint runs in the east-west direction while the other runs north-south. The foundation is comprised of spread footings and slab on grade. Composite steel beams and a concrete slab make up the floor system of the complex. Beams are typically spaced at ten foot intervals to eliminate shoring during construction. Girders are typically spaced thirty feet apart. The columns are mostly W12's, but some W10's and W14's are used as well. Trusses span the arena with lengths as longs as 166 feet. Special connections were utilized at mid-span and intersections due to the complexity of the structural system.

Fire Protection

The complex is in accordance with NFPA 13 and 14 with a complete automatic fire protection system. There are three different hazard levels within the building with the associated flow rates required for each classification. The three groups are light hazard, hazard group 1 and hazard group 2. The only area with hazard group 2 is the arena due to the large amount of people in a small area with a high ceiling. The light hazard areas include corridors, lobbies, stairs and offices while hazard group 1 is comprised of the mechanical and electrical rooms located throughout the building.

Transportation

Due to its small, maximum height of four floors, there are only a few elevators located in the complex. There are two elevators located in the physical education area and one in the facilities management area. There is an additional one near the arena to transport the handicap guests to their appropriate seats. Occupants of the building will mainly utilize the multiple stairwells located throughout the complex.

Energy Sources

Possible energy sources that the complex is able to utilize include electricity, natural gas and fuel oil. The fuel oil is stored in a 20,000-gallon underground double wall fiberglass tank. The fuel oil rates will not be considered for this report since the fuel is considered a back-up source of fuel. The electricity and natural gas are provided by Baltimore Gas and Electric (BGE); these rates are listed below in Table 1.

Table 1 – Local Energy Rates

	Modeled	**Designed**
Electricity Cost ($/kWh)	0.12	0.1112
Natural Gas Cost ($/Therm)	1.138	1.227

Existing Mechanical Systems Summary

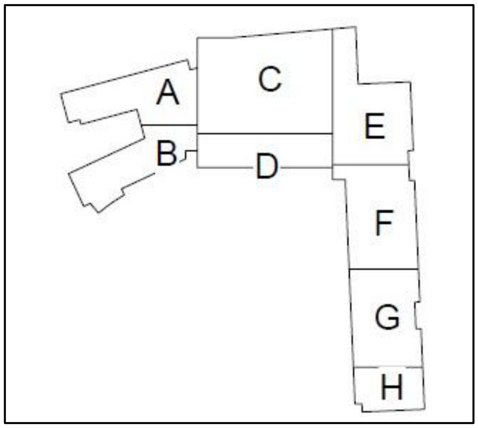
Design Objectives

The main design objectives for the Complex were to meet all ASHRAE Standards including ventilation requirements, acceptable indoor air quality, minimum energy requirements and more. In the middle of the design process LEED® certification was made another objective. The design was an energy efficient building using mainly a traditional Variable Air Volume (VAV) system. Single zone VAV, energy recovery units and dehumidification units were also implemented for the more complex spaces. The central utility plant is comprised of boilers, chillers and pumps with an accompanying cooling tower on the roof of the complex. After the completion of the complex it was able to successfully achieve a LEED® Silver Rating.

Mechanical System Overview

Due to the intricacy and varying spaces in the complex it is broken up into eight zones labeled A-H as seen in Figure 1 below. The complex is served by a total of fourteen air handling units (AHUs), some interior others exterior. The future central utility plant houses two 500 ton chillers, three dual fuel 250HP boilers and space for future expansion. The cooling tower is located close to the central utility plant, on the roof of zone A.

Figure 1 - Architectural Zoning



AHU-1 is controlled to maintain a unit discharge of 55°F, which provides sufficient cooling and dehumidification for all zones during design conditions. It serves zone A of level one which consists of shops served by constant air volume terminal units with reheat coils. Air handling units 2, 3 and 4 serve zone B on levels 1, 2 and 3, respectively; these zones are comprised of central services and facility maintenance offices. These three units utilize variable air volume (VAV) terminal units with hot water reheat coils. The arena, in zone C, is considered a single zone and is served by AHU-5 and AHU-6. Zone D includes the concourse on the second level with offices above, on the third level. This zone is served by AHU-7 on the second level and AHU-8 on the third level which both use VAV terminal units as well. The auxiliary gym is served by AHU-9 and AHU-10 in zones F and G, which also use a single zone VAV system. The classrooms and dance studio in zones G and H are served by AHU-11 with VAV air terminal units. AHU-12 and AHU-13 serve the multipurpose room and fitness area, respectively, which are also single zone VAV systems. The last unit, AHU-14, is a single zone heating only unit which serves the vehicle maintenance area in zone B. Other systems in the building include two energy recovery units which serve the locker rooms due to their high exhaust requirements and a pool dehumidification system for the indoor pool in zone E.

Design Conditions

The complex is located in Baltimore, MD so the design conditions for Baltimore were used for the design. The outdoor design conditions for Baltimore were obtained from ASHRAE Fundamentals 2005, shown in Table 2. Indoor design conditions were defined by the engineer and were unique for some of the more complex spaces as seen below in Table 3.

Table 2 - Outdoor Design Conditions

	Dry Bulb	Wet Bulb
Summer	95°F	78°F
Winter	0°F	-

Table 3 - Indoor Design Conditions

		Dry Bulb	Relative Humidity (occupied)	Dry Bulb (unoccupied)
Typical Spaces	**Cooling**	75°F	60% maximum	85°F
	Heating	70°F	no minimum	55°F
Arena and Aux. Gym	**Cooling**	75°F	50% maximum	85°F
	Heating	70°F	30% minimum	55°F
Pool	-	80°F - 86°F	50% - 60%	-
Utility Spaces	**Heating**	60°F	-	-

Design Requirements

Ventilation

In order to verify that the complex’s mechanical systems provide enough ventilation, a ventilation rate calculation from ASHRAE Standard 62.1 was performed. This procedure looks at the outdoor air intake rates based on the space types/application, number of occupants and the floor area of each space. Since some of the zones are very similar when considering space type, only nine of the fourteen air handing units were analyzed; the units considered address each type of zone.

The summary of the calculation is shown below in Table 4, while the detailed analysis of ASHRAE Standard 62.1 can be found in Technical Report 1. At the conclusion of this procedure it was discovered that three of the air handling units were not compliant. A reason for this finding can be from the occupancy values used. For these calculations a number given by the architect or the number of chairs/seats in an area were used for number of occupants in a given space. The zones that did not meet these requirements include high occupancy areas such as the dance studio and auxiliary gym. These areas will rarely be occupied at maximum level, but if they are the units may need to be resized or adjusted to meet these airflow rates.

Table 4 - Ventilation Rate Procedure Summary

Unit	Design Min CFM	ASHRAE 62.1 Min OA	Compliance
3	3800	1653	YES
4	3400	1599	YES
5	31000	13133	YES
6	31000	13133	YES
7	2800	1018	YES
8	7500	3593	YES
9	2300	8232	NO
10	2300	8232	NO
11	9150	11064	NO

Heating and Cooling Loads

An energy model was simulated in Carrier's HAP version 4.50 which analyzed the entire complex. Examples of the templates and data used can be found in Technical Report 2. Table 5 compares the summary of the energy model results to the engineer's design. The block load energy model resulted in different values than those designed for each air handling unit and energy recovery unit. The differences in these values could be consequences of the safety factors applied by the mechanical engineer or the details put into each space. The main reason for these differences is most likely due to the fact that a block load analysis was used in the model while the mechanical engineer used a space by space method for the design.

Table 5 – Modeled vs. Designed Energy Analysis

		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5/6	AHU-7	AHU-8
Cooling (MBH)	Designed	621	397	650	637	6540	509	1029
	Modeled	281.4	267.8	411.8	362.1	3084.2	245.1	481.9
Supply Air (cfm)	Designed	12250	9000	13750	14750	80000	11500	19600
	Modeled	5023	8453	12411	11426	72892	7316	16290
Ventilation Air (cfm)	Designed	4000	1975	3800	3400	62000	2800	7500
	Modeled	2062	1362	1694	1190	10800	762	1399
Heating (MBH)	Designed	529	389	594	637	1728	497	847
	Modeled	127.5	91.3	142	161.5	899.7	122.1	182.7

		AHU-9/10	AHU-11	AHU-12	AHU-13	AHU-14	ERU-1	ERU-2
Cooling (MBH)	Designed	958	1404	539	596	-	733	1091
	Modeled	779.9	8601.1	418.8	430.6	-	267	488.8
Supply Air (cfm)	Designed	23000	28000	13000	13950	4800	9820	14100
	Modeled	19057	22157	10162	8453	4773	9765	14022
Ventilation Air (cfm)	Designed	4600	9150	2600	2500	480	9820	1410
	Modeled	4295	5140	2168	2329	136	401	1190
Heating (MBH)	Designed	497	1210	562	603	207	283	404
	Modeled	386.9	352.2	201.8	185.9	140.4	71.5	162.4

Annual Energy Use

Table 6 below shows the annual energy consumption used by the complex broken down by component type which was performed for Technical Report 2. Referencing Figure 1, the largest consumer of energy in the building is the cooling tower fans. This big percentage is due to the large flow rate of the condenser at 1,015 GPM. The cooling tower for the complex is a very large tower and was sized with expansion in mind. The lights, electrical equipment, and air system fans consume the next largest amount of energy.

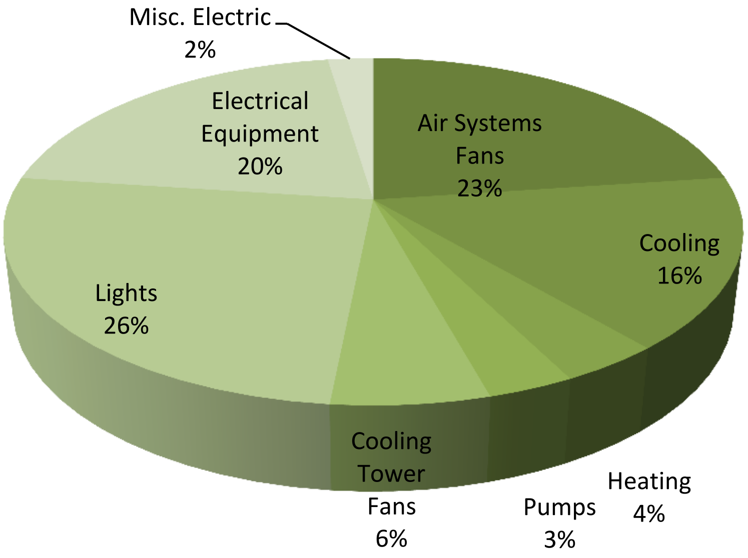
This annual energy consumption was compared to the Commercial Buildings Energy Consumption Survey (CBECS) 2003. In Table E2A (Major Fuel Consumption Intensities by End Use for all Buildings) of CBECS a building with the same range of square footage as the complex consumed an average of 100,200 BTU/SF. When comparing this value to the complex at approximately 92,000 BTU/SF the numbers produced by the model appear accurate.

These results were also compared to the engineer's results. Since the complex is a LEED® Silver Building an energy consumption study had to be performed for EA Credit 1. The engineer compared their results to the ASHRAE Standard 90.1 Baseline. These results can be seen in Appendix A. When comparing the engineer's results to the results done in Technical Report 2 the results are much higher. This is most likely due to the block loading method used for this report compared to the room by room method used by the engineer.

Table 6- Annual Energy Consumption

	Energy (kWh)
Air Systems Fans	1,434,527
Cooling	1,010,456
Heating	751,846
Pumps	201,676
Cooling Tower Fans	3,653,707
Lights	1,621,230
Electrical Equipment	1,289,010
Misc. Electric	150,600
Grand Total	**10,113,052**

Figure 1- Annual Energy Consumption Percentages



Equipment Summary

The complex is served by fourteen air handling units which are all variable air volume (VAV) units. Some of the units are single zone while others are conventionally zoned. There are a total of 154 air terminal units connected to their associated air handling unit. For the more challenging spaces the complex has two energy recovery units serving the locker rooms and a dehumidification unit for the pool area. All of these units are specified in Table 8, 9 and 10.

Table 8 - Air Handling Units

Unit	Area Served	CFM	Min OA (CFM)
AHU - 1	Shops (Level 1)	12250	4400
AHU - 2	Central Services (Level 1)	9000	1975
AHU - 3	Facility Maintenance (Level 2)	13750	3800
AHU - 4	Facility Maintenance (Level 3)	14750	3400
AHU - 5	Arena	40000	31000
AHU - 6	Arena	40000	31000
AHU - 7	Arena Offices (Level 3)	11500	2800
AHU - 8	Concourse (Level 2)	19600	7500
AHU - 9	Auxiliary Gym	11500	2300
AHU - 10	Auxiliary Gym	11500	2300
AHU - 11	Classrooms, Dance (Levels 1 &2)	28000	9150
AHU - 12	Multipurpose Room	13000	2600
AHU - 13	Fitness	13950	2500
AHU - 14	Vehicle Maintenance	4800	480

Table 9 - Energy recovery Units

Unit	Area Served	CFM	Wheel Type	Wheel Diameter (inches)
ERU-1	South Lockers	9820	Airfoil Plenum	22
ERU-2	East Lockers, Sports Med, Pool Lockers	14100	Airfoil Plenum	27

Table 10 - Pool Dehumidification Unit

Unit	Area Served	Cooling Capacity (MBH)	Supply Fan (CFM)	Return Fan (CFM)
PDU-1	Pool	730,000	28,000	29,450

A primary/secondary flow system is used for the water side of the mechanical system. The complex has two 500 ton centrifugal chillers which utilize a 1000 ton cooling tower to cool its condenser water. To heat the building three 250HP dual-fuel boilers were used. The major waterside equipment can be seen in Tables 11,12 and 13.

Table 11 - Chillers

		Evaporator			Condenser		
Unit	Capacity (Tons)	GPM	EWT (°F)	LWT (°F)	GPM	EWT (°F)	LWT (°F)
Chiller 1	500	1000	54	42	1200	85	97
Chiller 2	500	1000	54	42	1200	85	97

Table 12 - Cooling Tower

Unit	Capacity (Tons)	GPM	EWT (°F)	LWT (°F)
Cooling tower 1	1000	1250 per cell	97	85

Table 13 - Boilers

Unit	Capacity (HP)	Gross Output (MBH)
Boiler 1	250	8369
Boiler 2	250	8369
Boiler 3	250	8369

Major parts of the mechanical system are the pumps. The pumps are constant volume on the primary size and variable flow on the secondary side. A duplex variable flow tertiary pump system is utilized to distribute the chilled water to the various air handling units throughout the complex. The pumps associated with all the major equipment and their details, can be found in Appendix B.

Schematics

Figure 2 - Condenser Water Schematic

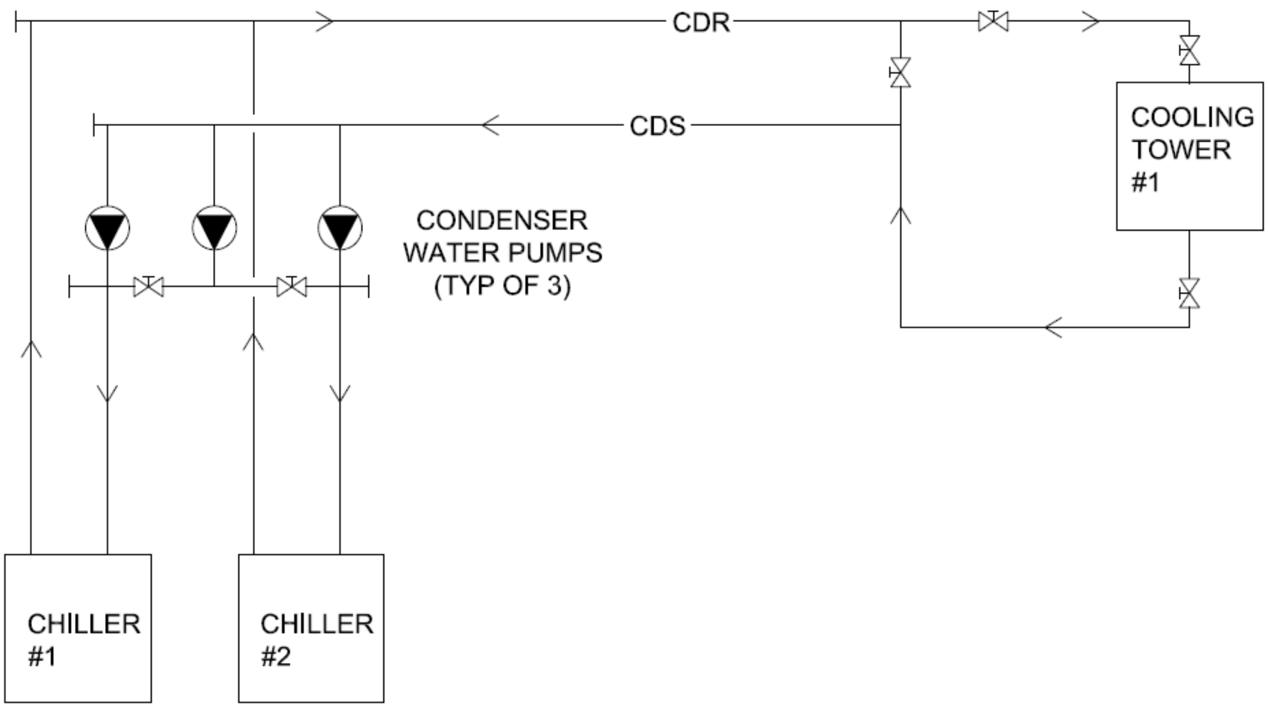


Figure 3 - Chilled Water Schematic

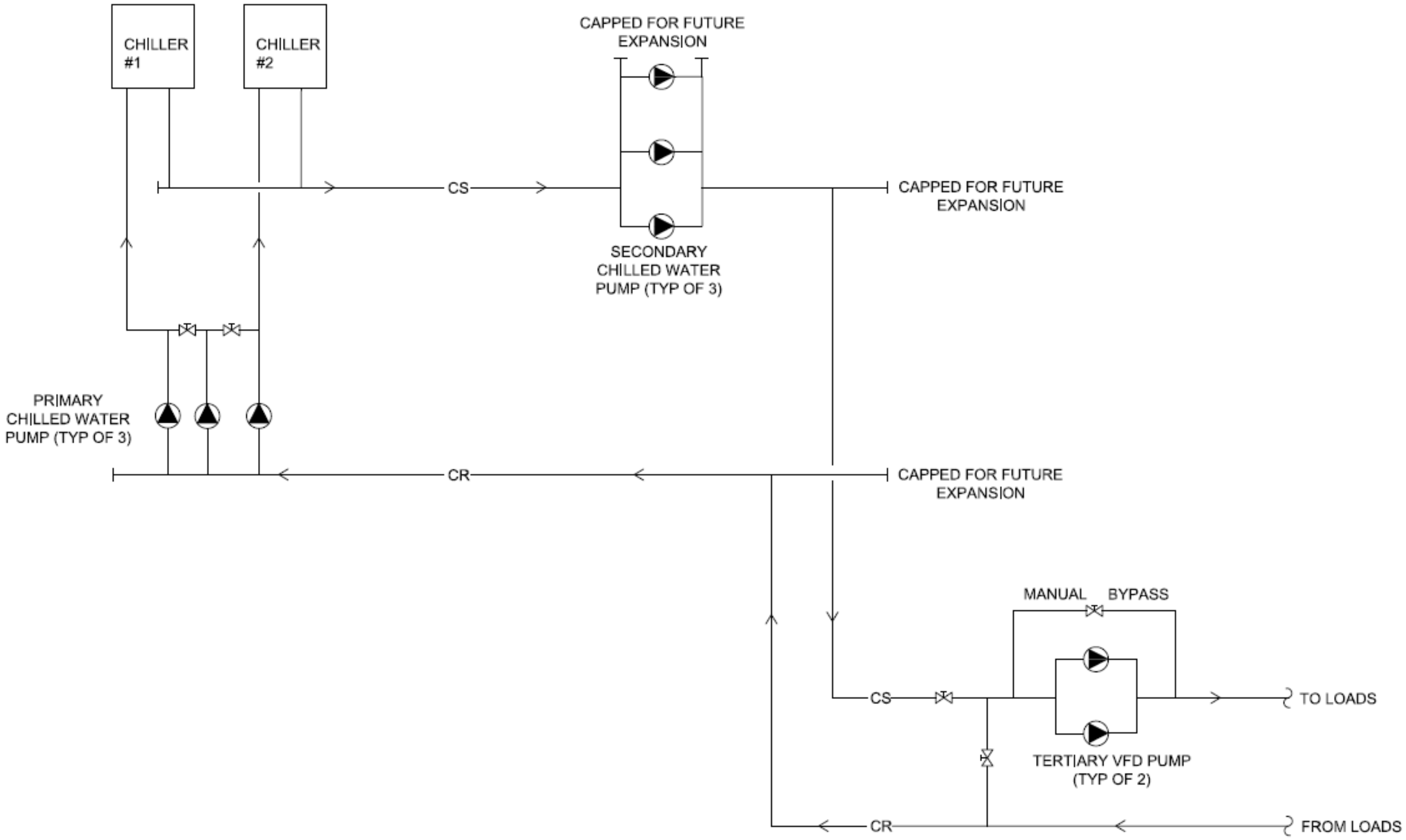
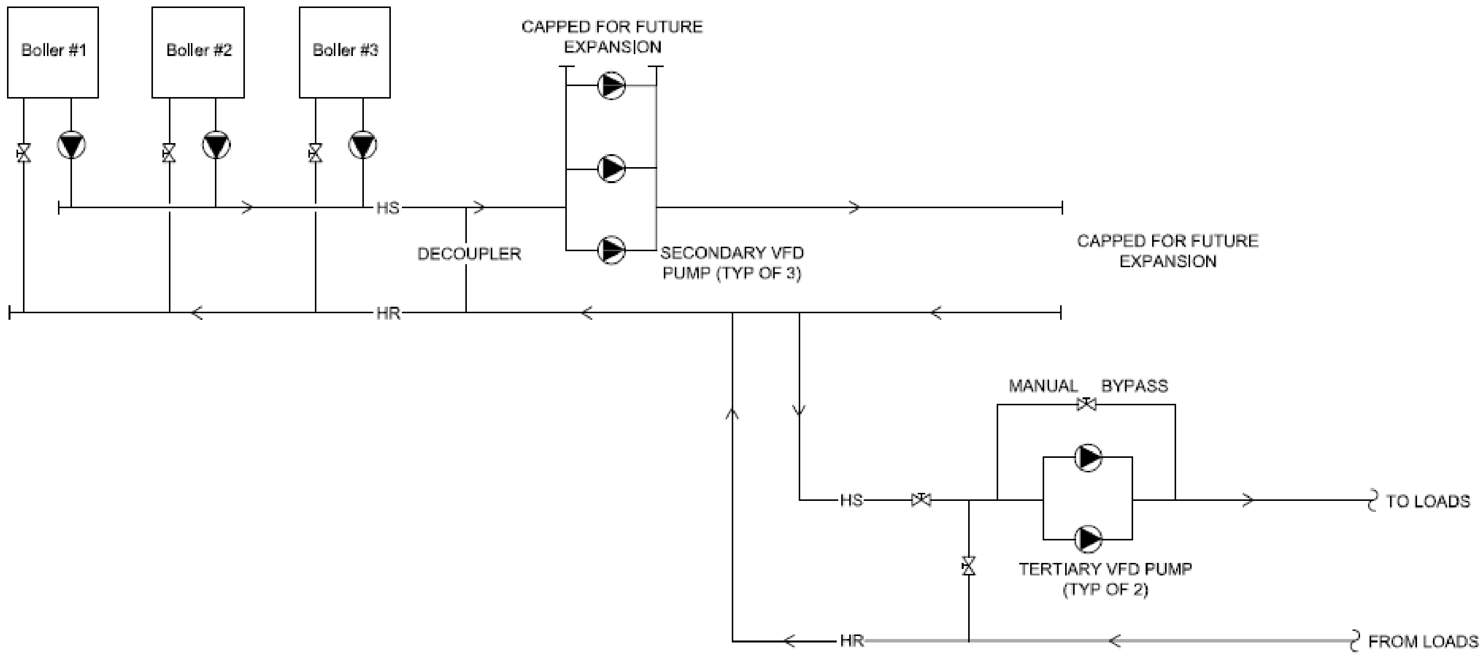


Figure 4 - Heating Hot Water Schematic



Description of System Operation

Air Side

The complex uses VAV system to condition the spaces. Each air handling unit (AHU) contains heating and cooling coils complete with associated piping and automatic temperature controls. For the zoned VAV systems, each air terminal unit receives conditioned air from the associated AHU which is controlled by a DDC control system. For the single zone VAV systems the AHU will serve as the actual air terminal unit. The associated DDC control system will control the amount of air the given space needs and allow the space to be served without being processed through any actual air terminal units.

Water Side

Cooling is provided by electric-driven high-efficiency centrifugal water chillers complete with remote induced draft cooling towers for heat rejection from the chillers seen in Figures 2 and 3. Each cooling tower is powered by a variable frequency drive to minimize energy consumed at off design outdoor conditions. The chiller refrigerant is environmentally friendly due to the LEED® requirements.

In Figure 4, the three 250HP dual-fuel boilers that provide heating for the building are illustrated. Two of the boilers satisfy the building's heating needs while the third is a standby boiler. The boilers produce water for heating that is distributed via pumps and piping. The heating system is somewhat similar to the chilled water system in that it has constant primary volume boiler pumps and variable flow secondary pumps. The tertiary pumps are arranged so one pump is active while the other is on standby.

Operating History of System

Currently the complex has been fully operational for 10 months. The electricity and natural gas rates for the complex come from a main facility, distributed by the university. Since the complex is so new and the numbers are still being organized and compiled the rates were not available for this report.

LEED Analysis for Mechanical Systems

A LEED® assessment was completed for the complex using LEED-NC 2.2 by the engineers. For this report the newer version of LEED® was used, LEED 2009 for New Construction. The new version includes 3 additional prerequisites and 6 categories for Energy and Atmosphere as well as 2 prerequisites and 5 mechanical system categories in Indoor Environmental Quality. The amount of possible points and their requirements for some of the categories were updated in the newer version as well as the minimum amount of points for each rating was increased as seen in Table 14. Only the credits associated with the mechanical systems were considered for this report.

Table 14 - Points Required for LEED Ratings

	Certified	Silver	Gold	Platinum
LEED-NC 2.2	26-32	33-38	39-51	52-69
LEED 2009	40-49	50-59	60-79	80+

Energy and Atmosphere (EA)

Prerequisite 1 for EA is to have fundamental commissioning of the building's energy systems, Prerequisite 2 is meeting the minimum energy performance and Prerequisite 3 is refrigerant management where no CFC based refrigerants can be used in the complex. All three of these prerequisites were met in order for the complex to even be considered for LEED®.

EA Credit 1 concentrates on optimizing energy performance through three optional compliance paths. The engineer was able to gain 10 points through Option 1, Whole Building Energy Simulation, saving 42% when being compared to the baseline. In the newer version the percentages and their related possible points changed, so with the new points spread the complex would be able to achieve 16 points in this category.

Credit 2 of EA focuses on on-site renewable energy to help decrease the environmental as well as the economic impacts associated with fossil fuel energy use. The design engineers decided not to attempt these points for the complex.

For Credit 3 of EA the complex was able to receive 1 point for having enhanced commissioning of the building. The newer version of LEED® has 2 points possible for this category without changing any of the requirements, so the complex earns a total of 2 points.

EA Credit 4 helps reduce the amount of ozone depletion to minimize the amount of contributions to climate change. LEED-NC 2.2 had only 1 point possible for this category while the newer version has 2 points possible. The complex was able to earn the point in the older version; since the options did not change in this category the complex can earn the maximum number of points available.

Measurement and Verification, EA Credit 5, and Green Power, EA Credit 6, were not attempted for the complex, therefore the possible points in the newer version will not be attempted either.

Indoor Environmental Quality (EQ)

The first prerequisite for IEQ is to establish minimum indoor air quality by meeting the requirements of Sections 4 -7 of ASHRAE Standard 62.1.2007. The design engineer met all the requirements of the standard in order to comply with this prerequisite. Prerequisite 2 requires that an Environmental Tobacco Smoke (ETS) Control be used in the building; since the complex is a smoke free building this prerequisite was achieved.

EQ Credit 1, Outdoor Air Delivery Monitoring, and Credit 2, Increased Ventilation, were not attempted for the complex in the older version, so they will not be considered for this report.

Credit 6.2 of EQ requires controllability of systems for a high level of thermal comfort for the occupants. The new and old versions of LEED® have the same requirements so the 1 point for this credit is accomplished by the complex.

EQ Credit 7.1 involves providing a comfortable thermal environment that helps support the wellbeing of the building's occupants. In order to gain the point associated with this section the building must be compliant with the thermal comfort conditions of ASHRAE Standard 55-2004. The complex overall is compliant with this standard so it gains the point for both the old and new versions. Credit 7.2, Thermal Comfort Verification, was not attempted by the design engineer for this building.

LEED Conclusion

When comparing the older version used in the design of the complex and the newer 2009 version, the complex still has the ability to achieve a LEED® Silver rating. In the sections where the complex achieved more points it was comparable to the point raise illustrated in Table 14, therefore the complex would most likely still be considered a LEED® Silver building under the newer version of LEED®.

Proposed Redesign Overview

Ground Source Heat Pumps

Geothermal heat pumps have many advantages over the conventional mechanical systems. When using a geothermal system for cooling the pumps disperse the excess heat found in the air into the ground through the loops in the ground. Zones A and B are the only sections of the building that operate year round so implementing a ground-source heat pump system will allow the central plant to be shut down during the summer months, being more efficient than running an entire plant. The system installed in the complex will be a cooling only system since it will only operate in the summer months. The space required for this system could easily be found within the complex and the surrounding land. The two zones being redesigned are adjacent to the current central utility plant so any additional equipment needed could be installed in the plant. The complex also has more than 10 acres surrounding it for installation of the heat pumps.

Heat Recovery Chiller

Adding a dedicated heat recovery chiller will allow the boiler to be shut down when the hot water needs are not at high demand. Heat-recovery chillers can produce up to 130°F which is sufficient enough for the building's hot water needs. Allowing the boiler to be shutdown will help reduce total energy costs as well as reduce carbon footprints because no fossil fuels will be utilized by the building directly. With the addition of this heat recovery chiller the overall size of the boiler may also be able to be downsized. There is sufficient space located in the central utility plant for the addition of this dedicated heat recovery chiller.

Breadth Topics

Electrical

When adding large equipment such as heat pumps and heat recovery chillers the first place to look is the electrical capacity of the building. An interesting study would be to see if the building's electricity already has enough capacity to add this equipment. Safety factors may have been accounted for during the design process to where the building could already handle these additions. If not, newer panel boards or motor control centers may need to be redesigned and added.

Construction Management

These two redesign components will drastically effect the overall construction of the complex. The construction budget and schedule will be modified and reconfigured to see if the energy savings due to these additions are overall worth it for the owner. If the heat pumps are installed directly adjacent to the building the construction will drastically be altered due to the delicacy of the bore holes. A Life Cycle Cost Analysis will be performed as well as comparing initial costs when adding these redesign components.

Ground Source Heat Pumps – Mechanical Depth

Objective

Zones A and B are the only zones that are operational year round so implementing a ground-source heat pump system will help reduce the overall energy of the complex by shutting down the central utility plant during the summer months. This section explains the proposed design of a ground source heat pump system for the mentioned zones.

Site Study

The site and its characteristics are very important when designing a ground source heat pump system. The soil's resistance determines the amount of heat transfer to and from the ground. A proper analysis of the site's geology is very expensive for a project of this size. An actual analysis of the site's soil was not performed for this project, but the information was not hard to find.

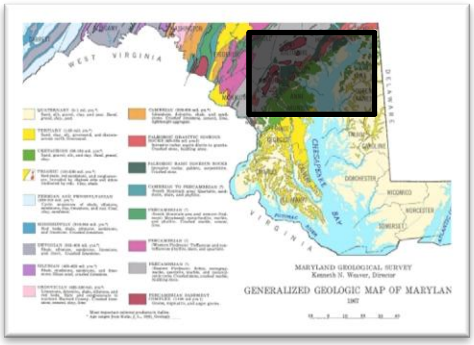


Figure 5 - MD Geology Map

The shaded box in Figure 5 depicts the area seen in Figure 6. Figure 6 is the close up view of Baltimore City; the yellow circle indicates approximately where the complex is located. The soil at the site is classified as Paleozoic basic igneous rocks, which is made up of intrusive rocks, serpentinite and crushed stone. This soil has a resistance of 0.6 Hr·ft·°F/BTU. This value was verified by comparing its inverse to the rock and soil types listed in Chapter 32 of the ASHRAE Handbook-HVAC Applications. This resistance makes this site an excellent candidate for implementing ground source heat pumps. Calculations with this thermal resistance of the soil were performed in order to calculate the number of wells that will need to be drilled to meet the demands for zones A and B of the complex.

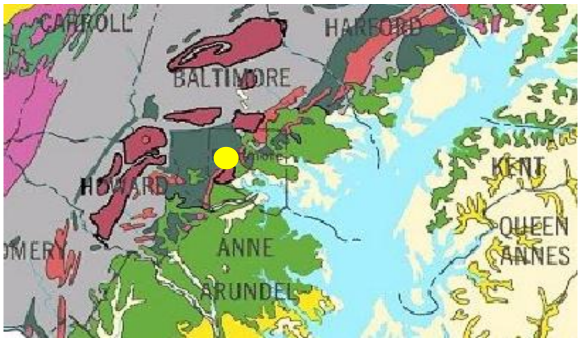


Figure 6 - MD Geology Map

Finding the space required for this type of system can be the most difficult part of the design process. Luckily, Coppin State Physical Education Complex is on a 10 acre lot which allows for ample space. The area that was selected for serving zones A and B is the parking lot adjacent to zone B, shown in the green box in Figure 7. The parking lot is approximately 40,000 square feet which is plenty of room for implementing the bore holes required.

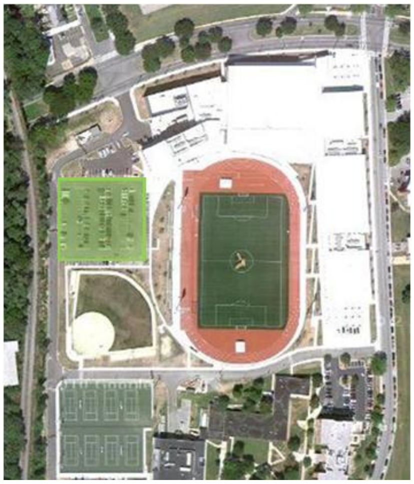


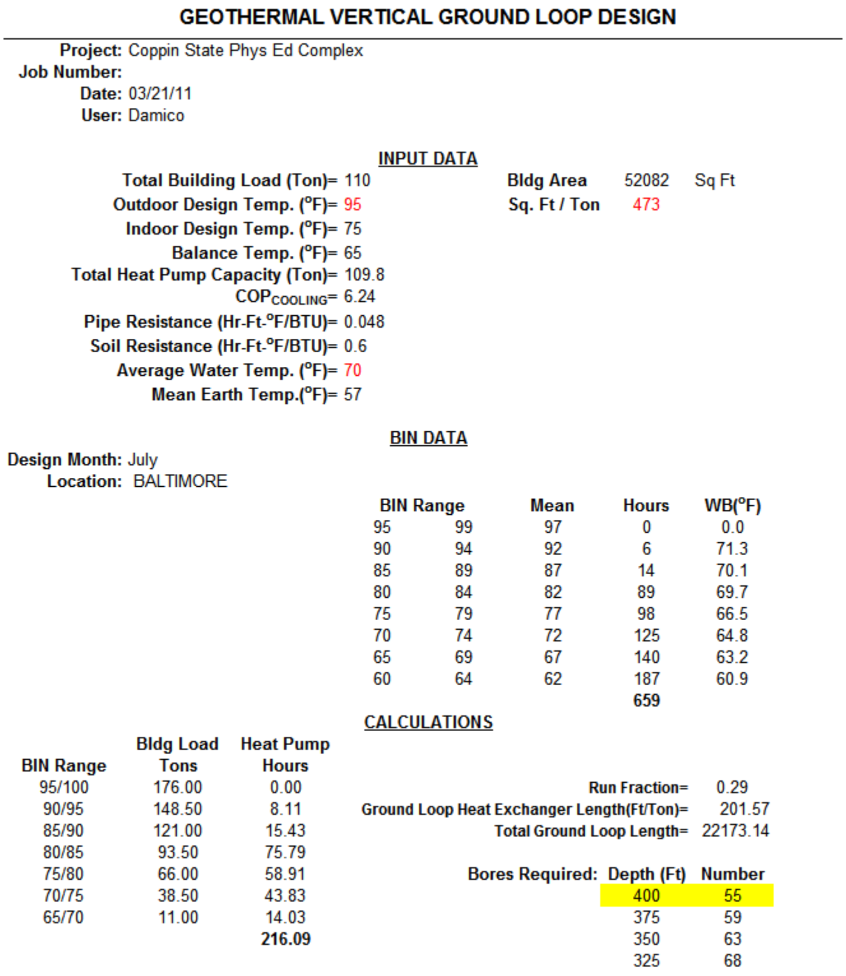
Figure 7 – GSHP Well Field Location

Calculations

Number and Length of Bores

In order to calculate the correct number and size of bore holes needed for this system, two methods were used. The first method was done by utilizing a spreadsheet created by McClure Company, and then the results were compared to equations found in Chapter 32 of the 2007 ASHRAE Handbook-HVAC Applications seen in Appendix C.

In Figure 8, below, the McClure Company spreadsheet is shown. Only the square footage of zones A and B were used for the calculation at approximately 52,082 square feet. The outdoor and indoor design temperatures were found in James Posey's Design Documents. The manufacturer's data for the ground source heat pump selected gave information such as $COP_{cooling}$ and average water temperature. The bin data, soil resistance and pipe resistance were found using sources such as 2007 ASHRAE Handbook-HVAC Applications and other books and websites.



GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: Coppin State Phys Ed Complex
Job Number:
Date: 03/21/11
User: Damico

INPUT DATA

Total Building Load (Ton)= 110
Outdoor Design Temp. (°F)= 95
Indoor Design Temp. (°F)= 75
Balance Temp. (°F)= 65
Total Heat Pump Capacity (Ton)= 109.8
$COP_{COOLING}$= 6.24
Pipe Resistance (Hr-Ft-°F/BTU)= 0.048
Soil Resistance (Hr-Ft-°F/BTU)= 0.6
Average Water Temp. (°F)= 70
Mean Earth Temp.(°F)= 57

Bldg Area 52082 Sq Ft
Sq. Ft / Ton 473

BIN DATA

Design Month: July
Location: BALTIMORE

BIN Range		Mean	Hours	WB(°F)
95	99	97	0	0.0
90	94	92	6	71.3
85	89	87	14	70.1
80	84	82	89	69.7
75	79	77	98	66.5
70	74	72	125	64.8
65	69	67	140	63.2
60	64	62	187	60.9
			659	

CALCULATIONS

BIN Range	Bldg Load Tons	Heat Pump Hours
95/100	176.00	0.00
90/95	148.50	8.11
85/90	121.00	15.43
80/85	93.50	75.79
75/80	66.00	58.91
70/75	38.50	43.83
65/70	11.00	14.03
		216.09

Run Fraction= 0.29
Ground Loop Heat Exchanger Length(Ft/Ton)= 201.57
Total Ground Loop Length= 22173.14

Bores Required:	Depth (Ft)	Number
	400	55
	375	59
	350	63
	325	68

Figure 8 - GSHP Calculation Spreadsheet (McClure Company)

Pipe Sizing

When figuring out the diameter of pipe in each bore multiple parameters had to be considered, for this project the Hazen Williams Formula was used (Appendix D). The first concern is the flow rate throughout the well field, which in this case is 350 GPM. With a total of 55 bores, each bore will have a flow rate of 6 GPM. The entire system will be split up into 5 equal systems with 11 bores each. This will allow the system to be in complete equilibrium as well as allow the system to work at part load. When calculating the diameter of each bore the overall flow rate must be considered since this system will be laid out in reverse return. In order to keep a high efficiency throughout all the wells a pressure drop between 0.5 and 3 feet per 100 feet is desired. This high efficiency is achieved by keep a turbulent flow through the pipes as well as maintaining an appropriate pressure drop. The actual diameter of each well can be found in detail in Appendix D.

System Configuration

For zones A and B there will need to be 55 bores installed at 400 feet. This amount of bores at this depth will have multiple impacts on the construction process, cost of the project and much more. The ground source heat pumps will feed the AHUs directly using a reverse return system; the first bore fed will be the first bore returned. This method is the least cost effective for the system already in place because the AHUs that feed zones A and B are water-cooled DX units. This option also reduces the amount of mechanical space needed since all that needs to be installed is a small water to water heat pump next to each AHU, which are all located on the roof. A simplified schematic is seen below in Figure 9.

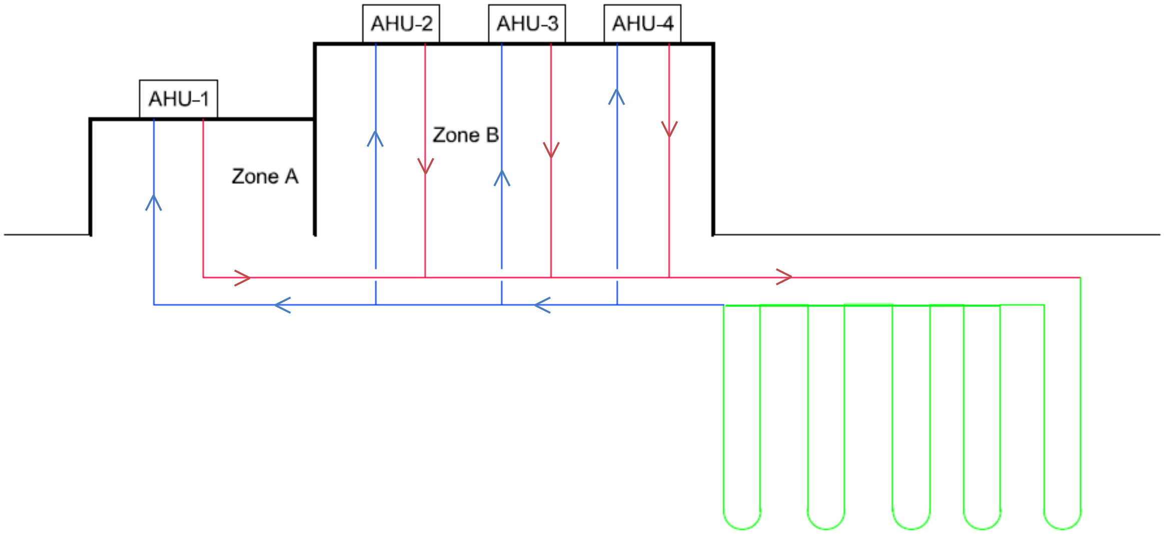


Figure 9 - GSHP Simplified Schematic

The specific site layout of the GSHP system is explained further in the Construction Management section of this report.

Pump and Piping Selection

The ground source heat pump system will have five small water to water heat pumps. When selecting the heat pumps multiple factors were considered including size, capacity, associated pressure drop and more. The pumps that were finally selected were Carrier's AQUAZONE 50PSW360 Water to Water Source Heat Pump with PURON®. This pump was selected due to its compatibility with system, design flexibility, ease of installation, and the use of an environmentally sound refrigerant.

Table 15 - Pump Schedule

Unit	EWT (°F)	GPM	Total Cooling Capacity (MBH)	Power (kW)	EER
50PSW360	50	70	304.6	12.43	24.5

For the piping of the GSHP system, polyethylene was selected as the preferred material. Polyethylene is used more frequently in applications such as GSHP mainly due to its high density, which helps the heat transfer process. Polyethylene can also be thermally fused which helps the installation process move faster as well as prevent any leaks during operation. The cost per linear foot and the installation of the pipe is explained further in the Construction Management section of this report.

Heat Recovery Chiller – Mechanical Depth

Objective

Adding a dedicated heat recovery chiller will allow the boiler to be shut down when the hot water needs of the complex are not at high demand. Heat recovery chillers can produce up to 130°F by extracting the heat from the return side of the water system. The heat recovery chiller will be able to meet the building's hot water needs while allowing the boiler to be shut down.

Calculations

In order to size the heat recovery chiller the following equation and values had to be used to find the GPM demand load for the complex.

$$\textbf{Reheat Load (MBH)} \cdot 1000 = \textbf{GPM} \cdot 500 \cdot \Delta T$$

$$\text{Reheat Load} = 3500\ \text{MBH} \qquad \Delta T = (140°F - 120°F) = 20°F$$

From this, a heat recovery chiller that can accommodate 350 GPM was selected. Two of McQuay's Scroll Templifier Water Heaters, Model TGZ, were selected for the complex; the details are listed below in Table 16 and Figure 10.

Table 16 – Heat Recovery Chiller Schedule

Unit	GPM	Input Power (kW)	Heating (MBH)	Cooling (MBH)
TGZ120A	209	109.5	2094.5	1720.9

Figure 10 – TGZ120A Templifier Water Heater

In order to see the energy savings related to installing the heat recovery chiller, the hourly consumption of hot water, condenser water and chilled water needed to be collected. Using Carrier's HAP and the model of the complex made for Technical Report 2, these values were easily found. The same equation shown for the sizing of the heat recovery chiller was used to determine the flow rates.

Once the hourly heating loads and hourly condenser water production were found the amount of heating water that the heat recovery chiller could produce was found. This value was compared to the heating water required for that hour and was determined if the heat recovery chiller could handle the load. The selected heat recovery chillers can handle approximately 52% of the heating water required for the complex year round.

Equipment Adjustments and Additions

Boilers

Since the heat recovery chiller can handle 52% of the heating water load the boilers can be downsized. The three current 250HP Cleaver Brooks boilers can be conservatively downsized to three 200HP boilers. Since the boilers are being downsized, a condensing boiler will be installed in case the heat recovery chiller cannot handle the load by itself, or it fails. Table 17 shows the product data for the new boilers. The addition of condensing boilers will not only help with redundancy but operating a condensing boiler is much more efficient than operating one of the large dual fuel boilers.

Table 17 – New Boiler Data

Equipment	Manufacturer	Model	Gross Output (MBH)
Dual Fuel Boilers	Cleaver Brooks	CEW200	6695
Condensing Boiler	Weil-McClain	UG-310	289

Mechanical Room Layout

Making these adjustments to the existing boilers and adding a heat recovery chiller with a condensing boiler, the mechanical room layout had to be attuned. Figures 11 and 12 show a simplified layout of the heating and cooling central utility plants, respectively. The more detailed floor plans can be found in Appendix E. Figure 13, shows the new layout of the heating central utility plant with the new and updated equipment.

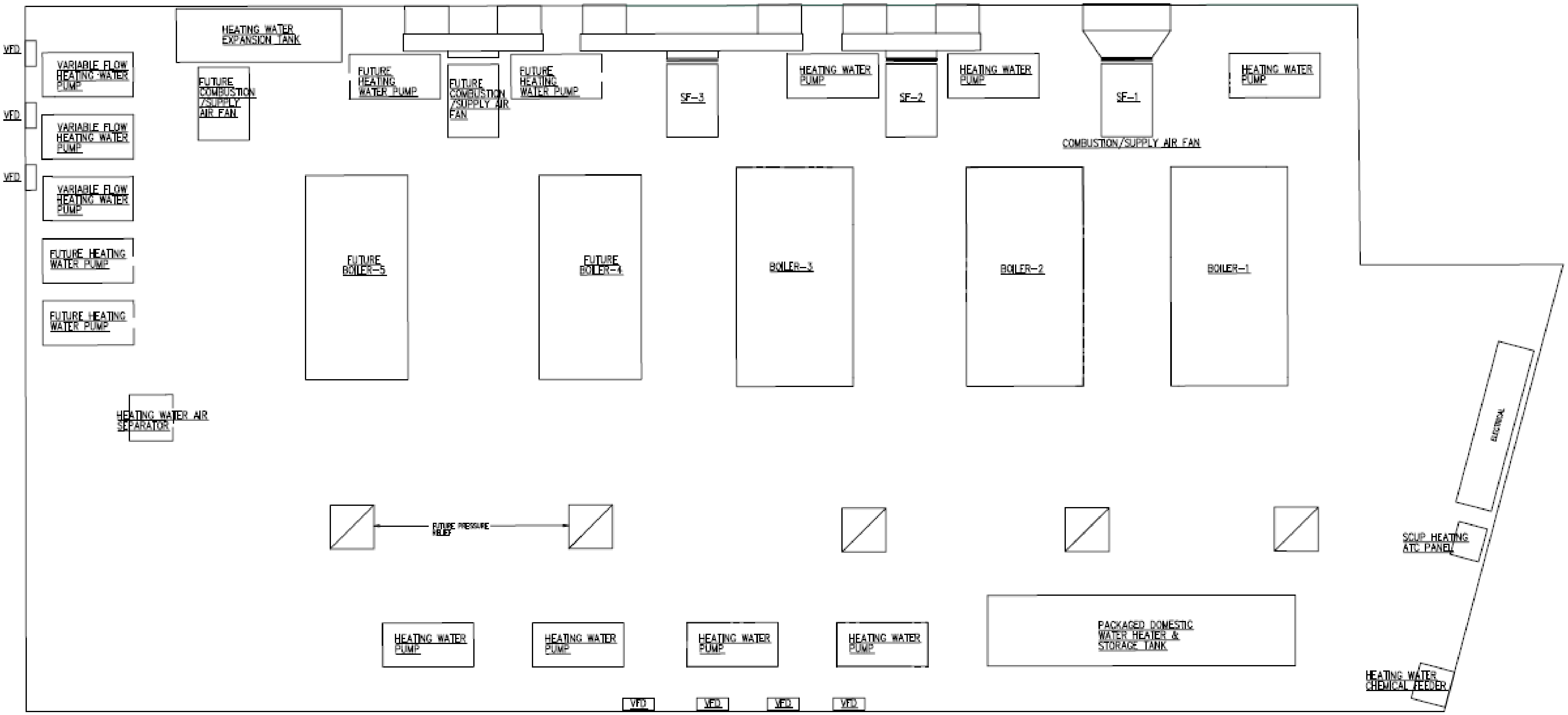


Figure 11 – Simplified Heating Central Utility Plant

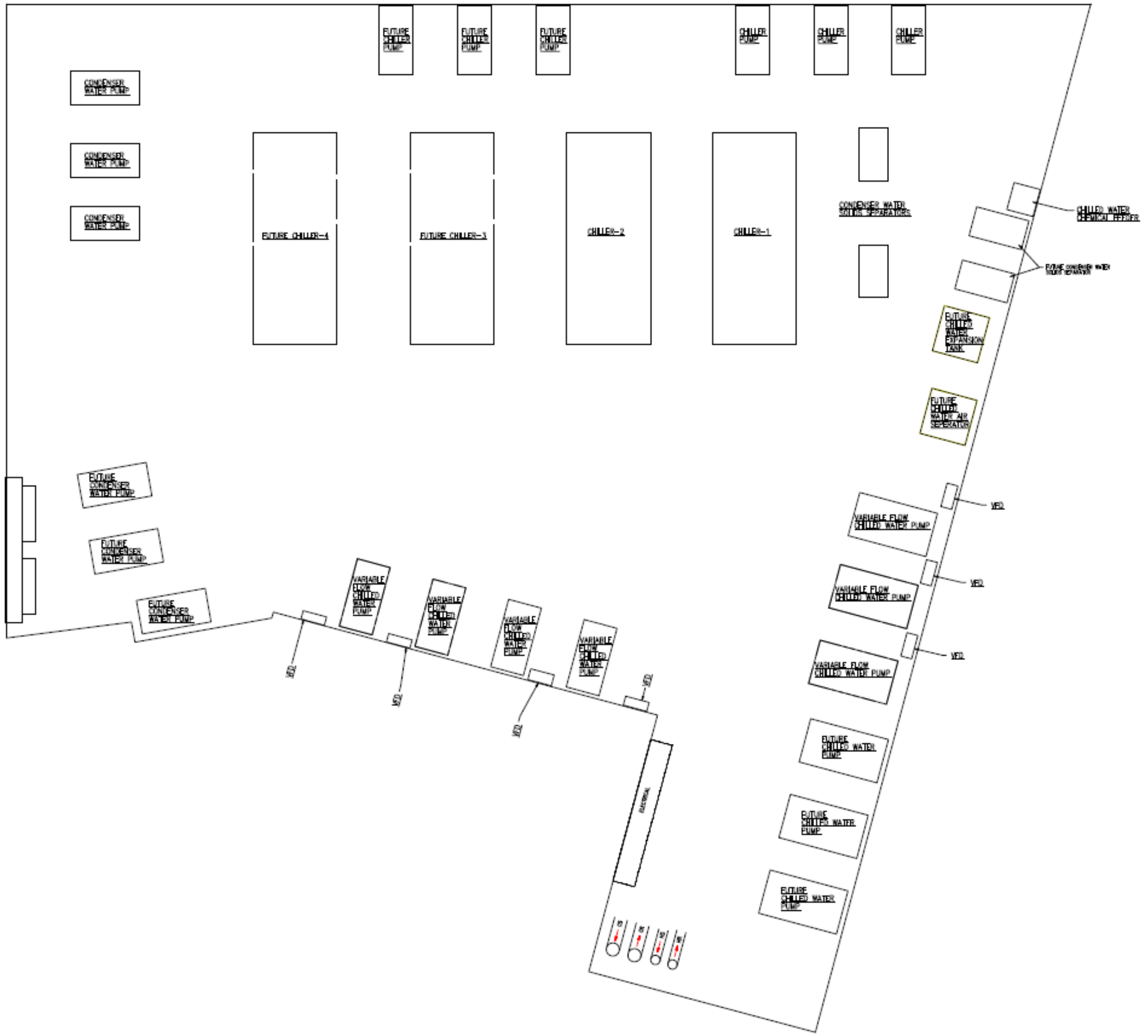


Figure 12 – Simplified Cooling Central Utility Plant

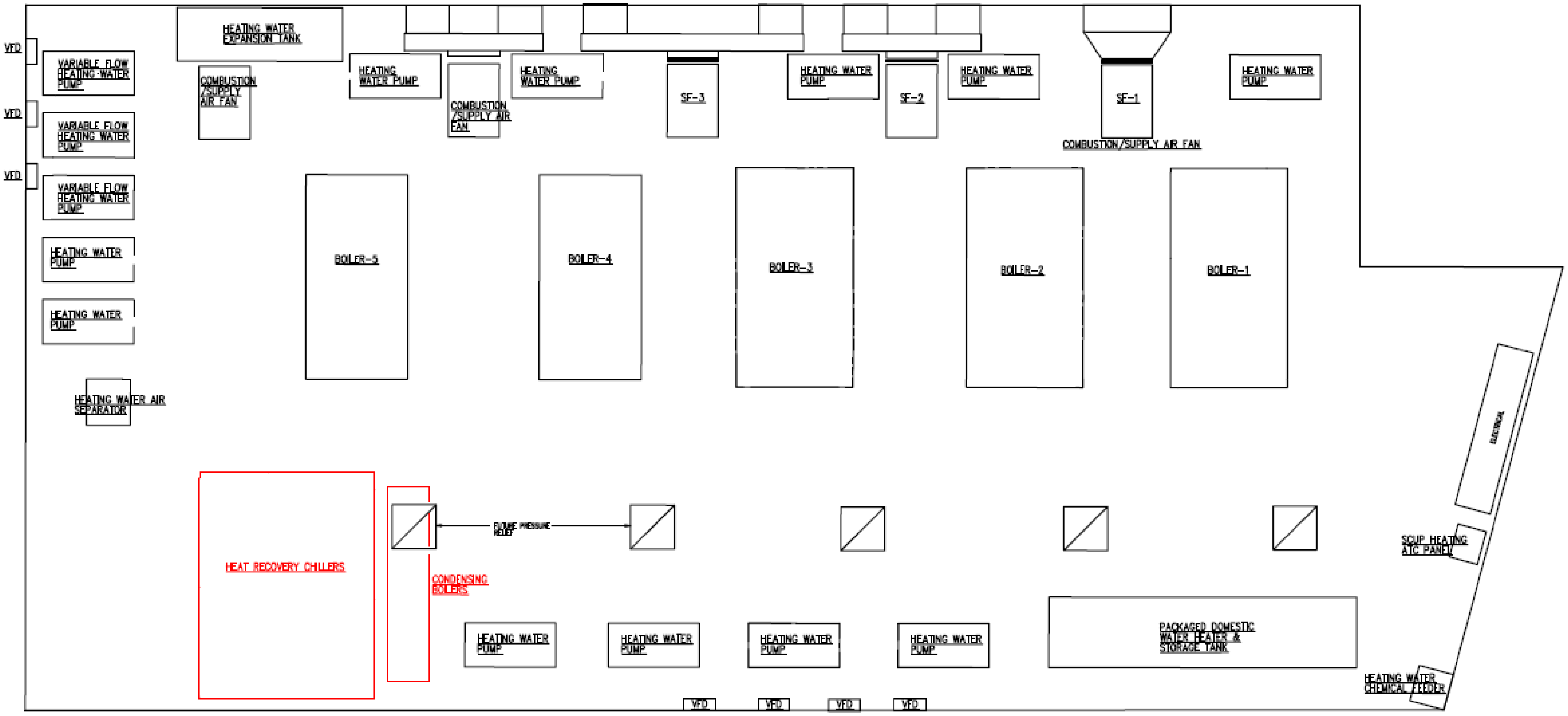


Figure 13 – Redesigned Heating Central Utility Plant

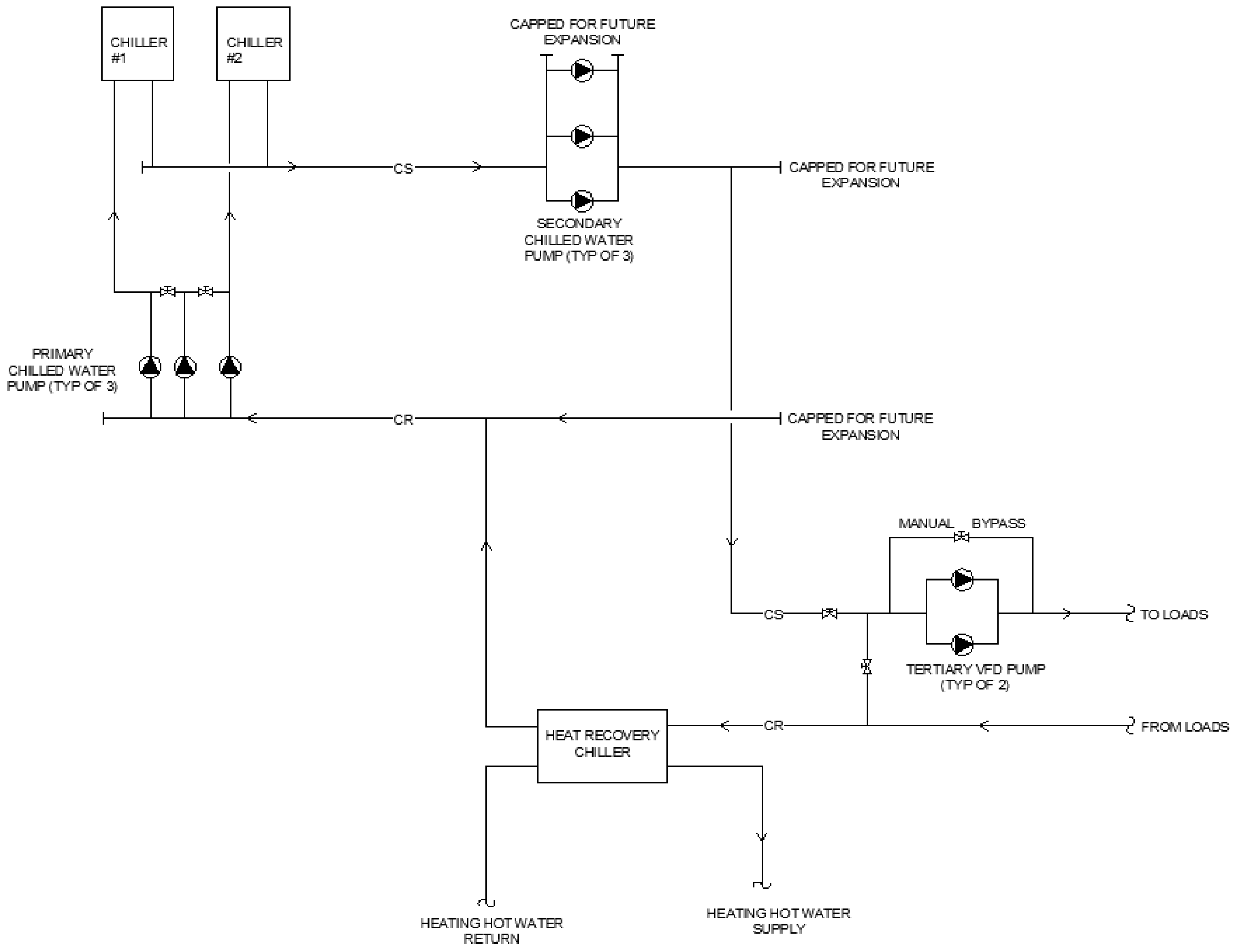


Figure 14 – Heat Recovery Chiller Schematic

Figure 14 shows the new schematic of the system with the heat recovery chiller installed. The two heat recovery chillers will be in parallel, one primary with an additional secondary during peak operating times. Since the heat recovery chillers are being added into the heating central utility plant where the boilers are located, a refrigeration leak detection system will have to be incorporated. The equation below with the expressed values was used to determine the amount of air needed to be exhausted in case of a leak.

$$Q = 100 \cdot G^{0.5}$$

Where, Q = airflow (CFM) G= 49.9kg of R134a

From this calculation, it was found that approximately 1450 CFM will be required to exhaust this space in case of a leak. Exhaust fans had to be selected to provide this amount of exhaust. Two ACME PDU135 roof up blast fans were chosen; their product data can be seen below in Table 18.

Table 18– Exhaust Fan Product Data

Fan Type	Model Number	Drive	Airflow (CFM)	Motor HP
Roof Upblast	ACME PDU135	Direct	750	1/3

Electrical Breadth

Objective

The proposed redesign calls for installing two new heat recovery chillers, five new water to water heat pumps, five new condensing boilers and downsizing the existing boilers. The addition of this equipment will affect the electrical loads and may cause the system to be resized. The main component of the electrical system that will need to be analyzed is the motor control center.

Calculations

First the horsepower of the equipment added and removed had to be determined. Tables 19 and 20 show the equipment for the ground source heat pumps and heat recovery chillers, respectively.

Table 19– GSHP Equipment

Equipment Added	HP	KVA	FLA
HP-1	16.6	18.4	41.4
HP-2	16.6	18.4	41.4
HP-3	16.6	18.4	41.4
HP-4	16.6	18.4	41.4
HP-5	16.6	18.4	41.4

Table 20 – HRC Equipment

Equipment Removed	HP	KVA	FLA
Boiler Blower Motor 1	10	11.14	14
Boiler Blower Motor 2	10	11.14	14
Boiler Blower Motor 3	10	11.14	14
Equipment Added			
New Boiler Blower Motor-1	7.5	8.4	10.1
New Boiler Blower Motor-2	7.5	8.4	10.1
New Boiler Blower Motor-3	7.5	8.4	10.1
Condensing Boiler Motor-1	1.75	2.0	2.4
Condensing Boiler Motor-2	1.75	2.0	2.4
Condensing Boiler Motor-3	1.75	2.0	2.4
Condensing Boiler Motor-4	1.75	2.0	2.4
Condensing Boiler Motor-5	1.75	2.0	2.4
HRC-1	23	25.8	31.1
HRC-2	23	25.8	31.1

As seen above in the table the full load amps (FLA) had to be found for each piece of equipment, these were found using NEC 2008. With this information, analyzing the additions of this equipment on to the existing motor control center can be performed.

Sizing and Scheduling

The equipment associated with the heat recovery chiller will be added to the current Motor Control Center 2 (MCC-2) that is serving the heating central utility plant. Motor Control Center 3 (MCC-3) which serves the cooling central utility plant will have the heat pumps added to it.

Sections of the current MMC-2 and MCC-3 are shown below in Tables 21 and 22. The spares that are in the schedules are not associated with the future expansions already designed, so the addition of these systems will not affect the future expansions.

Main Bus: 600A		Volts: 480VAC	Phase: 3		
Vertical Bus: 300A			Wires: 3		
Compartment No.	Circuit Number	Name Plate	Load		
			HP	KVA	FLA
1BL	MCC2-1	Boiler #1 Blower Motor	10	11.14	14
2BL	MCC2-2	Boiler #2 Blower Motor	10	11.14	14
3BL	MCC2-3	Boiler #3 Blower Motor	10	11.14	14
3M	MCC2-26	SPARE	-	-	-
4K	MCC2-31	SPARE	-	-	-
4M	MCC2-32	SPARE	-	-	-
5B	MCC2-33	SPARE	-	-	-
5D	MCC2-34	SPARE	-	-	-
5F	MCC2-35	SPARE	-	-	-
5J	-	SPACE	-	-	-
Total Load: 349 KVA			Total Load: 443.1 Amps		
		Demand Factor:70%			

Table 21 – MCC-2 Partial Schedule

Main Bus: 1200A		Volts: 480VAC	Phase: 3		
Vertical Bus: 600A			Wires: 4		
Compartment No.	Circuit Number	Name Plate	Load		
			HP	KVA	FLA
5BR	MCC3-27	SPARE	-	-	-
7HL	MCC3-48	SPARE	-	-	-
7HR	MCC3-49	SPARE	-	-	-
8DL	MCC3-55	SPARE	-	-	-
9G	-	SPACE	-	-	-
Total Load: 1399 KVA			Total Load: 1808.95 Amps		
		Demand Factor:70%			

Table 22 – MCC-3 Partial Schedule

The spares already have a circuit breaker installed and are ready for connections, while the buckets labeled “spaces” will require a new circuit breaker to be installed. The spaces listed above will have new equipment installed in them, as seen in Tables 23 and 24. These spaces will have a 150 frame size circuit breaker installed to keep the system consistent with what is already installed.

Main Bus: 600A		Volts: 480VAC	Phase: 3		
Vertical Bus: 300A			Wires: 3		
Compartment No.	Circuit Number	Name Plate	Load		
			HP	KVA	FLA
1BL	MCC2-1	New Boiler #1 Blower Motor	7.5	8.4	10.1
2BL	MCC2-2	New Boiler #2 Blower Motor	7.5	8.4	10.1
3BL	MCC2-3	New Boiler #3 Blower Motor	7.5	8.4	10.1
3M	MCC2-26	Condensing Boiler Motor - 1	1.75	2	2.4
4K	MCC2-31	Condensing Boiler Motor - 2	1.75	2	2.4
4M	MCC2-32	Condensing Boiler Motor - 3	1.75	2	2.4
5B	MCC2-33	Condensing Boiler Motor - 4	1.75	2	2.4
5D	MCC2-34	Condensing Boiler Motor - 5	1.75	2	2.4
5F	MCC2-35	HRC-1	23	25.8	31.1
5J	MCC2-37	HRC-2	23	25.8	31.1
Total Load: 435.8 KVA			Total Load: 524 Amps		
		Demand Factor:70%			

Table 23– New MCC-2 Partial Schedule

Main Bus: 1200A		Volts: 480VAC	Phase: 3		
Vertical Bus: 600A			Wires: 4		
Compartment No.	Circuit Number	Name Plate	Load		
			HP	KVA	FLA
5BR	MCC3-27	HP-1	16.6	18.4	41.4
7HL	MCC3-48	HP-2	16.6	18.4	41.4
7HR	MCC3-49	HP-3	16.6	18.4	41.4
8DL	MCC3-55	HP-4	16.6	18.4	41.4
9G	MCC3-62	HP-5	16.6	18.4	41.4
Total Load: 1491 KVA			Total Load: 1974 Amps		
		Demand Factor:70%			

Table 24 – New MCC-3 Partial Schedule

Once all the equipment was added to the existing MCCs, National Electric Code (NEC) 2008 was used to make sure the overall feeder sizes that existed would be able to handle the additional load. With only adding a small percentage of additional loads, the sizes of the feeders and associated equipment did not need to be resized. Each compartment's individual feeder was sized also using NEC 2008 which can be seen below in Tables 25 and 26.

Compartment #	Feeder Size
1BL	3#12+1#12G, 1/2" C
2BL	3#12+1#12G, 1/2" C
3BL	3#12+1#12G, 1/2" C
3M	3#8+1#10G, 1/2" C
4K	3#8+1#10G, 1/2" C
4M	3#8+1#10G, 1/2" C
5B	3#8+1#10G, 1/2" C
5D	3#8+1#10G, 1/2" C
5F	3#8+1#8G, 1" C
5J	3#8+1#8G, 1" C

Table 25 – New MCC-2 Feeder Sizes

Compartment #	Feeder Size
5BR	3#8+1#8G, 1"C
7HL	3#8+1#8G, 1"C
7HR	3#8+1#8G, 1"C
8DL	3#8+1#8G, 1"C
9G	3#8+1#8G, 1"C

Table 26 – New MCC-3 Feeder Sizes

Construction Management Breadth

Objective

The two redesign components discussed above will drastically effect the overall construction of the complex. The construction schedule will have to be modified as well as additional costs will have to be considered. Since the bore holes are going to be installed in the adjacent parking lot the set-up of the construction will most likely have to be altered. A Life Cycle Cost will also be performed to compare the initial costs versus the energy savings related to the new equipment.

Cost Estimations

Drilling the well field will not only cost in terms of man power but also in renting the additional equipment needed for installation. Table 27 shows the breakdown of the cost of both drilling and renting the rigs, while Table 28 shows the cost of polyethylene pipe.

Table 27 – Well Field Costs

Length of Pipe (ft)	Man Power (ft/day/rig)	# of rigs	Days	Man Power Cost per linear foot	Piping Installation Cost	Renting rig ($/week)	Cost rigs	Total Price
22000	400	2	28	$24	$528,000	$4,500	$24,750	$ 552,750.00

Table 28 – Polyethylene Pipe Costs

Size (in)	# of Wells	Depth (ft)	Total Length (ft)	Price per 40'	Price per Size
3	30	400	12000	1.32	15840
2	15	400	6000	1.1	6600
1.25	10	400	4000	0.66	2640
				Total	**$ 25,080.00**

Schedule and Site Impact

Schedule

As shown above it will take 55 days to complete the drilling with one rig. For the complex, two rigs will be rented over a six week period (assuming 5 day work week). The project broke ground in October of 2007 and was completed in February of 2010, so adding in a 6 week project will not affect the overall construction schedule that much.

During construction of the complex, excavation was being performed from Jan 15th, 2008 until May 8th, 2008. This 85 day process is perfect for working in the drilling of the well field with it.

Site

Figure 15 – Well Field Layout

The well field will be installed in the parking lot adjacent to zone B and will be laid out as shown in Figure 15. The small blue box shows the size of the actual field in relation to the entire parking lot (45'x40'). The pink lines show the different systems in relation to one another.

Having the well field be in this location will effect where other equipment will be placed throughout the rest of the construction process. Currently the trailers are parked in this exact location during most of the construction process, as seen as the red box in Figure 16. This location is exactly where the well field will be installed, so the trailers must be relocated.

The trailers can easily be moved to the existing softball field, illustrated by the blue box. This area allows for easy access to deliveries and will not disrupt any utility work since there aren't any major systems that run through this area. Construction on the new softball field begins in June of 2009 so the trailers will have to be moved at this time. In the current construction schedule the trailers were moved into zone B in April of 2009, this same move will occur in the new site schedule.

Figure 16 - Site Picture during Excavation

Redesign Energy and Cost Evaluation

Energy Savings

Each system was modeled using Carrier's HAP, the same program used in the previously mentioned technical reports. Figure 17 illustrates the energy savings associated with each system analyzed. These energy savings are mainly due to shutting down different areas of the central utility plant. The ground source heat pump system shuts down the entire plant throughout the summer months, while the heat recovery chiller allows the boilers to be shut down during non-peak hours.

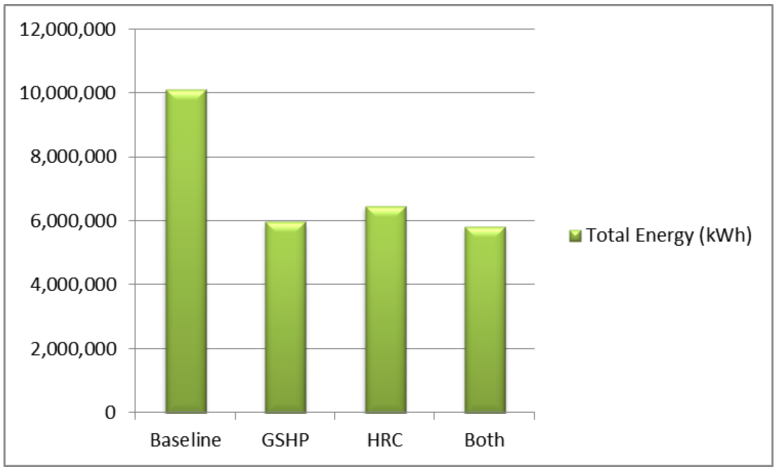


Figure 17 – Energy Used per System

When comparing the systems by only their total energy consumption, using both ground source heat pumps and a heat recovery chiller is the best option. When comparing the existing design, the baseline, to using both systems over 4 million kWh are saved in a year; that translates to a 58% total energy savings.

Cost Savings

These energy savings also have monetary savings associated with each. As explained above, each system had equipment added and removed related with the redesign. The cost of each piece of equipment was found using RS Means Mechanical Cost Data 2008, when the complex was being constructed. Tables 29 and 30 show the price break down for all the equipment added and removed.

Equipment Removed	Cost
Boiler 1	$ 131,500.00
Boiler 2	$ 131,500.00
Boiler 3	$ 131,500.00
Equipment Added	
New Boiler -1	$ 129,650.00
New Boiler -2	$ 129,650.00
New Boiler -3	$ 129,650.00
Condensing Boiler	$ 6,499.00
Condensing Boiler	$ 6,499.00
Condensing Boiler	$ 6,499.00
Condensing Boiler	$ 6,499.00
Condensing Boiler	$ 6,499.00
HRC-1	$ 250,500.00
HRC-2	$ 250,500.00
Total Cost Added	**$ 527,945.00**

Table 29 – Cost for Heat Recovery Chiller

Equipment Added	Cost
HP-1	$ 24,900.00
HP-2	$ 24,900.00
HP-3	$ 24,900.00
HP-4	$ 24,900.00
HP-5	$ 24,900.00
Total Cost Added	**$ 124,500.00**

Table 30 – Cost for GSHP

The equipment added and removed, as seen above, causes an increased up front cost. Adding both systems, a ground source heat pump and a heat recovery chiller, will help with costs over time. Figures 18 and 19 show the breakdown of natural gas and electrical costs of both the baseline and the redesigned system. As seen in the tables above, the new system not only helps reduce costs overall, but helps cut down costs over the summer by almost 50%.

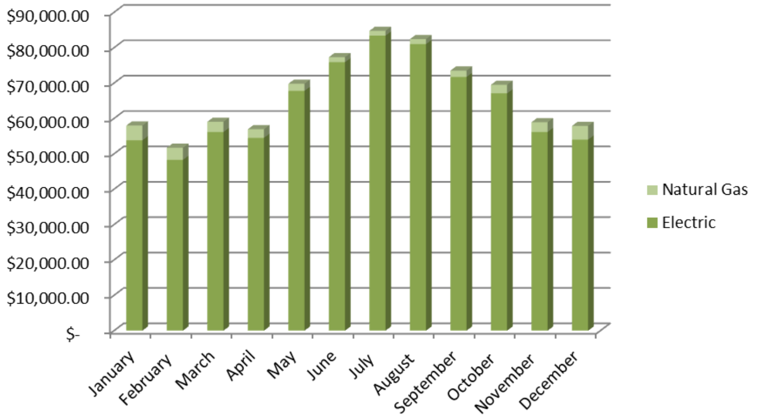


Figure 18 - Baseline Cost of Utilities

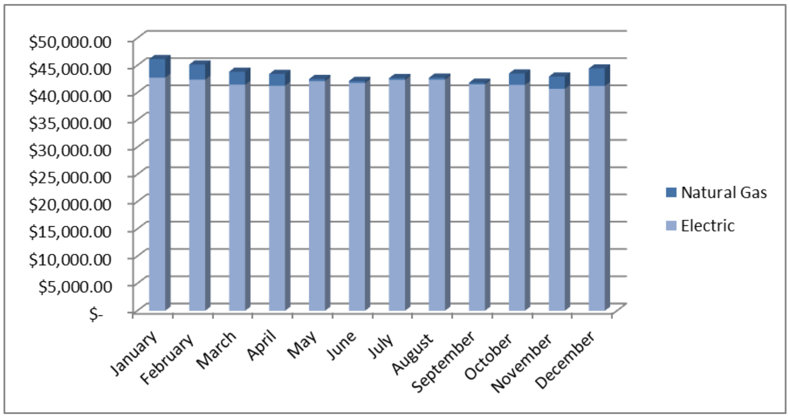


Figure 19 - Redesign Cost of Utilities

A 30-year Life Cycle Cost (LCC) was performed for the ground source heat pump system, the heat recovery chiller system, and a combination of both systems being installed. A discount rate of 7% was used and all the overhauls and yearly maintenances were considered. The details of this process can be seen in Table 31, while Figure 20 shows the simplified break down of capital cost and discounted payback period in years. The LCC shows that the heat recovery chiller system has the fastest payback period but as seen in the previous analyses it does not have the best energy savings overall. Installing both systems has a bit longer of a payback period and the largest capital cost but has the best energy savings overall. Since the complex is a LEED® Silver Building, the owner will most likely be willing to pay for the extra expenses needed to install the more energy efficient systems. If the owner wouldn't be willing to spend all the money needed, just a heat recovery chiller would be the best option, since it has the lowest capital cost and shortest payback period.

Table 31 - Life Cycle Cost Details

	Initial Capital Cost	Discount Rate	Yearly Maintance	30-Year Life Cycle Cost (NPV)	Discounted Payback Period (years)
Baseline	$ 1,567,600.00	7%	$ 87,283	$ 9,130,491	0
GSHP	$ 2,293,202.00	7%	$ 90,976	$ 9,505,982	13.6
HRC	$ 1,799,600.00	7%	$ 98,625	$ 9,635,367	4.7
Both	$ 2,694,202.00	7%	$ 110,763	$ 10,049,383	9.8

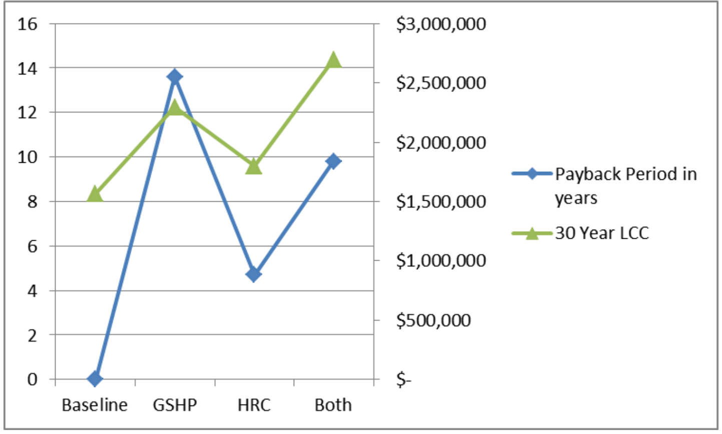


Figure 20 - Life Cycle Cost Analysis

Annual Emissions

The redesign system that incorporates both a heat recovery chiller and a ground source heat pump system considerably reduces the amount of annual emissions. Table 32 and Figure 21 show the reduction of the same pollutants analyzed in Technical Report 2 and how they compared to the baseline mechanical system.

Pollutants	lb of Pollutant per 1000 cubic feet of Natural gas	Natural Gas per year (1000 cubic feet)	Amount of Pollutant per year (lb)
CO2	11.6	20,530	238,148
Nox	0.0164	20,530	337
Sox	1.22	20,530	25,047

Table 32 - Redesign Annual Emissions

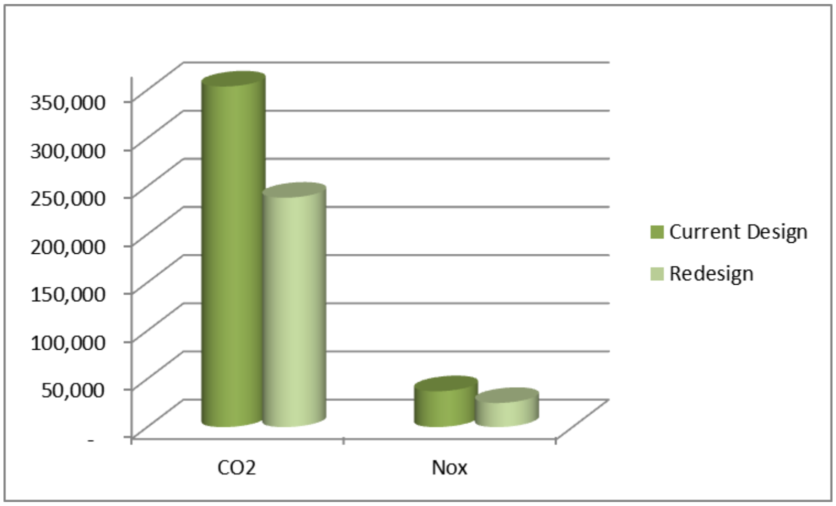


Figure 21 - CO_2 and NO_x Annual Emissions Comparison

Appendix A – Engineer's Annual Energy Consumption Results

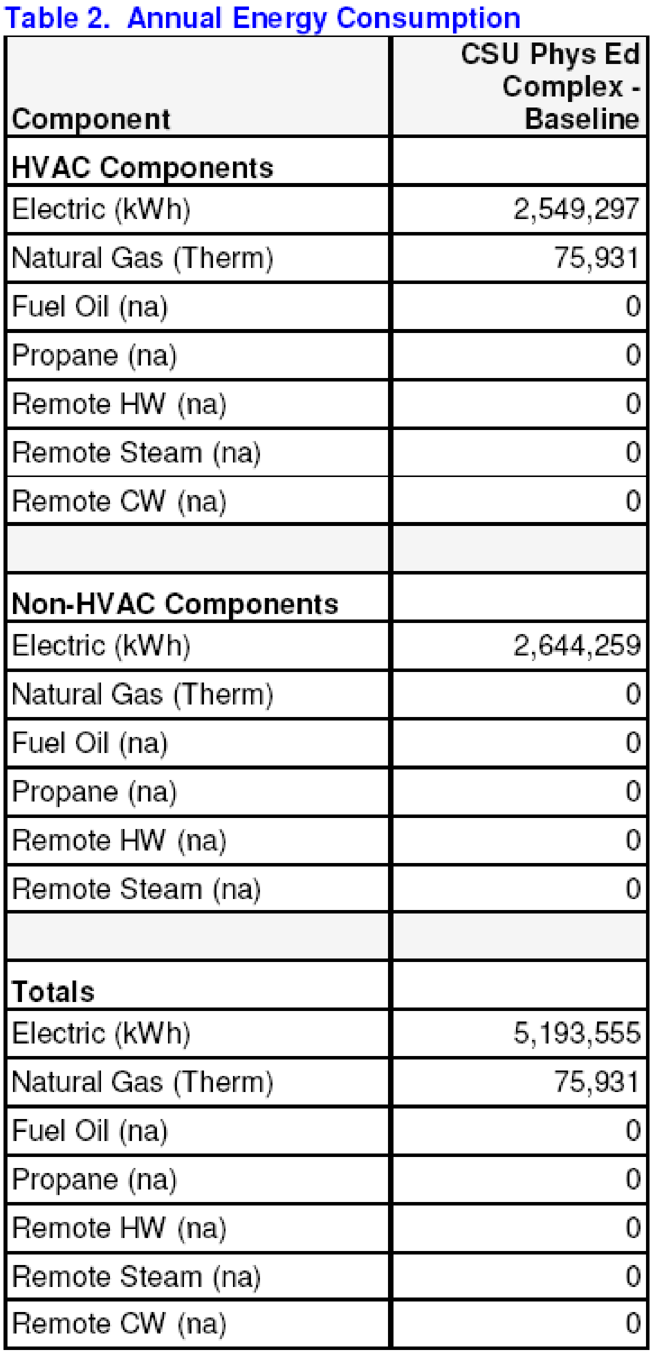


Table 2. Annual Energy Consumption

Component	CSU Phys Ed Complex - Baseline
HVAC Components	
Electric (kWh)	2,549,297
Natural Gas (Therm)	75,931
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0
Non-HVAC Components	
Electric (kWh)	2,644,259
Natural Gas (Therm)	0
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Totals	
Electric (kWh)	5,193,555
Natural Gas (Therm)	75,931
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0

Appendix B – Pumps

Unit	Service	GPM	Size (inches)	HP
P-1	Primary/Boiler Heating Water	670	6.5	7.5
P-2	Primary/Boiler Heating Water	670	6.5	7.5
P-3	Primary/Boiler Heating Water	670	6.5	7.5
P-4	Secondary Heating Water	670	9	20
P-5	Secondary Heating Water	670	9	20
P-6	Secondary Heating Water	670	9	20
P-7	Tertiary Heating Water - PEC	900	12	40
P-8	Tertiary Heating Water - PEC	900	12	40
P-9	Tertiary Heating Water - FMB	300	8.5	10
P-10	Tertiary Heating Water - FMB	300	8.5	10
P-11	Chiller/Primary Chilled Water	1000	8.8	20
P-12	Chiller/Primary Chilled Water	1000	8.8	20
P-13	Chiller/Primary Chilled Water	1000	8.8	20
P-14	Condenser Water	1250	9.8	40
P-15	Condenser Water	1250	9.8	40
P-16	Condenser Water	1250	9.8	40
P-17	Secondary Chilled Water	1000	10.4	30
P-18	Secondary Chilled Water	1000	10.4	30
P-19	Secondary Chilled Water	1000	10.4	30
P-20	Tertiary Chilled Water - PEC	1500	11.5	60
P-21	Tertiary Chilled Water - PEC	1500	11.5	60
P-22	Tertiary Chilled Water - FMB	350	8.2	10
P-23	Tertiary Chilled Water - FMB	350	8.2	10
P-24	Domestic HW Recirc	20	7.1	1
P-25	AHU-1 Preheat Coil Circ	35	4.7	0.5
P-26	AHU-2 Preheat Coil Circ	26	4.6	0.5
P-27	AHU-3 Preheat Coil Circ	40	5.2	0.5
P-28	AHU-4 Preheat Coil Circ	42	5.3	0.5
P-29	AHU-5 Preheat Coil Circ	115	5.7	1.5
P-30	AHU-6 Preheat Coil Circ	115	5.7	1.5
P-31	AHU-7 Preheat Coil Circ	33	4.7	0.5
P-32	AHU-8 Preheat Coil Circ	58	4.9	0.75
P-33	AHU-9 Preheat Coil Circ	33	4.7	0.5
P-34	AHU-10 Preheat Coil Circ	33	4.7	0.5
P-35	AHU-11 Preheat Coil Circ	81	5.2	1
P-36	AHU-12 Preheat Coil Circ	37	4.7	0.5
P-37	AHU-13 Preheat Coil Circ	40	5.2	0.5
P-38	AHU-14 Preheat Coil Circ	14	4.5	0.33
P-39	PDU-1 HX Circulator	100	6.1	1
P-40	Pool Water Heat Exchanger	60	4.9	0.5
P-41	ERU-1 Heating Coil	18	4.6	0.5
P-42	ERU-2 Heating Coil	18	4.6	0.5
P-43	Domestic HW Recirc	15	4.7	0.33

Appendix C – GSHP Equations

$$L_c = \frac{q_a \cdot R_{ga} + [q_{lc} - 3.142 \cdot W_c] \cdot [R_p + PLF_m \cdot R_{gm} + R_{gd} \cdot F_{sc}]}{t_g - \left[\frac{t_{wi} - t_{wo}}{2}\right] - t_p}$$

F_{sc}= *short circuit heat loss factor*
L_c= *required bore length for cooling, ft*
q_a= *net annual average heat transfer to ground, Btu/h*
q_{lc}= *building design cooling block load, Btu/h*
R_{ga}= *effective thermal resistance of ground (annual pulse), h-ft-°F/Btu*
R_{gd}= *effective thermal resistance of ground (daily pulse) , h-ft-°F/Btu*
R_{gm}= *effective thermal resistance of ground (monthly pulse) , h-ft-°F/Btu*
R_p= *thermal resistance of pipe and borehole, h-ft-°F/Btu*
t_g= *undistributed 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 at outlet, °F*
W_c= *power input at design cooling load, Btu/h*
PLF_m= *part load factor during design month*

$$F_{of} = \frac{4 \cdot \alpha \cdot \tau_f}{d_p^{\,2}}$$

$$R_{ga} = \frac{G_f - G_1}{k_g}$$

$$F_{o1} = \frac{4 \cdot \alpha \cdot [\tau_f - \tau_1]}{d_p^{\,2}}$$

$$R_{gm} = \frac{G_1 - G_2}{k_g}$$

$$F_{o2} = \frac{4 \cdot \alpha \cdot [\tau_f - \tau_2]}{d_p^{\,2}}$$

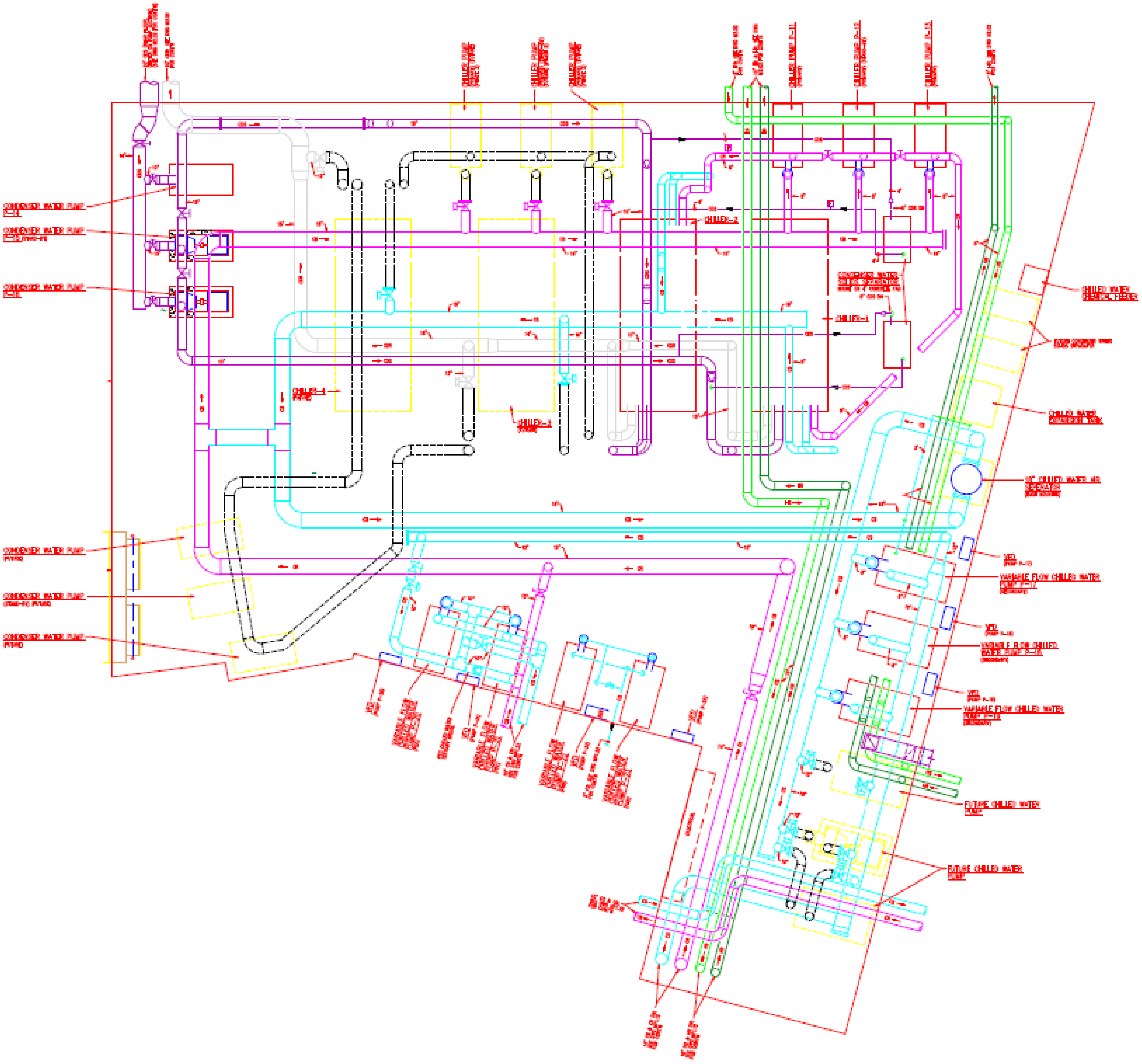
$$R_{gd} = \frac{G_2}{k_g}$$

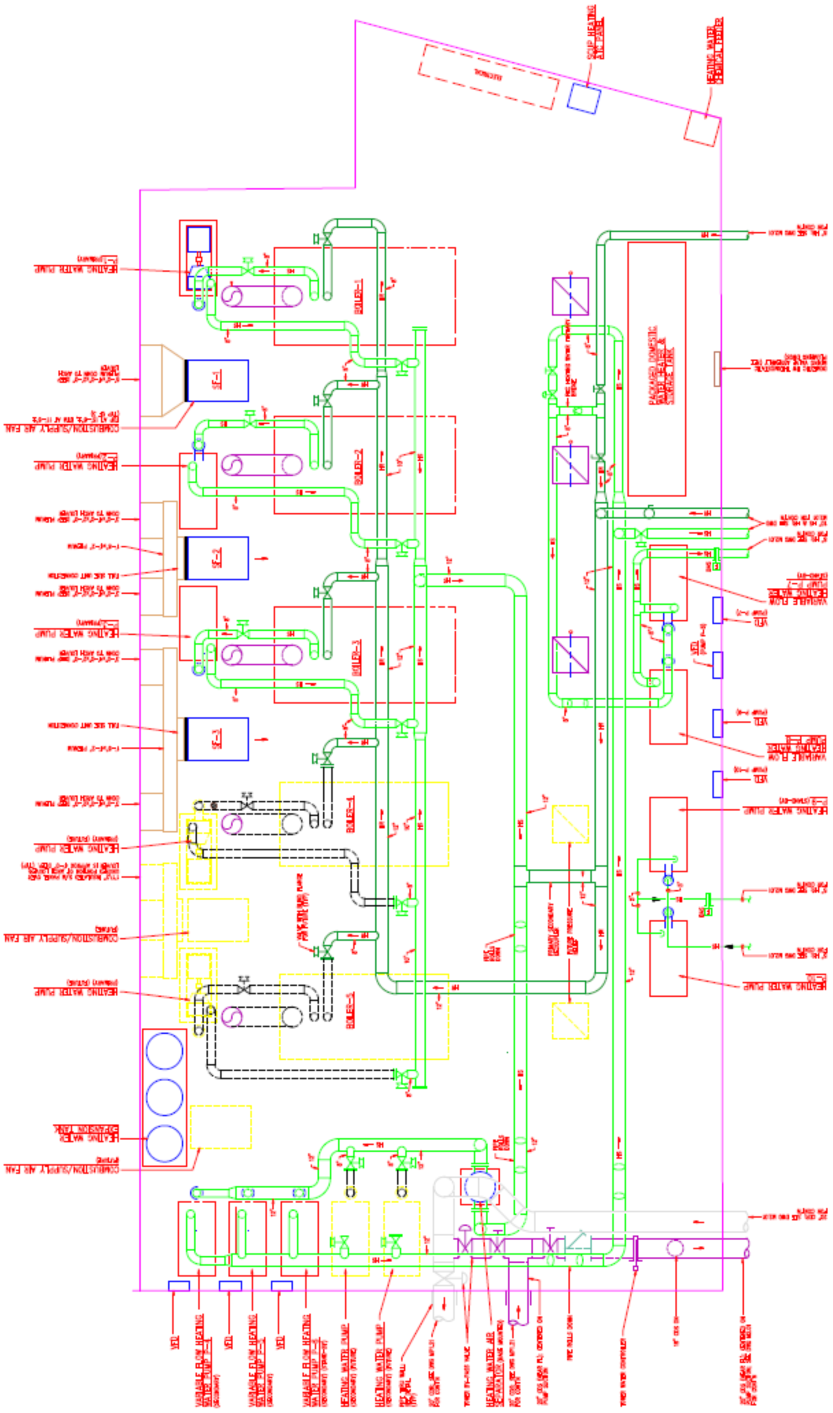
F_{of} = *Fouriers number for* τ_f
F_{o1} = *Fouriers number for* τ_1
F_{o2} = *Fouriers number for* τ_2
α = *Thermal diffusivity of the ground,* m^2*/day*
d_p= *Outside diameter of pipe, ft*
k_g= *Thermal conductivity of the ground, Btu /h-ft-°F*

Appendix D – GSHP Pipe Sizing Worksheet

11	6	70.0	21.53	3	2.864	0.2387	3.4861	1.4267	0.2853	1.7120	High Efficiency
10	6	63.6	19.57	3	2.864	0.2387	3.1692	1.1958	0.2392	1.4350	High Efficiency
9	6	57.3	17.61	3	2.864	0.2387	2.8523	0.9838	0.1968	1.1806	High Efficiency
8	6	50.9	15.65	3	2.864	0.2387	2.5353	0.7910	0.1582	0.9492	High Efficiency
7	6	44.5	13.70	3	2.864	0.2387	2.2184	0.6177	0.1235	0.7413	High Efficiency
6	6	38.2	11.74	3	2.864	0.2387	1.9015	0.4643	0.0929	0.5572	High Efficiency
5	6	31.8	9.78	2	1.943	0.1619	3.4428	2.1924	0.4385	2.6309	High Efficiency
4	6	25.5	7.83	2	1.943	0.1619	2.7543	1.4503	0.2901	1.7403	High Efficiency
3	6	19.1	5.87	2	1.943	0.1619	2.0657	0.8513	0.1703	1.0215	High Efficiency
2	6	12.7	3.91	1.25	1.358	0.1132	2.8192	2.3001	0.4600	2.7601	High Efficiency
1	6	6.4	1.96	1.25	1.358	0.1132	1.4096	0.6371	0.1274	0.7646	High Efficiency

Appendix E – Central Utility Plant Floor Plans





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