Final Report

Mechanical System Redesign - Ground Source Heat Pumps

Glen Burnie High School: Building E Glen Burnie, MD

Wade Myers; BAE Mechanical Option

Thesis Advisor: William Bahnfleth

04/07/2011

Glen Burnie High School: Buildings D, E & F
Glen Burnie, MD

Building D

Project Summary

Number of Stories:…………………………………... 2-3 by building
Total Building Size:………………………………… 110,000 SF
Total Renovation Costs:…………………………... $6,000,000
Project Delivery Method:…………………………… Design-Bid-Build

Project Team

Owner/Occupant: ………………Anne Arundel County Public Schools
Architect:………………………JRS Architects
MEP Engineer:…………………Johnson, Mirmiran & Thompson
Civil & Structural Engineer:……Carroll Engineering
General Contractor:……………..RWC Contracting
Mechanical Contractor:…………Chilmar

Mechanical System Summary

- Building D is cooled by a system of unit ventilators.
- Building F has a variable air volume system fed by 5 air handling units and 1 rooftop unit, as well as fan coil units located in the locker rooms.
- Both Buildings D & F receive chilled water from chillers located in Building A.
- Building E's cooling consists of a constant air volume system fed by 9 air handling units, as well as a unit ventilator which serves the gymnastics area.
- Building E is supplied by its own chiller.
- Heating for all 3buildings is created and supplied by steam boilers located in Building F.

Building E

Architecture

- Campus style high school comprised of 6 buildings.
- Building D a.k.a. Old Main houses art and language classrooms.
- Building E is the physical education building, housing the primary gymnasium and locker rooms, as well as a wrestling room, a weight room, and a gymnastics area.
- Building F is the Business Education Building and also houses an auxiliary gym and locker rooms.

Electrical System Summary

- Building D receives power from a 1600 amp, 480/277 volt, 3 phase 4 wire distribution switchboard.
- Buildings E & F are powered by a 2000 amp, 480/277 volt, 3 phase 4 wire distribution switchboard.
- Lighting consists of fluorescent lamps in classrooms and metal halide lamps in gym areas.

Building F

Structural System Summary

- Building D uses 1 way floor slabs with concrete beams and columns.
- Building E utilizes solid and ribbed floor slabs with concrete beams and columns.
- Building F consists of 2 way floor slabs supported by steel columns and beams.

Wade Myers **Mechanical Option**
www.engr.psu.edu/ae/thesis/portfolios/2011/wgm5002/index.html

Table of Contents

Executive Summary

Glen Burnie High School is a campus style high school located in Glen Burnie, MD. The campus is comprised of 6 buildings, but for the purposes of this report, only Building E was evaluated. Building E is the Physical Education Building and features a constant air volume system served by 9 air handling units with finned tube radiators, convectors and cabinet unit heaters acting as supplemental heat. There is also an individual unit ventilator serving the gymnastics area. As part of the current mechanical renovation, Building E is receiving a new chiller which will only serve Building E. Heating water is supplied to the building by steam boilers located in Building F.

The current system designed for this renovation was able to adequately meet the needs detailed by the client. However, there are other options that could potentially save the owner money while still performing at a level that meets or exceeds the current system. Based on the available ground area on the campus, a Ground Source Heat Pump system was selected to replace the air-cooled chiller. Ground loops were sized to meet 105 tons of the required 120 tons and installed under the baseball field next to Building E. This allowed for a major reduction in the size of the chiller from 155 tons to 20 tons. As a trade-off, new pumps were installed to circulate the ground water and a new heat exchanger was needed to cool the building's chilled water supply.

Building E has not had any recent window replacements. The windows that are currently in place are older single pane models which suffer from old age and poor thermal performance. As an architectural breadth the existing windows were replaced with newer Insulating Glass Units and windows were added to the previously windowless Southern façade. In addition, the gymnasium's window layout was reconfigured from multiple fixed windows to a single strip window layout. This matched other windows of the building and gave the façade a more modern look. The new windows performance had an effect on the HVAC design and the lighting of the spaces due to the increase in available ambient light. Overall, the renovation was able to significantly reduce the heating and cooling loads of the building by reducing summer season heat gain and winter season heat loss.

An evaluation of the changes to the schedule and cost estimate associated with the GSHP system and window renovation was performed as a construction management breadth. Neither the window renovation nor the Ground Source Heat Pump system had an effect on the construction schedule because neither is associated with the critical path of the renovation. When removed equipment savings are considered, the costs of both alterations are roughly the same at $50,846 and $51,273 for the window and GSHP systems, respectively. Based on the energy rates and associated savings, payback periods were calculated to be 17.1 years for the GSHP system and 9.7 years for the window renovation. If both alterations are considered together, then a total cost of $102,119 and annual savings of $8,273.71 averages the payback period to 12.3 years.

Project Summary

Building Name	Glen Burnie High School: Building E
Building Location	Glen Burnie, MD
Building Occupant	Anne Arundel County Public Schools
Occupancy Type	Education - High School
Size	110,000 Square Feet
Number of Stories	3
Project Team	Owner: Anne Arundel County Public Schools
	Architect: JRS Architects
	Mechanical & Electrical Engineer: JMT
	Civil & Structural Engineer: Carroll Engineering
	General Contractor: RWC Contracting
	Mechanical Contractor: Chilmar
Construction Dates	May 2010 - August 2011
Renovation Costs	$6,000,000
Project Delivery Method	Design - Bid - Build

Table 1: Renovation Project Summary

Building Overview & Existing Conditions

Architecture:

Glen Burnie High School is an existing campus style high school located in Glen Burnie, MD. The school was originally built in phases starting in 1934 with the construction of Old Main and ending in 1976 with the completion of the Media Building. Since that time it has had minor renovations performed in 1979, 1996, 2000, and again in 2002. In 2009, the most recent renovation was proposed. This renovation, involving Buildings D, E & F, calls for a new chiller to serve Building E as well as mechanical equipment replacement in all three buildings. This project has already been set into motion and is expected to be completed in August of 2011.

While the campus is comprised of 6 buildings and the current renovation involves 3 of these, this report will only consider Building E. The primary school gymnasium is located in this building, the Physical Education Building. Building E also contains locker rooms, a wrestling room, a weight room and a gymnastics area.

Building Enclosure:

The building enclosure for Glen Burnie High School consists of a traditional brick façade mounted on 8"CMU. Window types for the buildings feature single pane windows with some Insulating Glass Units in Building F which were installed within the past few years.

The original single pane windows in Building E are currently in need of replacement and provide an opportunity for an architectural breadth to be explored.

Glen Burnie High School's roofing material is a modified bituminous, or rubberized asphalt, roof membrane on top of half inch wood fiber board. These are both above a layer of tapered rigid insulation, which allows for sloping to the roof drains, all before reaching the actual roof structure itself.

Electrical & Lighting System Summary:

Building E uses a 480/277 volt, 3phase 4 wire system to provide power. A 2000 amp distribution switchboard is in place to provide service to the building, as well as Building F. Lighting in the building is fairly typical of a school environment. In the locker room and office type environments, 277 volt T12 fluorescent lamps are used. The fixtures are either 4 foot or 8 foot recessed bulkhead mounted. The gymnasium areas use a typical gymnasium lighting system comprised of pendant mounted metal halide lamps.

Structural System Summary:

Each of the buildings utilizes a different construction method for their structural systems because the occupancy types and story heights vary from one building to the next. Floor slabs vary around the buildings from 12 inches with the 2 way construction, to 5 inches with flat slabs. Building E uses concrete beams and columns to support its concrete floor slabs. The floor slabs vary between a combination of 1 way slab and 2 way joist, or waffle slab, systems. The columns in Building E transition to smaller sizes as the stories increase and the loads they must support decrease. These sizes range from 12x25 at the ground level to 8x12 at the third story, with a typical concrete beam size being 12x12.

Construction Management:

The current mechanical renovation that is being performed on Building E is being delivered as a Design-Bid-Build project. Design started when the engineering firm Johnson, Mirmiran & Thompson was given their notice to proceed in September of 2009. After the design was finalized and the bid was won, the contractors were given their notice to proceed in May of 2010. The final renovation cost estimate as of this posting is $6,000,000.

This project is currently under construction with RWC Contracting acting as the general contractor and Chilmar, a sub company of RWC, as the mechanical contractor. The entire project is expected to last 15 months with an estimated completion date in August of 2011, in time for the next school year to begin.

Communications:

In 2002 the entire school campus had a public address system upgrade performed. This upgrade replaced the existing speakers located in the classrooms and on exterior walls. This allowed for better and more reliable communication to the faculty and students both inside the classroom, as well as between buildings. This last part being more important with Glen Burnie High School because it is a campus of multiple buildings where students travel between buildings as opposed to a traditional one building school where exterior communication is not as important.

Sustainability Features:

An economizer is in place for varying outdoor air quantities in order to reduce the cooling and heat requirements on the system. In addition, the mechanical pump rooms in Building E have plate and frame and shell and tube heat exchangers for the chilled and heating water systems, respectively. Finally, the largest mechanical room which houses 3 of the building's air handling units contains 3 energy recovery ventilating units, one for each AHU.

Mechanical System Overview

Design Objectives & Requirements:

Because Glen Burnie High School was already constructed and in use, the purpose of the renovation was to upgrade some of the equipment and overall performance of the existing mechanical system. This created the need to maintain compatibility of the new equipment with the current. There were other restrictions to the mechanical design that resulted from this project being a renovation. Since there was a system already in place, the energy sources which were in use before the renovation were favored to reduce the cost of switching to a new source. The selection of equipment was further limited because of dimensional requirements caused by existing mechanical spaces.

Existing System Information:

Glen Burnie High School is a campus style high school, this means that some parts of the mechanical systems in the buildings are interconnected to systems that act as a central plant for more than one building. However, there are some pieces that only serve certain buildings, and each building's individual HVAC system is different. For cooling, Building E is receiving a new chiller which will only serve Building E as part of the current renovations. Hot water for heating and domestic use is supplied to the building by steam boilers located in the boiler room of Building F.

Heating and cooling is supplied to Building E by 9 constant air volume air handling units, 9 hot water convectors, 3 cabinet unit heaters and a single unit ventilator which serves the gymnastics area. The purpose of the cabinet unit heaters and convectors is simply to supply additional heat in passageways and storage rooms, while the gymnasiums supplemental heat system is comprised of finned tube radiators along the exterior walls.

Major Renovation Equipment Breakdown:

The mechanical renovation to Glen Burnie High School consisted of the replacement of terminal equipment, such as unit ventilators and fan coil units, as well as larger equipment;

a chiller was added to Building E. In order to conserve energy, energy recovery ventilating units were also added to 3 of the air handling units in Building E. Table 2 lists and briefly describe all of the major equipment that will be installed as a part of the renovation to Building E.

Building E Equipment List				
Chillers	**GPM**	**Capactiy (tons)**	**EER**	**Quantity**
CH-1	370	140.8	9.8	1
Air Handling Units	**CFM**	**Cooling (MBH)**	**Heating (MBH)**	**Quantity**
AHU-1	900	31.3	30.9	1
AHU-2	1300	56.4	56.6	1
AHU-3	1300	113.3	110.1	1
AHU-4	2000	165.6	162.7	2
AHU-5	2500	213.2	250.5	1
AHU-6	2800	234.7	228.8	1
AHU-7	7200	404.4	352.1	2
Unit Ventilators	**CFM**	**Cooling (MBH)**	**Heating (MBH)**	**Quantity**
UV-1	2000	55.3	109.2	1
Cabinet Unit Heaters	**CFM**	**HP**	**Heating (MBH)**	**Quantity**
CUH-1	345	1/10	21	1
CUH-2	505	1/10	29.2	2
Convectors	**GPM**	**Mounting**	**Heating (MBH)**	**Quantity**
CONV -1	0.9	Surface	9	4
CONV -2	1.1	Surface	11	3
CONV -3	1.2	Recessed	12	2
Exhaust Fans	**CFM**	**Static (IN W.G.)**	**RPM**	**Quantity**
EF-1	800	0.25	1725	1
EF-2	1400	0.5	1725	1
Pumps	**GPM**	**Head (FT H2O)**	**RPM**	**Quantity**
CHW	309	60	1750	2
HW	186.5	40	1750	2
Glycol	370	60	1750	2
Heat Exchangers	**GPM**	**Steam (lb/hr)**	**Type**	**Quantity**
HX-1	309/370	--	Plate & Frame	1
HX-2	2000	187	Shell & Tube	1
Energy Recovery Ventilator	**CFM**	**Exhaust CFM**	**Summer/Winter Eff (%)**	**Quantity**
ERV-1	2000	1900	.58/.59	2
ERV-2	2800	2700	.58/.59	1

Table 2: Building E Equipment List

Existing Conditions:

Energy Sources & Rates:

Baltimore Gas & Electric is the supplier of natural gas and electricity to the Glen Burnie High School campus. Below, Tables 3 & 4 list the rates and rate schedules for BG&E.

Baltimore Gas & Electric Rates					
Electricity				Gas	
Demand Charge	Peak	Mid-Peak	Off-Peak	≤10000 therms	>10,000 therms
($/kW)	(¢/kWh)	(¢/kWh)	(¢/kWh)	($/therm)	($/therm)
3.95	11.551	9.265	8.824	0.9675	0.8648

Table 3: Baltimore Gas & Electric Rates

BG&E Rate Schedule		
Start	End	Rate
11:00 PM	7:00 AM	Off-Peak
7:00 AM	10:00 AM	Mid-Peak
10:00 AM	8:00 PM	Peak
8:00 PM	11:00 PM	Mid-Peak

Table 4: BG&E Rate Schedule

In addition to natural gas and electricity, there is the possibility to utilize a Ground Source Heat Pump system for the campus based on the available land space. This could be utilized from the land occupied by the baseball and football fields. However, cost needs to be considered, as well as construction times, as installation would interrupt the sports seasons.

Annual Energy Use:

Actual annual energy use information is not available for Glen Burnie High School. Using Trane Trace the annual energy use was calculated for this report at the same time and based on the heating and cooling loads for the building. Overall energy use for the building is 1,414,369 kBTU/year.

Mechanical System Design Parameters:

Design Air Conditions:

Glen Burnie High School was designed based on the outdoor air conditions stated in ASHRAE Fundamentals 2005 for Baltimore, MD. Indoor air conditions were selected based on standard practice and existing conditions for the buildings. Table 5 shows these design conditions.

Design Air Conditions					
Outdoor Design Conditions			Indoor Design Conditions		
Summer		Winter	Cooling	Heating	Relative Humidity
DB (F)	MCWB (F)	DB (F)	DB (F)	DB (F)	%
93.9	74.9	12.9	78	72	50

Table 5: Design Air Conditions

Ventilation Requirements:

The design outdoor air rates are much higher than what is required by ASHRAE. This is because most of the systems utilize 100% OA. This was done because the building's primary purpose is a gymnasium that sees near constant activity. Using 100% OA keeps the air contamination level to a minimum and helps keep the occupants healthy. The laundry room and other low occupancy areas use a more reasonable OA percentage. Table 6 shows the design airflow values.

Building E Outdoor Airflow Rates			
System	Design Airflow (CFM)	Design OA (CFM)	% OA
AHU-1	2000	2000	100
AHU-2	2800	2800	100
AHU-3	2000	2000	100
AHU-4 & 5	14400	6000	42
AHU-6	2500	2500	100
AHU-7	1300	350	26.9
AHU-8	900	100	11.1
AHU-9	1300	1300	100
UV-1	2000	550	27.5
Total	29200	17600	60.3

Table 6: Building E Outdoor Airflow Rates

Design Heating & Cooling Loads:

The heating and cooling loads were calculated for the renovation using Trane Trace. In order to reduce discrepancies, Trace was used to calculate all new loads for this report associated with the proposed mechanical and architectural system redesigns which will be mentioned later. Table 7 shows a breakdown of heating and cooling loads by zones.

Building E Load Summary				
Zone	Cooling Load (ton)		Heating Load (MBH)	
	Before	After	Before	After
AHU-1	5.7	3.7	101	61.8
AHU-2	16.7	13.7	203.1	160.1
AHU-3	7.9	4.5	91.6	56
AHU-4 AHU-5	84.4	80.1	696.8	394.9
AHU-6	5	3.2	14.2	12.8
AHU-7	4.2	1.7	80.4	28.3
AHU-8	3.5	2.7	72.9	32.8
AHU-9	7	3.3	93.1	57.3
UV-1	6.4	7.5	164	95.7
Total	140.8	120.4	1517.1	899.7

Table 7: Building E Load Summary

These before and after loads are a comparison of the original design model and a new one that was performed for this report and includes the window renovation from the architectural breadth which will be discussed later. As can be seen, the installation of new windows greatly improves the efficiency of the building envelope. This allows for a decrease in the amount of heating and cooling production for the building, thus saving energy. In addition to the changes brought on by the windows, the way the models were created also contributed to the differences. The designer's model was created on a room by room basis, while this report dealt with a block load. There were also differences in the load assumptions. For this report, in order to obtain a more accurate model the default climate design values in Trace were replaced with values from ASHRAE Fundamentals. Lighting, miscellaneous, and people loads were also set up for different room types, instead of using a default value for all spaces. However, the designer was able to use more accurate information for room occupancy and other equipment loads from the actual building.

System Schematics:

Figures 1 & 2 show the piping schematics for the chilled water and heating water systems of Building E.

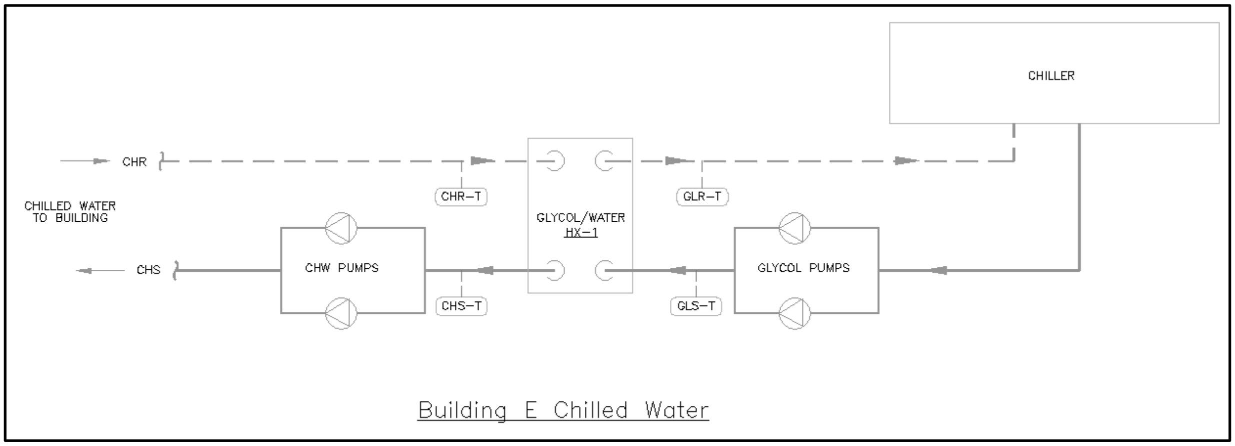


Figure 1: Building E Chilled Water

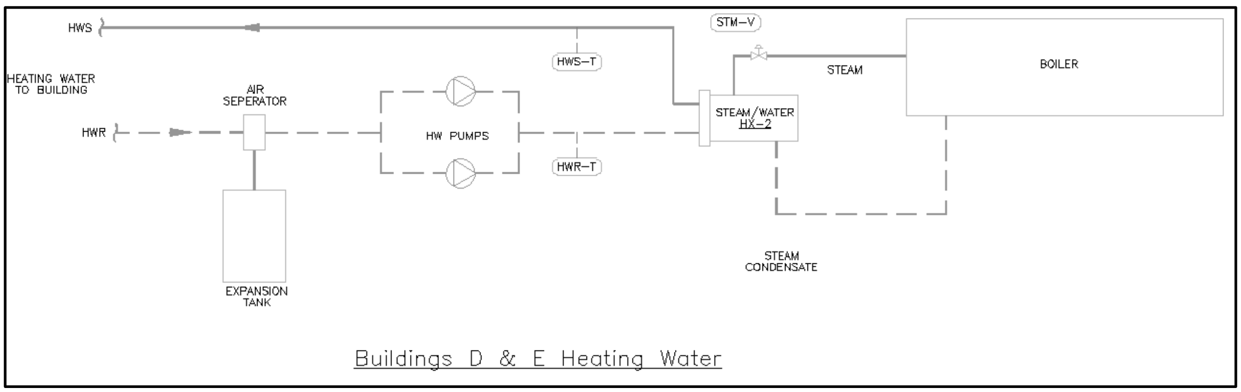


Figure 2: Building E Heating Water

System Operation:

Chilled Water:

Building E's chilled water system is more intricate than a standard system due to the installation of a new chiller and heat exchanger. When the outdoor air temperature is above the setpoint, the chiller is activated. Activation of the chiller energizes the chilled water and glycol pumps in lead/lag operation. The lag pump is only operational when the lead pump fails to energize and designation of lead/lag operates according to schedule and is adjustable to balance wear on the pumps. Heat is then transferred inside the heat exchanger between the glycol solution and chilled water. Temperatures are monitored by the glycol and chilled water supply and return temperature sensors, and the glycol solution temperature is maintained inside the chiller.

Heating Water:

Heating water is supplied by boilers located in Building F. These boilers are energized when the outdoor air temperature is below the setpoint and there is a demand for heating in the buildings based on thermostat readings. The heating water pumps are energized and deliver the heating water to the load. The pumps operate in a lead/lag fashion with the lag pump only operational when the lead pump fails to energize. The lead/lag designations once again operate according to schedule and are adjustable. A steam/water heat exchanger transfers heat between the steam generated in the boilers and the heating water delivered to the load. Temperatures are monitored by the supply and return heating water temperature sensors and a steam valve is modulated based on the required amount of steam needed to satisfy the load.

Proposed Mechanical System Redesign

Ground Source Heat Pumps:

The current system designed for this renovation was able to adequately meet the needs detailed by the client. However, this design utilizes an air-cooled chiller which produces chilled glycol that is then pumped to a heat exchanger in a separate mechanical room to cool the chilled water supply for Building E. The amount of energy used by a chiller of this size could be reduced or possibly even eliminated, as well as other equipment costs, by replacing or supplementing this branch of the system with a Ground Source Heat Pump system.

Because this project is for a high school, there is plenty of available ground for a system to be installed. Bores can be dug and loops installed underneath the athletic fields and, if required, beneath the parking lots as well. This would only be done if absolutely necessary to minimize interruption to normal school functionality caused by construction. Because the athletic fields are the proposed site for the system, installation would best be performed during the summer months when there is a break in the sports seasons. This coincides with the majority of the heavy construction periods so this additional system installation would need to be examined for its impact on the existing construction schedule.

Proposed Breadth Studies

Architectural:

Over the years some of the windows on campus have been replaced with better performing glazing. However, Building E has not yet been included in the window replacements. The windows that are currently in place are older single pane windows which are in need of replacement due to age and poor thermal performance. It is proposed that the existing windows be replaced with newer multi-pane windows with better glazing and U-Values which will limit heat gain in the summer and reduce heat loss in the winter. Instead of simply swapping out one window for an identical window with better performance, a new window design will be installed in the East, West and South walls of the building. These new windows for the East and West walls will create more window area for the main gymnasium resulting in more sunlight to the space. The South wall of the building, which covers the gymnastics area, currently has no windows. By adding windows to this important solar wall, the area will be provided with natural sunlight and views to the outside. Obviously, performing the window replacement will have an effect on the HVAC design by changing the envelope loads experienced by the mechanical systems, the lighting of the spaces due to the increase in available ambient light, as well as the façade of the building itself. The biggest factor that comes with the addition of a window replacement to the scope of work is the effect on the cost and schedule of the project. This leads to the final breadth area of study.

Construction Management:

In the process of adding a Ground Source Heat Pump system and a window replacement to Building E, there will be changes to the cost and time of the renovation. An evaluation of the increase in schedule time will be performed and checked for the ability to limit the length of the renovation. While the installation of the GSHP system and windows will increase the length of the renovation, it would be possible to install the windows at the same time. This should limit the overall increase in the length of the renovation to that of the ground loops alone. The cost of the new equipment and windows will inevitably cause the cost of the renovation to increase. However, the savings in energy and first cost by reducing the size of major equipment such as chillers will allow for a quicker payback time then by doing only individual pieces of the proposed alterations.

Ground Source Heat Pump System

Ground Study:

In order to be able to properly utilize a Ground Source Heat Pump system, the ground in which the loops will be installed must be examined. Realizing this, the ground properties of the Glen Burnie High School campus were researched. Using the web soil survey application on The United States Department of Agriculture Natural Resources Conservation Service website it was found that the ground is comprised of Patapsco-Fort-Mott-Urban Land complex sand for the first 7 feet and quartz sandstone underneath this. See Figures 3 & 4 for approximate locations of the Glen Burnie High School campus on geological maps of Maryland.

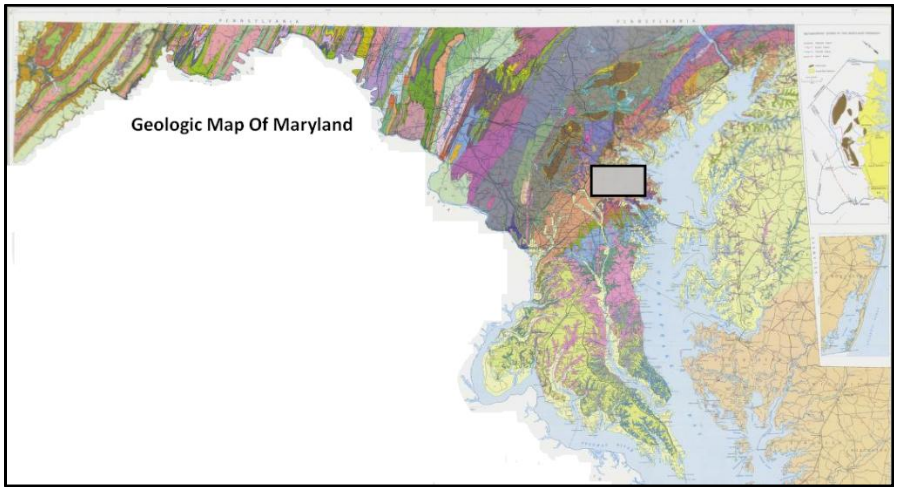


Figure 3: Geologic Map of Maryland

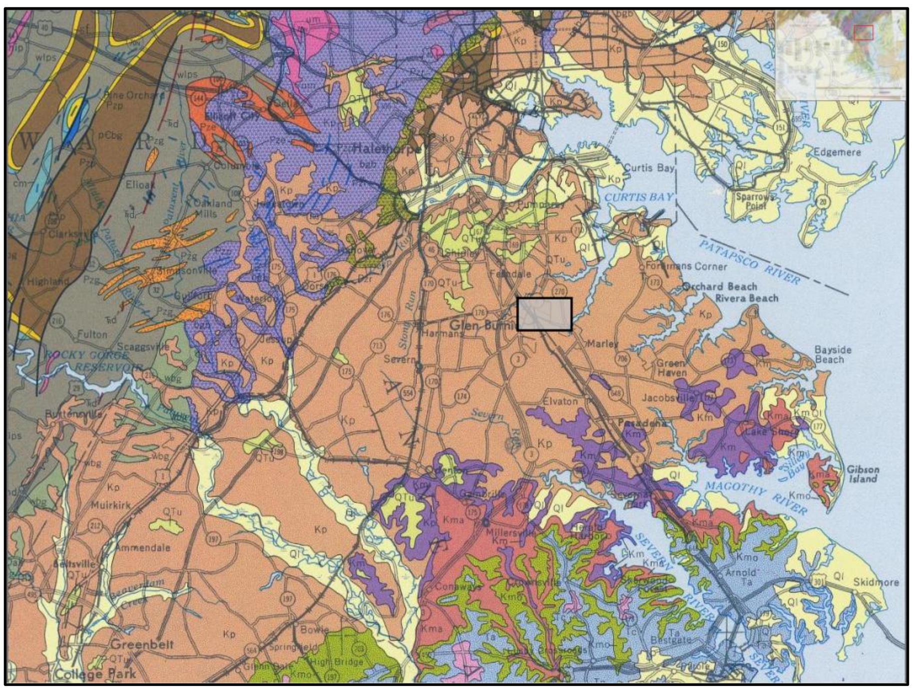


Figure 4: Geologic Map of Glen Burnie, MD

Using Table 5 in Chapter 32 of the 2007 ASHRAE Handbook – HVAC Applications, it was determined that Heavy sand, 5% water and Sandstone were the closest representations to the site's actual soil and rock makeup. Table 8 shows the properties of these materials. Aside from the ground properties, in order to calculate the required bore length, the properties of the well piping and grouts/backfills need to be calculated as well. Using the McQuay Geothermal Heat Pump Design Manual, these properties were selected from Tables 9 & 10.

GSHP System Ground Properties				
Type	Material	Density (lb/CF)	Conductivity (BTU/h-ft-°F)	Diffusivity (SF/day)
Soil	Heavy Sand, 5% Water	120	1.2 - 1.9	1.0 - 1.5
Rock	Sandstone	--	1.2 - 2.0	0.7 - 1.2
Grout	15% Bennonite/85% SiO_2 Sand	--	1.0 - 1.1	--

Table 8: GSHP System Ground Properties

U-Tube Dia.	SDR or Schedule	Pipe (Bore) Thermal Resistance (h•ft•F°/Btu)			
		For Water Flows Above 2.0 US gpm	20% Prop. Glycol Flow 3.0 US gpm	20% Prop. Glycol Flow 5.0 US gpm	20% Prop. Glycol Flow 10.0 US gpm
¾ in. (0.15 ft)	SDR 11	0.09	0.12	NR	NR
	SDR 9	0.11	0.15	NR	NR
	Sch 40	0.10	0.14	NR	NR
1.0 in. (0.18 ft)	SDR 11	0.09	0.14	0.10	NR
	SDR 9	0.11	0.16	0.12	NR
	Sch 40	0.10	0.15	0.11	NR
1 1/4 in. (0.22 ft)	SDR 11	0.09	0.15	0.12	0.09
	SDR 9	0.11	0.17	0.15	0.11
	Sch 40	0.09	0.15	0.12	0.09
1 1/2 in. (0.25 ft)	SDR 11	0.09[1]	0.16	0.15	0.09
	SDR 9	0.11[1]	0.18	0.17	0.11
	Sch 40	0.08[1]	0.14	0.14	0.08

Table 9: GSHP System Pipe Thermal Resistances

Natural Soil Cond.	0.9 Btu/h•ft•F°		1.3 Btu/h•ft•F°			1.7 Btu/h•ft•F°	
Backfill or Grout Conductivity	0.5 Btu/h•ft•F°	2.0 Btu/h•ft•F°	0.5 Btu/h•ft•F°	1.0 Btu/h•ft•F°	2.0 Btu/h•ft•F°	0.5 Btu/h•ft•F°	1.0 Btu/h•ft•F°
4 in. Bore							
¾ in. U-tube	0.11 (NR)	-0.05	0.14 (NR)	0.03	-0.02	0.17 (NR)	0.05
1 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.13 (NR)	0.04
5 in. Bore							
¾ in. U-tube	0.14 (NR)	-0.06	0.18 (NR)	0.04	-0.04	0.21 (NR)	0.06
1 in U-tube	0.11 (NR)	-0.04	0.14 (NR)	0.03	-0.02	0.16 (NR)	0.05
1 1/4 in U-tube	0.06	-0.03	0.09	0.02	-0.02	0.12 (NR)	0.04
6 in. Bore							
¾ in. U-tube	0.18 (NR)	-0.07	0.21 (NR)	0.04	-0.05	0.24 (NR)	0.07
1 in U-tube	0.14 (NR)	-0.06	0.17 (NR)	0.03	-0.04	0.21 (NR)	0.06
1 1/4 in U-tube	0.09	-0.04	0.12 (NR)	0.03	-0.02	0.15 (NR)	0.05
1 1/2 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.11 (NR)	0.04

Table 10: GSHP System Bore/Grout Correction Factors

Bore Length Calculation:

Chapter 32 of the 2007 ASHRAE Handbook – HVAC Applications deals with the sizing of Ground Source Heat Pump systems. This chapter includes the equation to calculate the required bore length as well the equations needed to calculate some of the variables. These equations were entered into Engineering Equation Solver for accuracy. See Appendix A at the end of this report for details on this calculation and the EES results. The following equation is the main equation which was used to calculate the required overall bore length.

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

Where:

F_{sc}= *short circuit heat loss factor*
L_c= *required bore length for cooling, ft*
PLF_m= *part load factor during design month*
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*

After calculating the additional parameters for the equation and entering all of the values into EES, a result for the required bore length was obtained of 27,246 ft.

System Layout:

After calculating the required length for the GSHP system, the next step was to decide what kind of piping system would be used and where the piping would go in relation to the site.

To minimize the impact of installing the system, a vertical bore field was chosen for the redesign and the only ground that was considered for the installation of the loops includes the athletic fields of the campus. This land, occupied by the tennis courts, multiple baseball fields, football field and track, accounts for an available area totaling 23.6 acres or 1,028,016 square feet. Figure 5 is a map of the site for Glen Burnie High School. The red line shows borders of the Glen Burnie High School campus site and the shaded region denotes the area available for the installation of the GSHP bores.

Figure 5: Glen Burnie High School Site

In order to reduce the amount of bore holes required, the GSHP system was not sized to handle the entire load for Building E. Instead, the system was sized for 105 of the 120.4 tons of required cooling capacity. This decision resulted in a reduction of the required bore length from 30,933 feet to the earlier mentioned 27,246 feet and a savings of over 4000 feet of piping.

According to Chapter 32 of the 2007 ASHRAE Handbook – HVAC Applications, the minimum recommended separation distance between bores is 20 feet and the typical range for bore depths is between 50 and 600 feet, depending on the site characteristics. Based on this information and the fact that cost increases exponentially the deeper the bores are drilled, a bore depth of 275 feet was chosen with a 20 foot separation. This resulted in 100 bores being needed to meet the required length. To eliminate unnecessary piping from the building to the bore field, these were laid out as closely to the building as possible in a 10 x 10 grid, shown in Figure 6.

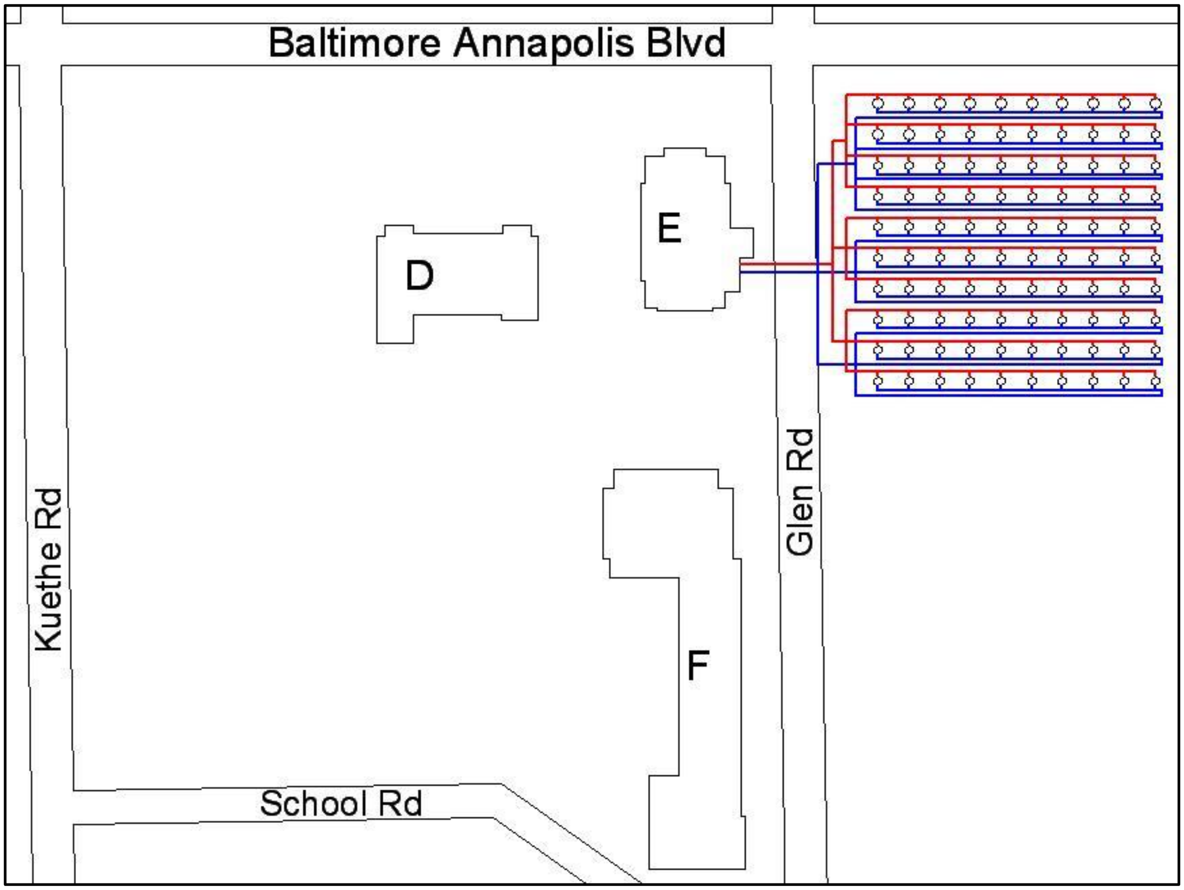


Figure 6: Ground Source Heat Pump Piping & Bore Layout

This grid was further divided into 3 sections to allow for a more efficient part-load performance from the system. This also allows for the sections to be cycled under part loading so as to reduce the ground temperature and fully discharge the deactivated loops. The 3 sections all utilize the same piping setup with individual headers for each section. These headers are then tied into 1 main header for the whole system that is then routed into the existing mechanical room of Building E. From here the pipes are connected to a heat exchanger and the rest of the chilled water system of the building.

Reverse-Return piping is one of the standard piping layouts for GSHP systems and was the selected type for this project. Because the piping provides self-balancing, additional balancing valves are not needed. This setup also lowers the overall head seen by the pumps by increasing or decreasing the pipe size as the flow varies. Figure 7 shows a diagram of a typical Reverse-Return piping layout.

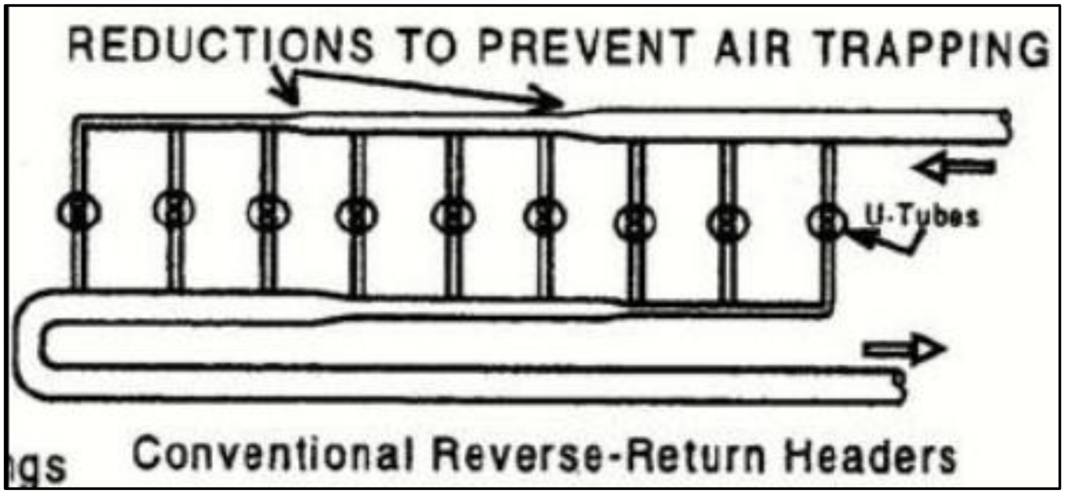


Figure 7: Diagram of Reverse-Return Piping

System Impact:

Each of the sections is supplied with its own pump, with a second pump for full redundancy and pump cycling, allowing for easier loop cycling and individual loop control. Operation of the GSHP system is simple. The first pump and loop is activated when a demand for cooling is present. As the load increases beyond the capacity of this loop, the second pump and loop is activated. The same occurs for the third loop and this process is reversed as the cooling demand decreases. Figure 8 on the next page shows schematically how the Ground Source Heat Pump system will be integrated into the current chilled water system.

In order to properly size the new ground water and chilled water pumps, flow rates and head needed to be calculated. Based on McQuay's design manual, a flow of 3 gpm/ton was used. This comes to a total of 315 gpm to meet the peak GSHP load of 105 tons. After dividing the total flow among the individual sections and calculating their respective heads, the selection parameters for the ground water pumps were found. Using these numbers and values from the existing system the chilled water pump parameters were calculated as well. These values can be seen in Table 11.

Pump Selection Parameters		
Ground Loop Section	**Flow Rate (GPM)**	**Total Head (FT H_2O)**
GWP-1	126	80
GWP-2	94.5	70
GWP-3	94.5	75
CHWP-1	360	65

Table 11: Pump Selection Parameters

Using these parameters, the pumps were selected to maximize efficiency and effort was given to utilize the same models where possible. Each pump was selected to be a Bell & Gossett Series 1531 pump and the pump curves are shown in Figures 9, 10 & 11.

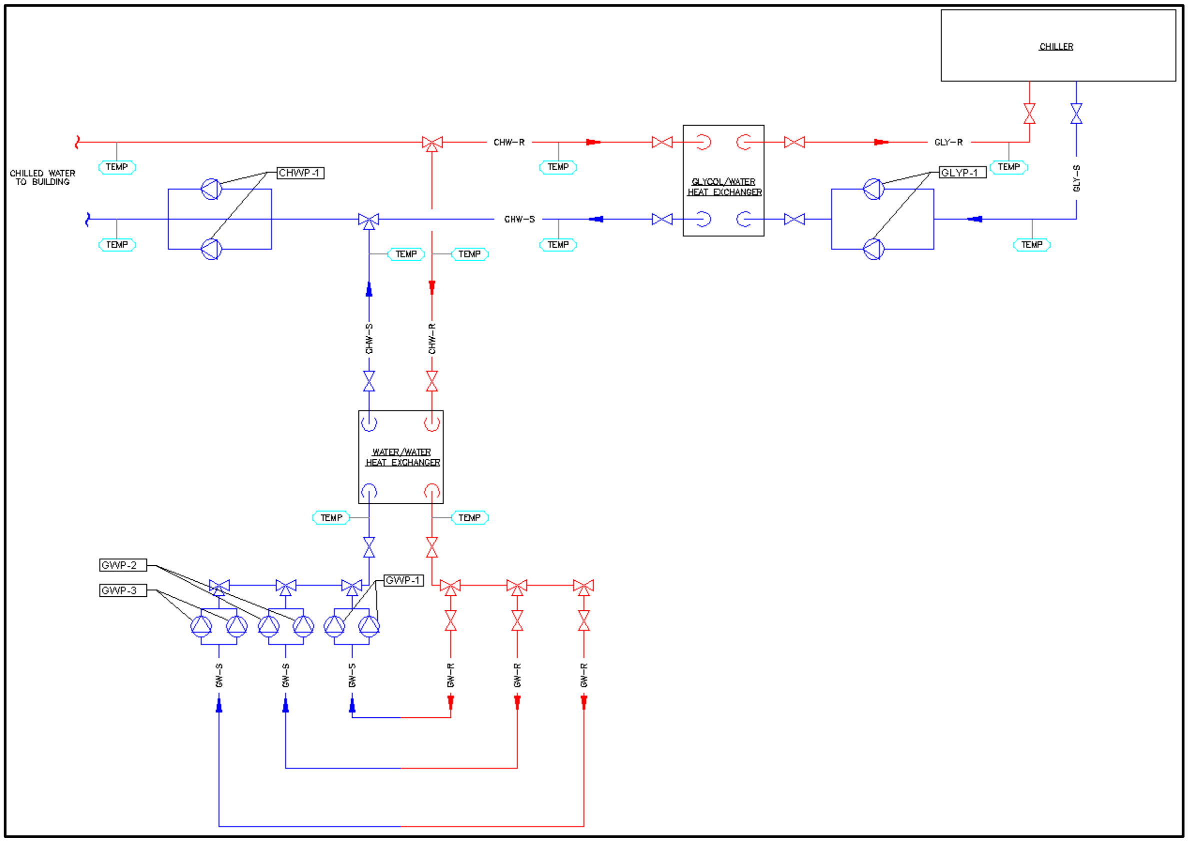


Figure 8: GSHP/Chilled Water Piping and Pump Schematic

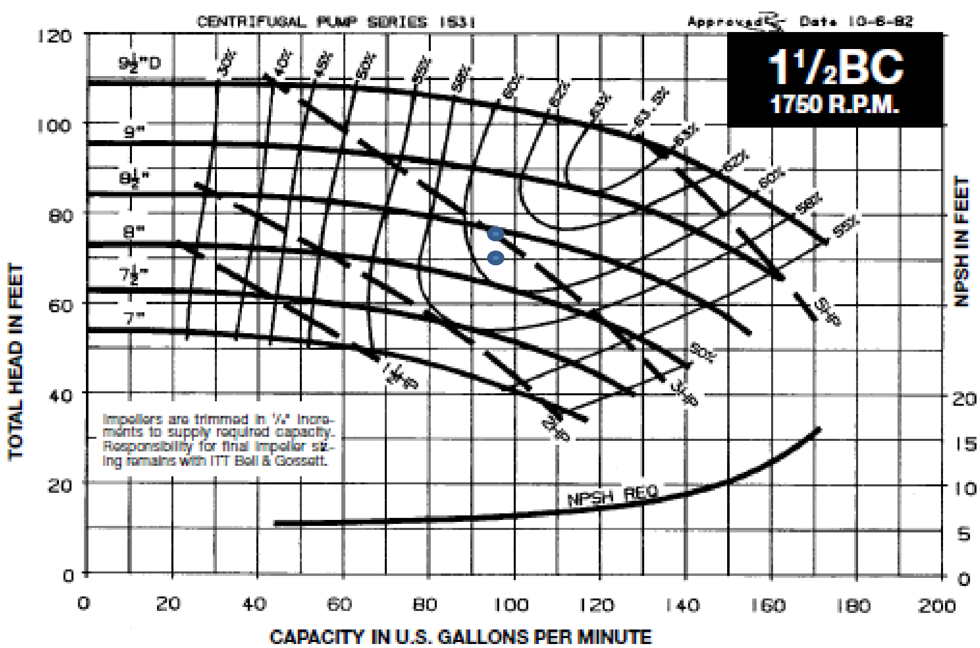


Figure 9: Ground Water Pumps 1 &2 Curve

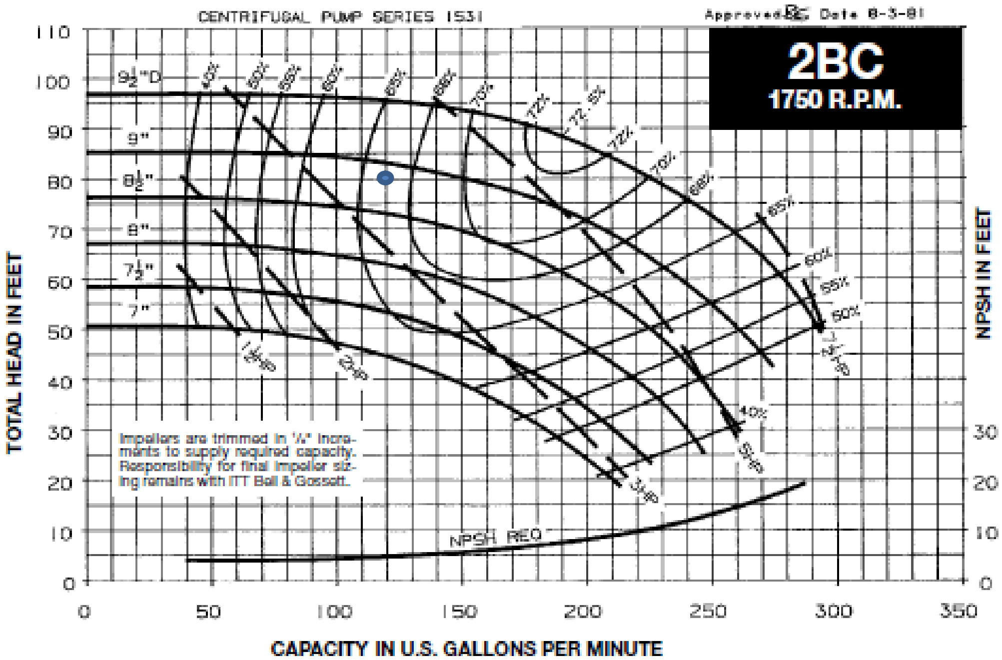


Figure 10: Ground Water Pump 3 Curve

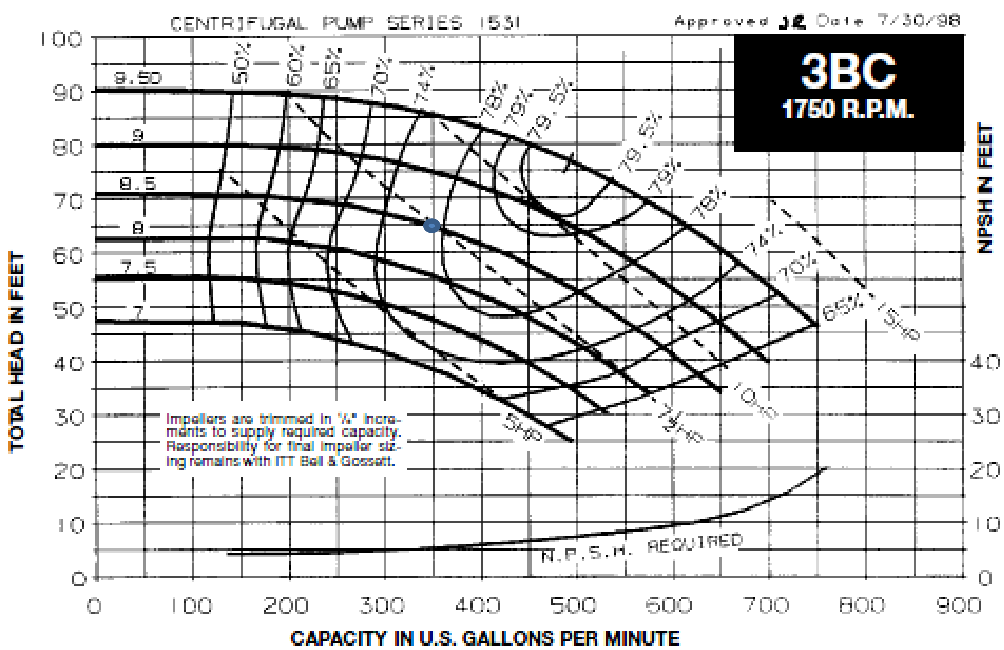


Figure 11: Chilled Water Pump 1 Curve

As stated earlier, the Ground Source Heat Pump system was sized to handle 105 tons of the 120.4 tons of required cooling. This results in a large reduction to the size of the chiller used. Instead of using a 155 ton chiller for all the cooling needs, the GSHP system will handle the loads for the majority of the cooling season and a new 20 ton chiller will be used for design day and abnormal load conditions. For information on this new chiller, see Table 12.

Building E New Reduced Chiller		
Model	**Capacity (Tons)**	**EER**
Trane CGAM 20	18.9	9.9

Table 12: Ground Water Pump Selection Parameters

This chiller will be installed in the new chiller enclosure that is being created as part of the current renovation and will operate in the same fashion as the original that it is replacing. This means that the chiller will operate in its low temperature setting providing a water-glycol solution that will be run through a heat exchanger to cool the chilled water supply for the building.

In addition to the load reduction to the building, there is also a reduction in the energy use as well. Because the GSHP system was only used to meet cooling loads, the reduction in the heating energy use comes solely from the window replacement which will be discussed in the architectural breadth. The reduction in the cooling energy use is a combination of the window replacement and the large reduction in the size of the chiller needed. Table 13 shows the comparison of the energy use before and after the system changes.

Building E Energy Reduction			
Cooling (kBTU/yr)		**Heating (kBTU/yr)**	
Before	**After**	**Before**	**After**
174,210	47,163	1,056,069	644,483

Table 13: Ground Water Pump Selection Parameters

This information was then used in the construction management breadth to analyze the payback periods for the window replacement and the Ground Source Heat Pump system.

Architectural Breadth

System Study & Design:

Building E is in need of a window replacement due to age and sub-par performance from the current single pane units. To address this issue while still maintaining an element of design, the building's windows were replaced and a new window scheme was designed for the East, West and South walls. Aside from the benefits to the mechanical system of higher performing windows, aesthetics were another important factor when selecting the windows. The new units needed to serve the purpose of allowing in sunlight while providing views to the outside, but this replacement also allowed for the opportunity to increase the look of the building's façade.

The East and West walls enclose the main gymnasium and the Southern wall borders the gymnastics area. Currently, there are 6 windows, measuring 8' 4" w x 9' 5" h, along each of the Eastern and Western walls to provide sunlight to the gym. Views to the outside were not an important factor based on the activities which take place in the gym and because the windows need to be closer to the ceiling to accommodate the bleachers surrounding the court. These windows were replaced with new fixed Insulating Glass Units. The new design calls for a single window, measuring 70' w x 9' 6" h, to span the length of the wall, instead of using 6 individual ones. This window selection was done to provide a constant span of glass along the wall which gives a more modern look to the building. This concept of a strip window was also applied to the Southern wall. To maintain symmetry and because there were no windows to replace on this wall, the same window height of 9' 6" from the gymnasium was used and a new window spanning 55' was selected.

The decision to eliminate the use of several windows per wall for the building was made in an effort to increase the aesthetics of the façade. The buildings of the campus are fairly old and this new window layout design will hopefully give the buildings a newer look. The major theme of modern architecture is to simplify the building and get rid of decoration that is seen as unnecessary. So for a wall that requires windows, it seems natural to make one window that is the required size instead of dealing with multiple windows and spacing patterns. This new design ultimately gave Building E a simplified, modern look while increasing the amount of day lighting and the envelope's efficiency.

System Impact:

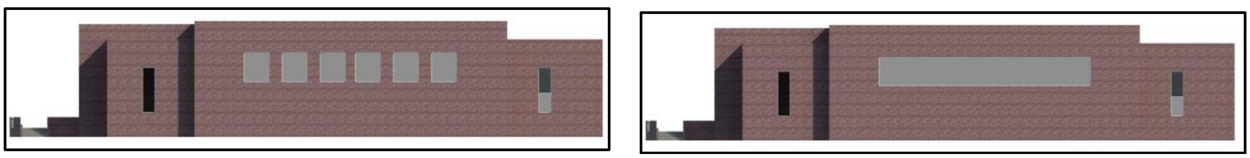
Before the window replacement was performed, the cooling load seen by the HVAC system totaled 140.8 tons. After the new windows were installed the loads dropped to 120.4 tons. Table 14 shows the change in load to the 2 main areas affected by the renovation.

Window Replacement Load Changes		
Area	**Load Before (tons)**	**Load After (tons)**
Gymnasium	84.4	80.1
Gymnastics Area	6.4	7.5

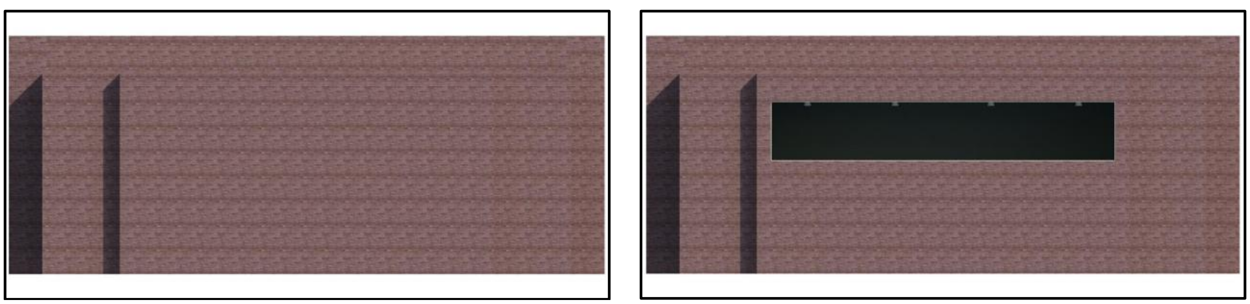
Table 14: Window Replacement Load Changes

It is clear that by adding windows to the Southern wall that the loads increased in the gymnastics area, but the overall building loads were able to decrease from the installation of better performing windows. The overall change of 3.2 tons to these 2 areas shows a trend of decreasing loads that was carried over to the rest of the building resulting in an overall decrease in loads of 20.4 tons.

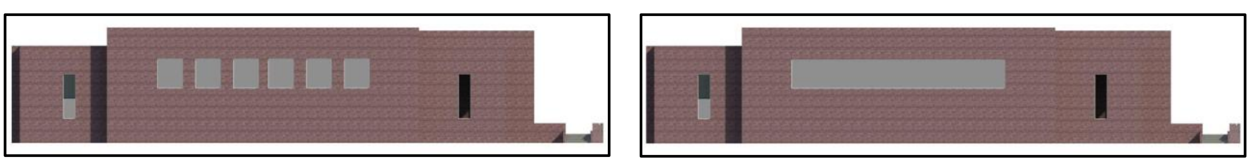
Figures 12 - 17 are elevations of the exterior walls which show how the façade of Building E changed due to the window replacement. For interior perspectives and exterior models, see Appendix B at the end of this report.



Figures 12 &13: Building E West Elevation Before & After



Figures 14 & 15: Building E South Elevation Before & After



Figures 16 & 17: Building E East Elevation Before & After

Construction Management Breadth

Schedules:

RS Means was used to determine the construction times for both the Ground Source Heat Pump system and the window renovation. Tables 15 & 16 show the determined schedule variables used in the analysis.

GSHP System Schedule Variables			
Component	**Time**	**Amount**	**Total**
Bores	1,000 L.F./Day	27,246 L.F.	28 Days
Piping	1,000 L.F./Day	27,246 L.F.	28 Days
Grout	1,000 L.F./Day	27,246 L.F.	28 Days
Headers	530 L.F./Day	9,320 L.F.	18 Days
Pumps	1.5 Units/Day	8 Units	6 Days
Heat Exchanger	1 Unit/Day	1 Unit	1 Day

Table 15: GSHP System Schedule Variables

Window Renovation Schedule Variables			
Component	**Time**	**Amount**	**Total**
Demo Existing Windows	200 S.F./Day	2,220 S.F.	12 Days
Install New Windows	90 S.F./Day	2,572.5 S.F.	29 Days

Table 16: Window Renovation Schedule Variables

Costs:

When possible, actual equipment price information was used in the cost estimate for the GSHP system. When information was not available, the latest versions of RS Means were used. Table 17 shows the cost breakdown for the Ground Source Heat Pump system.

GSHP System Cost	
Component	**Cost ($)**
Bores	47,408
Piping	37,950
Grout	5,995
Pumps	28,390
Heat Exchanger	3,000
Removed Equipment Cost Savings	-71,470
Total	51,273

Table 17: Ground Source Heat Pump System Cost

As shown in Table 17, there is a significant amount of savings attributed to the removal of equipment. As stated earlier, the chiller for Building E was able to be drastically reduced in size. This accounted for the largest portion of the savings. Additionally, the chilled water pumps which were installed as part of the renovation are not needed anymore, as new ones were selected as part of the GSHP system. This cost could be reduced even more if full redundancy of the pumps is eliminated from project.

RS Means was solely used to determine the cost of the window replacement as actual cost information was not available. This had to include the cost of removing the existing windows as well as the cost of the new windows. Table 18 shows the cost breakdown for the window renovation.

Window Renovation Costs	
Component	**Cost ($)**
Demo Existing Windows	2,354
Install New Windows	48,492
Total	50,846

Table 18: Window Renovation Costs

System Impact:

Actual construction schedules for Building E were not available for use. Therefore, the schedule information was calculated for this report and assumptions were made based on their anticipated impact on the critical path. The cost information was able to be integrated into the existing cost estimate and this comparison allowed for the proposed alterations feasibility to be determined.

Neither the window renovation nor the Ground Source Heat Pump system have significant effects on the schedule because no part of these additions end up on the critical path. The installation of the ground loops takes place outside of the building as site work, so it can occur simultaneously with the equipment replacement in the buildings, without interruption. With this system, there is also a chiller which needs to be installed, but this chiller can simply replace the installation of the original chiller on the schedule. The new pumps and heat exchanger that need to be installed in the mechanical room can be added to the schedule at a point after the renovation's new heating water pumps and glycol heat exchanger are installed, and work is proceeding in another area of the building. The window renovation has more of a potential to disrupt the schedule because its construction takes place in the building. However, the window demolition and installation in corridors can be worked around the other construction in the building and the amount of work beyond the window renovation that takes place in the gymnasium is limited. There is approximately 170 L.F. of ductwork that will be installed at the ceiling. Based on a duct installation time from another building on campus of 30 L.F./Day, the ductwork should be installed after only 6 days. This is extremely small compared to the total length of the project and leaves plenty of time for the new gymnasium windows to be installed. Figures 18 & 19 detail a rough schedule of the calculated parameters.

	Task Name	Duration	Start	Finish	Predecessors	R
1	Drill Ground Bores	28 days	Mon 5/3/10	Wed 6/9/10		
2	Install Ground Loop Piping	28 days	Tue 5/4/10	Thu 6/10/10	1SS+1 day	
3	Grout Boreholes	28 days	Wed 5/5/10	Fri 6/11/10	2SS+1 day	
4	Install Headers	17 days	Thu 5/6/10	Fri 5/28/10	3SS+1 day	
5	Install Pumps	6 days	Mon 5/17/10	Mon 5/24/10		
6	Install Heat Exchanger	1 day	Tue 5/25/10	Tue 5/25/10	5	
7	Demo Existing Windows	12 days	Mon 5/3/10	Tue 5/18/10		
8	Install New Windows	29 days	Tue 5/4/10	Fri 6/11/10	7SS+1 day	

Figure 18: GSHP & Window Renovation Schedule

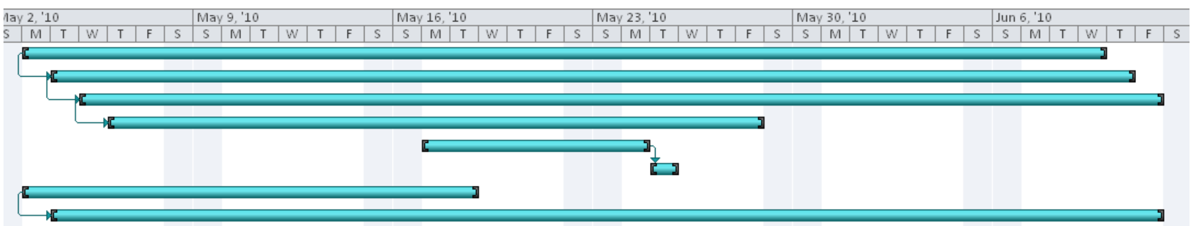


Figure 19: GSHP & Window Renovation Gantt Chart

As seen in the schedule, each step of the ground loop installation process is dependent on the step before it. However, there is only a 1 day lead time for each step to ensure there is enough progress to allow the next step to begin. For the pump and heat exchanger installation, 2 week's time was allowed for crews to complete the installation of the heating water pump and heat exchanger in the mechanical room.

Both system alterations save energy, and therefore money, but in order to determine the feasibility of the systems, the first costs and lifecycle costs need to be examined. New aluminum windows will have no operation or maintenance costs once installed, so until the school deems that a replacement is necessary life-cycle costs can be ignored. As stated earlier, the 411,586 kBTU/year of energy savings for the heating system is entirely caused by the window replacement. In addition, the windows accounted for 25,240 kBTU/year of the total 127,047 kBTU/year in energy savings to the cooling system. Based on BG&E's energy rates listed earlier in Table 3, a total annual savings of $5,261.35 was calculated. This results in a simple payback period of 9.7 years for the $50,846 window renovation.

The Ground Source Heat Pump system has operating costs associated with it, but these were included in the energy reduction calculations from before. The GSHP system was only considered and sized for Building E's cooling system, so the remaining savings of 101,807 kBTU/year results from the reduction in energy usage that would have been used by resized or eliminated equipment. Once again, using the energy rates for BG&E, a total annual savings of 3,012.36 was calculated. With an initial cost of $51,273, the simple payback period comes to 17.1 years. Like the windows, there will come a time when the pumps or other associated equipment needs replacement, but research and trends have shown that this is around the 20 year mark, after the payback period is over. If both of these systems are considered together, then the first costs and energy savings can be combined to reach a total first cost of $102,119 and maximized annual savings of $8,273.71. This averages the payback period to 12.3 years.

Conclusion

The current mechanical renovation to Glen Burnie High School successfully met the challenge of replacing the original equipment while maintaining compatibility with existing equipment and energy sources and not reducing usable space. Overall, the operation of the building's mechanical system adequately satisfied the required standards of supplying the heating and cooling needs to the buildings and maintaining occupant comfort and controllability. For a basis of comparison, a Ground Source Heat Pump system was designed to replace the air-cooled chiller system that was selected for the current renovation. Based on the available ground area on the campus, a GSHP system is a practical fit that is quickly becoming a popular choice with institutional buildings. Ground loops were sized to meet 105 tons of the required 120 tons and installed under the baseball field next to Building E. This allowed for a major reduction in the size of the chiller from 155 tons to 20 tons. As a trade-off, new pumps were installed to circulate the ground water and a new heat exchanger was needed to cool the building's chilled water supply.

Because Building E has not had any recent window replacements, an architectural breadth consisting of replacing the existing windows with newer Insulating Glass Units was performed. In addition, windows were added to the previously windowless Southern façade and a new sing strip window pattern was designed for the gymnasium. This matched other windows of the building and gave the façade a more modern look. The new windows performance had an effect on the HVAC design and the lighting of the spaces due to the increase in available ambient light. Overall, the renovation was able to significantly reduce the heating and cooling loads of the building by reducing summer season heat gain and winter season heat loss.

An evaluation of the changes to the schedule and cost estimate associated with the GSHP system and window renovation was performed as a construction management breadth. Neither the window renovation nor the Ground Source Heat Pump system had an effect on the construction schedule because neither is associated with the critical path of the renovation. When removed equipment savings are considered, the costs of both alterations are roughly the same at $50,846 and $51,273 for the window and GSHP systems, respectively. Based on the energy rates for Glen Burnie High School and the associated savings, payback periods of 17.1 years for the GSHP system and 9.7 years for the window renovation were calculated. It is recommended that both alterations be considered together. This results in a total cost of $102,119 and annual savings of $8,273.71 which averages the payback period to 12.3 years.

List Of Figures

List Of Tables

References

2007 ASHRAE Handbook - HVAC Applications

2008 ASHRAE Handbook - HVAC Systems and Equipment

2009 ASHRAE Handbook - Fundamentals

2011 RS Means - Various

ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality

ASHRAE Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings

Bell and Gossett Pump Catalogs

Bid Documents and Project Specifications for Glen Burnie High School Buildings D, E & F

LEED 2009 For New Construction and Major Renovations

McQuay Geothermal Heat Pump Design Manual

Pacific Pump and Power HDPE Friction Loss Data Sheet

Trane Product Catalogs

The United States Department of Agriculture Natural Resources Conservation Service

Acknowledgements

Sam Kulceski, and the rest of the design team at JMT who worked on Glen Burnie High School.

AACPS for their permission to use their buildings.

My thesis advisor, Dr. Bahnfleth.

The Penn State AE faculty for all of their help and support throughout my education.

My fellow 5th year classmates.

Appendix A

File:GSHP.EES 3/25/2011 5:28:51 PM Page 1
EES Ver. 8.740: #1610: For use by students and faculty in Architectural Engineering, Penn State University

Parameters

Negative values are for cooling

$d_b = 0.25$ [ft]

$q_a = -1.26 \cdot 10^6$ [BTU/hr]

$q_{lc} = -1.26 \cdot 10^6$ [BTU/hr]

$W_c = 50000$ [BTU/hr]

$PLF_m = 1$

$R_p = 0.09 + 0.02$

Temperatures

$t_g = 57$

$t_{wi} = 60$

$t_{wo} = 52$

$t_p = -3.9$

FOURIER NUMBER CALCULATION

Time of Operation

$\tau_1 = 3650$ [days]

$\tau_2 = 3680$ [days]

$\tau_f = 3680.25$ [days]

$\alpha = 1$ [ft^2/day]

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

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

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

EFFECTIVE THERMAL RESISTANCE CALCULATIONS

$G_f = 1.04$ [dim]

$G_1 = 0.66$ [dim]

$G_2 = 0.29$ [dim]

File:GSHP.EES 3/25/2011 5:28:51 PM Page 2
EES Ver. 8.740: #1610: For use by students and faculty in Architectural Engineering, Penn State University

$k_g = 1.02$

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

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

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

Short Circuit Losses

$F_{sc} = 1.02$

BOREHOLE LENGTH CALCULATION

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

SOLUTION
Unit Settings: Eng F psia mass deg

$\alpha = 1$ [ft²/day]	$d_b = 0.25$ [ft]
$F_{o1} = 1936$	$F_{o2} = 16$
$F_{of} = 235536$	$F_{sc} = 1.02$
$G_1 = 0.66$ [dim]	$G_2 = 0.29$ [dim]
$G_f = 1.04$ [dim]	$k_g = 1.02$ [Btu/hr*ft*Degrees$_F$]
$L_c = -27246$ [ft]	$PLF_m = 1$
$q_a = -1.260E+06$ [Btu/hr]	$q_{lc} = -1.260E+06$ [Btu/hr]
$R_{ga} = 0.3725$	$R_{gd} = 0.2843$
$R_{gm} = 0.3627$	$R_p = 0.11$
$\tau_1 = 3650$ [days]	$\tau_2 = 3680$ [days]
$\tau_f = 3680$ [days]	$t_g = 57$ [F]
$t_p = -3.9$ [F]	$t_{wi} = 60$ [F]
$t_{wo} = 52$ [F]	$W_c = 50000$ [BTU/hr]

6 potential unit problems were detected.

KEY VARIABLES
$L_c = -27246$ [ft]

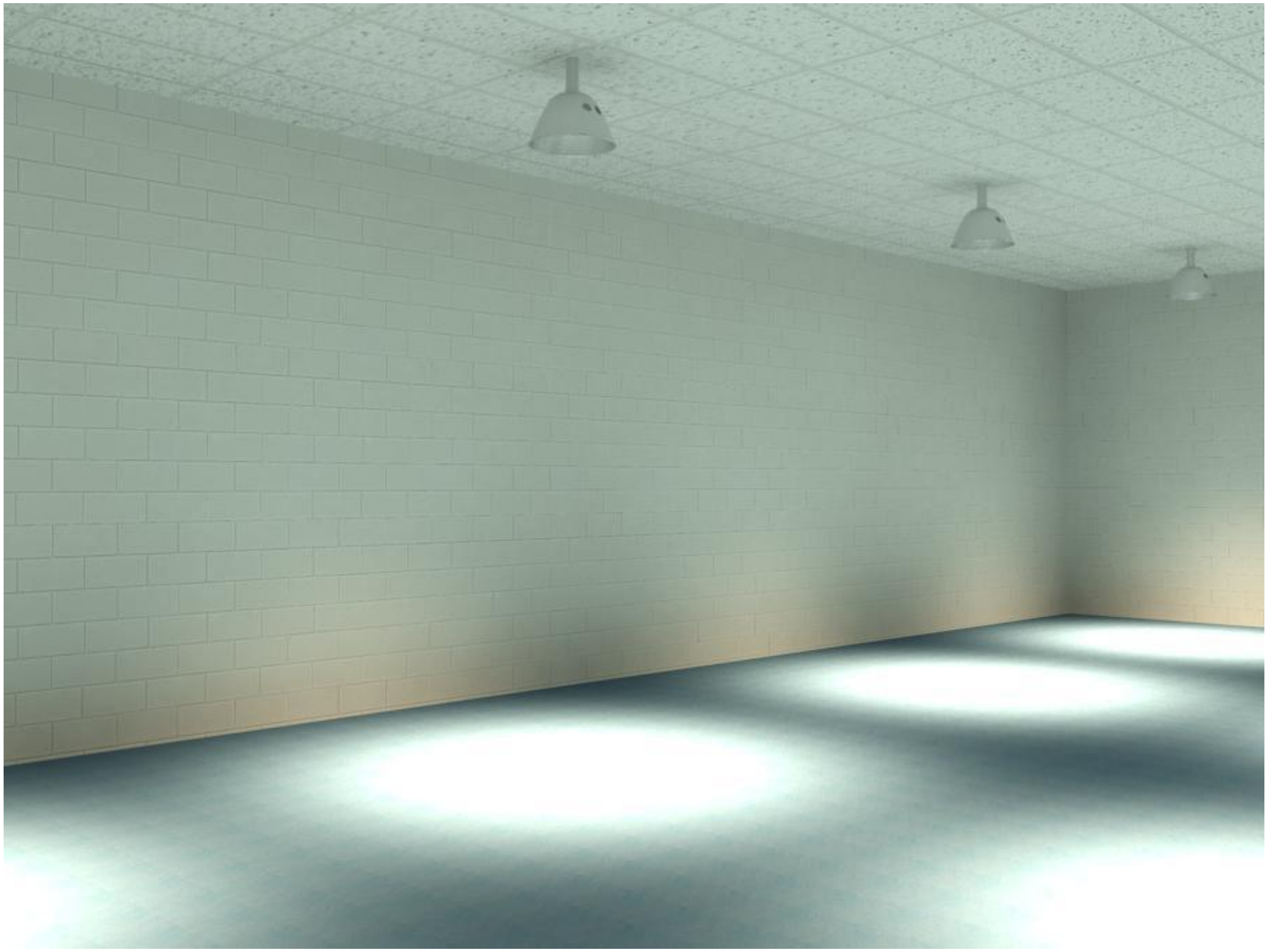
Appendix B

Building E Gymnasium West Before

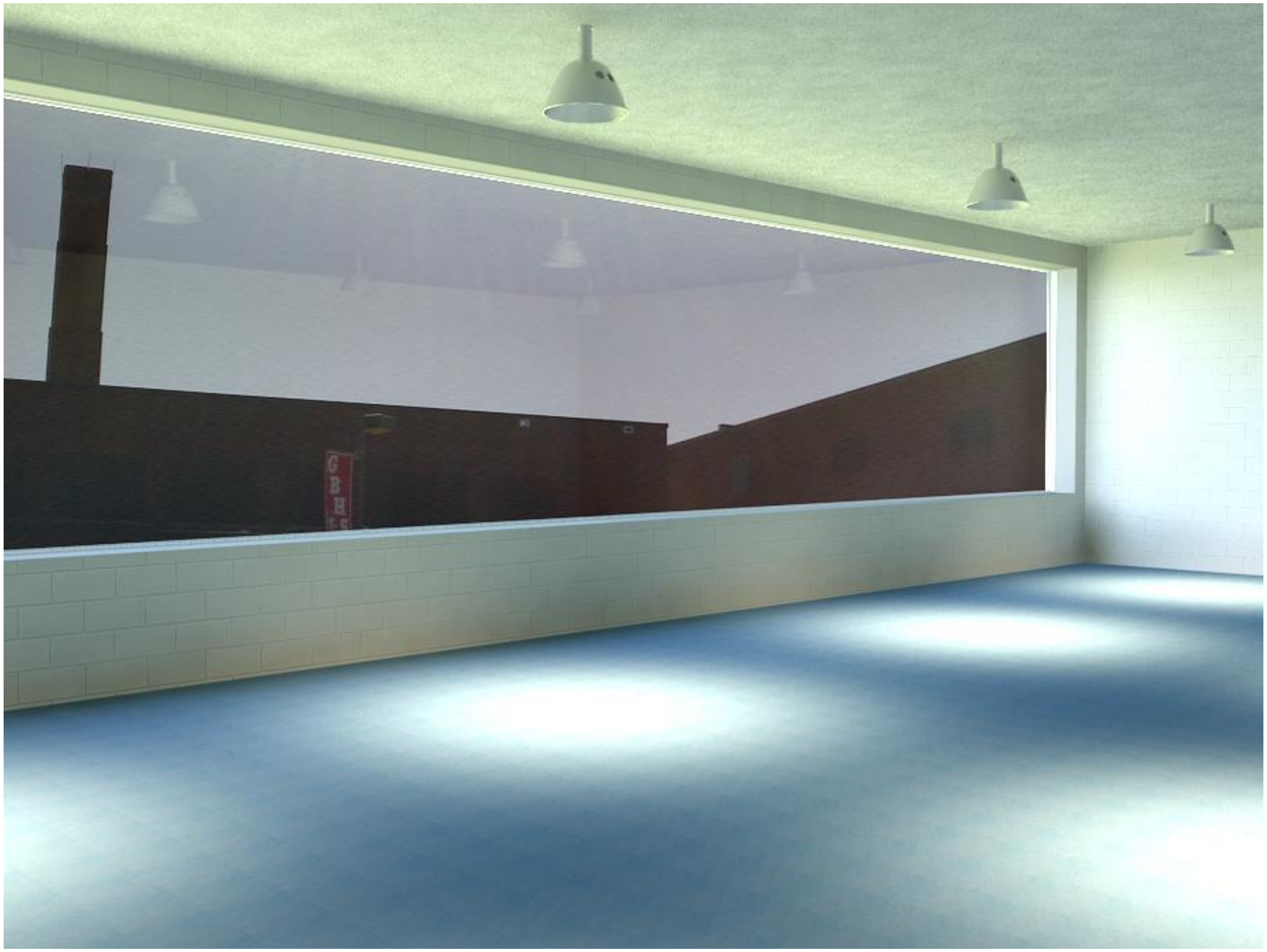
Building E Gymnasium West After

Building E Gymnasium East Before

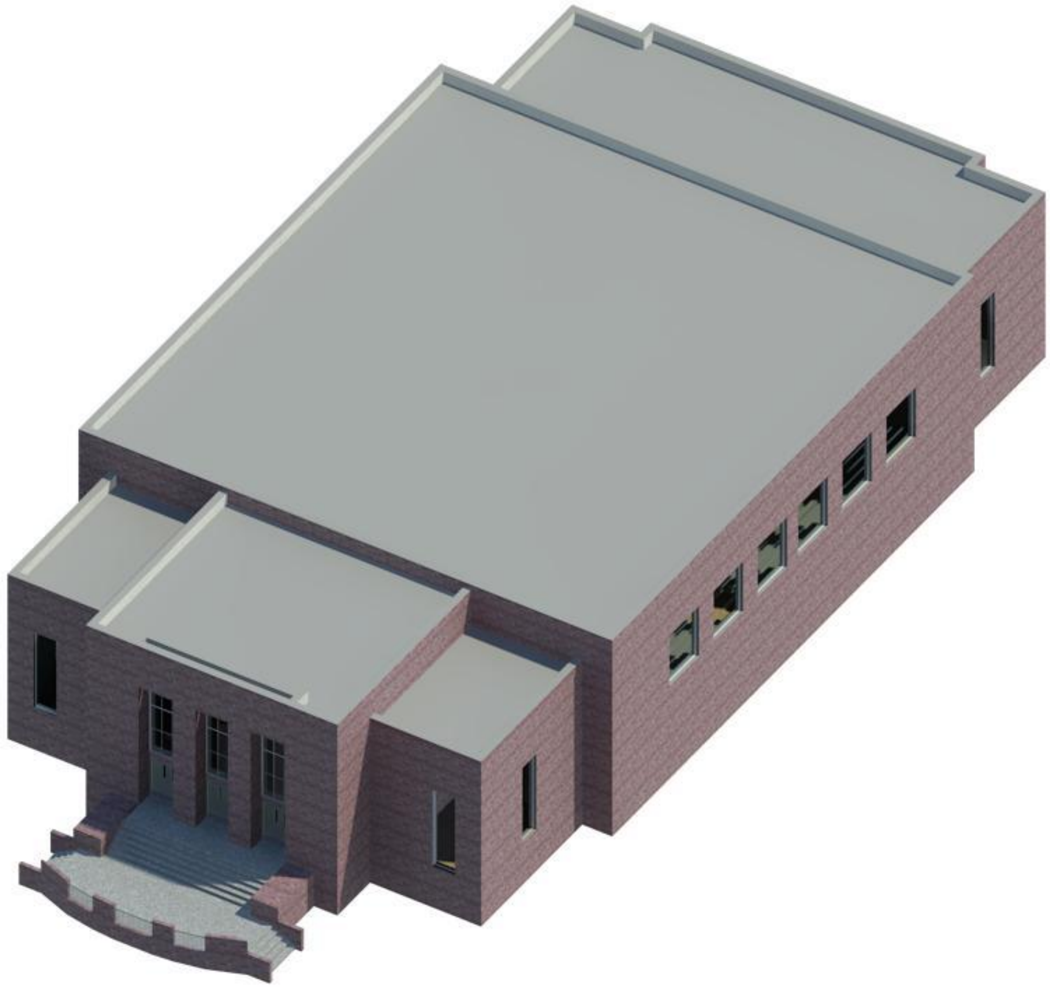
Building E Gymnasium East After



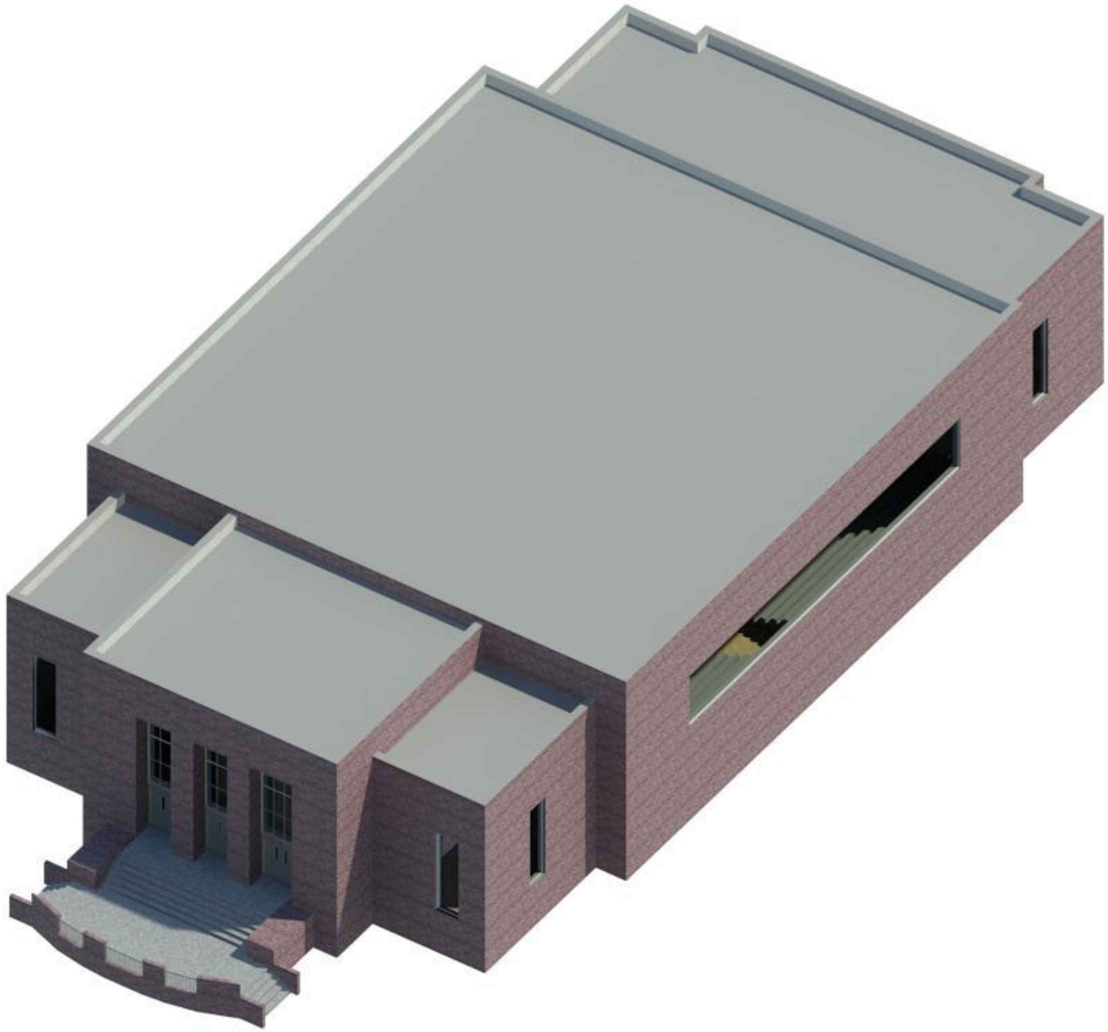
Building E Gymnastics South Before



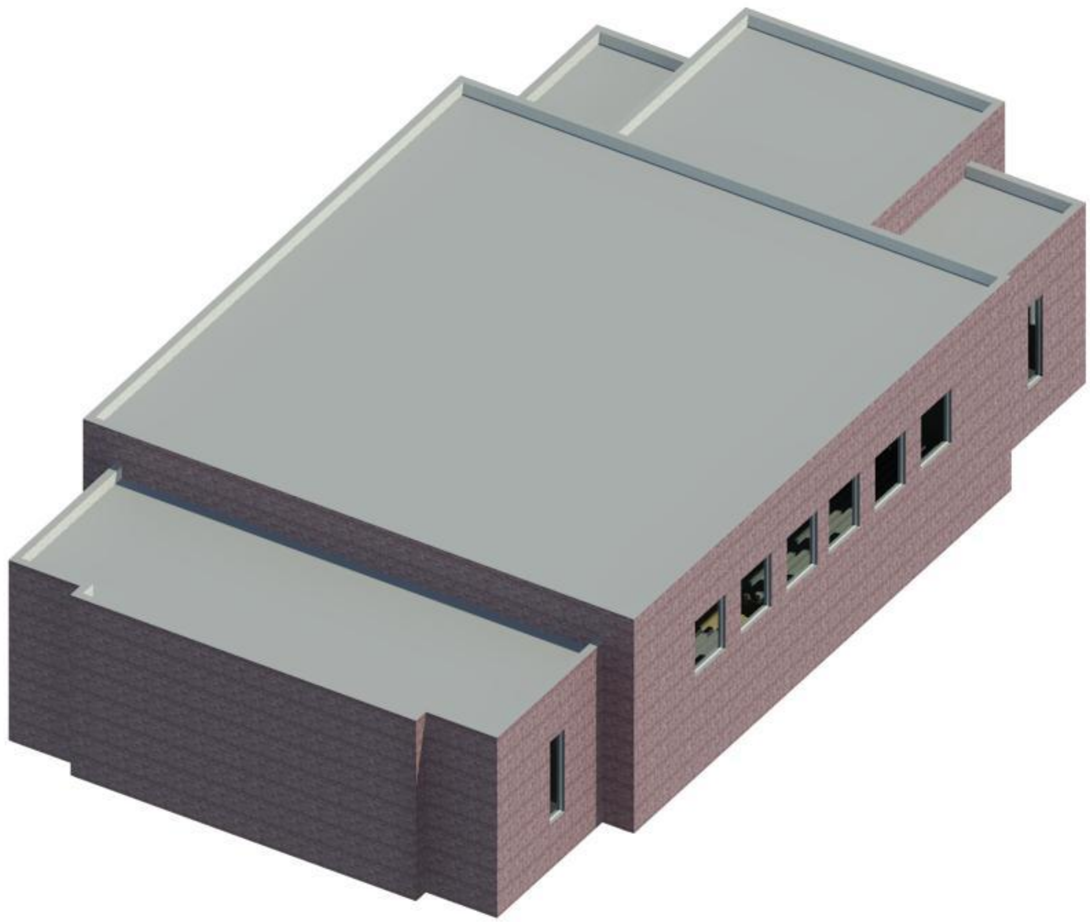
Building E Gymnastics South After



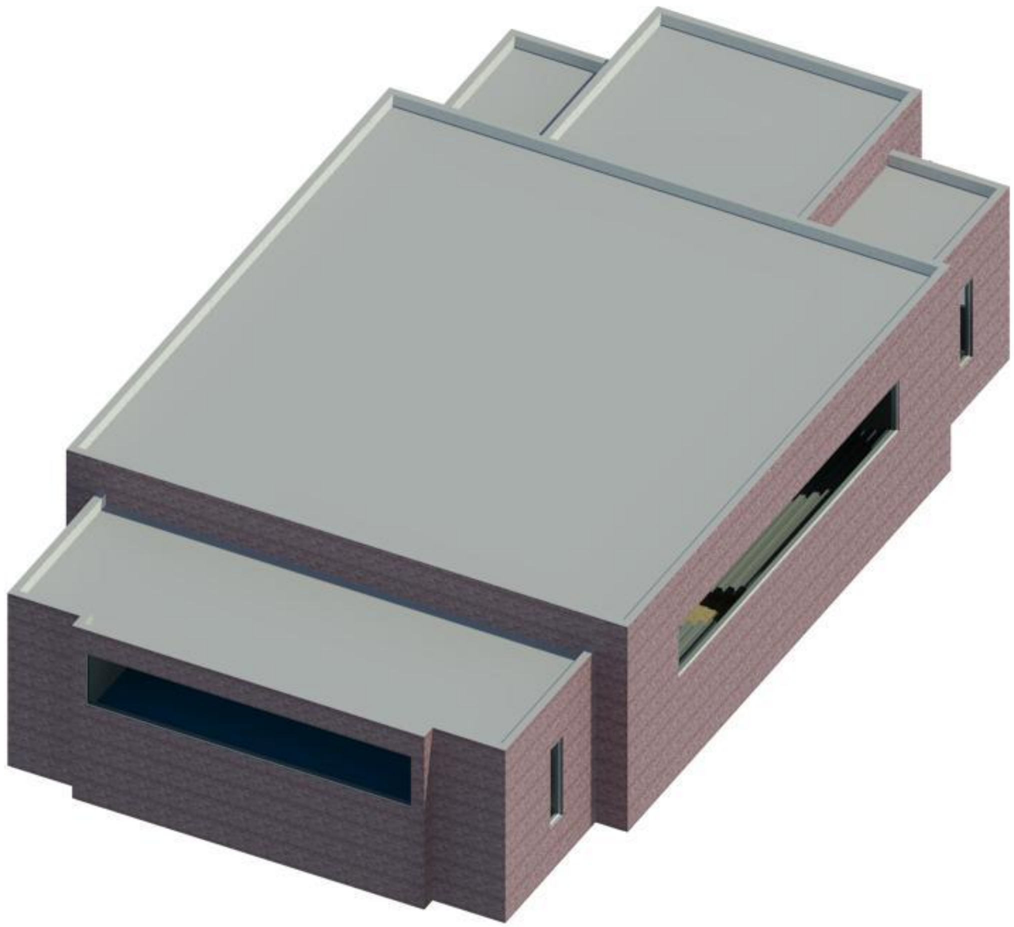
Building E North & West Façades Before



Building E North & West Façades After



Building E South & East Façades Before



Building E South & East Façades After