Grunenwald Science and Technology Building

Clarion University- Clarion, PA

AE 482 Mechanical Final Report:

System Alternatives

Shane Helm
The Pennsylvania State University
Architectural Engineering- Mechanical
Advisor: Dr. Jelena Srebric

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Executive Summary

The HVAC systems that were implemented in the Grunenwald Science and Technology Building provide innovative designs which resulted in an energy efficient building. The design engineers faced many challenges in the design to meet the efforts of Clarion University to achieve a LEED Gold or Platinum rated building. In this report, the original designs of the mechanical systems are evaluated, critiqued, and a redesign of the buildings systems is accomplished. The redesigns that were done in the Grunenwald Science and Technology Building were than compared to that of the original design.

The mechanical system does use sustainable ideas and energy consumption reduction as a basis for the initial design approach. The building does implement 5 VAV AHU's, 3 of which are 100 percent outdoor air, and the other 2 are standard VAV systems that use an economizer with CO2 measurement controlling the damper for outside air. The Grunenwald Science and Technology Building uses (2) 250 ton centrifugal chillers which are water cooled by 2 cooling towers. Hot water is produced by passing the campus generated steam through a plate and frame heat exchanger with water, and the water is used in the pre-heating and heating coils of the AHU's.

The Alternative Designs for the building include the implementation of a DOAS with parallel systems of radiant ceiling panels, active chilled beams, and passive chilled beams, and Geothermal Heat Pumps. The parallel systems ceiling area of the DOAS system was found to be only practical for the implementation of active and passive chilled beams, as the required ceiling area for the radiant ceiling is greater than that of the available area due to the lighting system and the diffusers used. The energy savings for the passive and active chilled beams were found using Trace 700 to be $13,177 and $10,284, respectively. The passive chilled beams had a payback period of 2.48 years while the payback period for the active chilled beams was calculated to be 6.45 years. The Geothermal heat pump was designed utilizing equations to calculate pipe length from Chapter 32 of the 2007 ASHRAE Handbook HVAC Applications. The Geothermal Heat Pump associated energy savings were found using Trace 700 to be $26,983 and $24,807 for different efficiency fluids in the ground source pipes. The payback periods were found to be 27.28 years for the higher efficient fluid compared to 29.67 for the standard fluid.

The Construction Management Breadth consists of the placement and possible schedule for the installation of the geothermal well field. The placement is an optimization of the borehole depths, number of boreholes, and the size required for the field. The cost for the installation of the geothermal system was found using RS Means cost data.

The Architectural Breadth consists of designing fixed horizontal shades on the South and Southwest Façade to the optimum depth in order to block the direct summer solar beams and allow the direct winter solar beam into the building. Sample spaces were constructed in Revit with the solar shade to compare the direct solar beam in the space for the two facades for the winter solstice, summer solstice, and equinoxes.

Project Overview and Existing Conditions

Project Team:

Owner:	Clarion University
Architect:	Bohlin Cywinski Jackson
General Contractor/CM:	L.S Fiore
Mechanical Engineer:	Brinjac Engineering
Electrical Engineer:	Brinjac Engineering
Plumbing Engineer:	Brinjac Engineering
Structural Engineer:	Brinjac Engineering
Civil Engineer:	Brinjac Engineering
IT/Telecom:	Brinjac Engineering
Fire Protection:	Brinjac Engineering

Architecture:

At Clarion University the overall design goal for the Grunenwald Science and Technology Building was to focus on sustainability, but to allow for collaboration between departments in their studies. With the building built to be sustainable, it is also itself supposed to be a model for sustainable design for the students and faculty at Clarion University. Located at the center of the Clarion University campus, it allows for all students to be able to benefit from this project in using the laboratories and classrooms. The new Science and Technology Building replaces the outdated and non-flexible layout employed by the Pierce Science Building constructed in 1968.

The Clarion University Science and Technology Building provides new state of the art laboratories, while increasing the needed classroom and office space for the faculty and students as the university continues to grow. As designed and laid out, the laboratories and classroom spaces are to be flexible to provide separate configurations for each different area of study located within the Science and Technology Building. Laboratories and Classrooms are located on the first three levels in two separate wings accessed from the central entrance. The building program is approximately 50% laboratory, 20% classroom, and 10% office space. In the center of the building, the newly renovated planetarium was preserved from the previous Pierce Science Center along with a large lecture hall located on the first floor, directly below the planetarium. Located in the building are offices for the Academic Department Chairs in the following areas of study, Chemistry, Biology, Mathematics, and Physics.

Building Enclosure:

The building facade uses brick masonry along with recycled pre-patina colored copper to accent one another. Curtain wall systems are used to establish the entrances of the building, which are made of aluminum and glass, from the ground level to the third floor. Throughout the facade large fenestrations are used to increase the natural daylight obtained in the classrooms and seminar rooms.

The material used on the roof is a white EPDM, which increases the amount of heat that is reflected away from the Science and Technology Building. The use of the material can be seen in the Figure C above, the material is below the extra mounts for future expansion of solar photovoltaic panels.

Sustainability Features:

Clarion University's Science and Technology Building was designed to meet LEED certification, obtaining a LEED Silver rating upon completion. The use of recycled materials in the construction of the building was done in the facade with the pre-patina colored copper, and the reuse of wood in shelving systems throughout the building. Floors throughout are highly polished concrete rather than carpet or tiling. Incorporated into the design of the building is a 65 kWe turbine, which operates in conjunction with 26 kWe solar photovoltaic panels, located on the roof of the building. These two together are used to provide electricity to the building and heat produced from the turbine will be recovered and used within the buildings heating system. The use of a rainwater collection system supplies non-potable lab water and urinal water. Building automations allow for energy efficient lighting and HVAC design in the classrooms and offices.

Construction:

The construction process included the demolition of the previously existing building on the site, along with the preservation and renovation of the 2 story observatory located at the center of the new Science and Technology Building. The construction process began in October 2006 and finished up in June 2009 with a project delivery method of Design-Bid-Build.

Electrical System:

The electrical utility is connected through an existing primary electrical service manhole, on site of the Science and Technology Building. The service enters weatherproofed double ended switchgear with a 15 kV rated switch; the service is then stepped down from 12470 V using a 750

KVA oil filled transformer to 120/208 3 phase and from 12470 V using a 2500 KVA oil filled transformer to 277/480 3 phase. Each then enters the building through a 3000 A main breaker and is distributed throughout the building. The 120/208 service is used for the lighting and receptacle loads in the building while the 277/480 service is used to operate the AHU, chillers, and the life safety panels. The life safety is stepped down after the Main Life safety panel from 277/480 to 120/208 using both a 75 KVA and a 112.5 KVA dry type transformer in order to serve the lighting and stand by loads in the building. The entire Science and Technology Building is backed up by a Natural Gas Emergency Generator, 250 KW 277/480 3 phase, 4 wire. The generator has a 500 A- 3 pole line circuit breaker and is located outside in a weatherproof enclosure.

Lighting System:

The lighting system consists of many indirect/direct pendant dual lamp and single lamp types using both T5HO and T8 fluorescent lamps in the classrooms, labs, and some offices. In the Science and Technology Building, recessed lighting is used with 2' x 4' 2 lamp troffer with both T5HO and T8 fluorescent lamps, and recessed down lights using compact fluorescent lamps. LED's are used for the emergency exit signs located throughout the building. The use of Daylight sensors (photocells) allows for the fluorescent lights to be dimmed when the natural light is high or for the fluorescent lights to be raised when natural light is low in a space. All classrooms, labs, and offices are equipped with occupancy sensors which will shut the lights off in that particular room if no movement is detected for 10 minutes.

Structural System:

The foundation caissons, piers, walls, and slab on grade are all cast-in-place concrete. The caissons rest on medium hard to hard bedrock that is present underneath the site approximately 4-10 feet below the first floor grade of the building. The foundation, piers, walls, elevated slabs, slab on grade, and stairs will use 4000 psi concrete at 28 days. The slab on grade is 4" Normal weight concrete, reinforced with 6 x 6- W2.9 x W2.9 welded wire fabric over a vapor barrier and 4" crushed stone. Elevated slabs are 4-1/2" concrete slab on 20 gage, 2" deep galvanized steel floor deck, reinforced with 6 x 6- W2.9 x W2.9 welded wire fabric. The roof slab is 3-1/2" concrete slab on 18 gage, 3" deep galvanized composite steel floor deck, reinforced with 6 x 6- W2.9 x W2.9 welded wire fabric.

The two wings are steel construction which consists of columns ranging in size from W8x28 to W8x48 and W10x49 to W10x100. The steel girders in the Northeast wing vary in size from W21x44 to W21x83 with beams varying in size from W18x35 to W18x55. The steel girders in the South Wing range in size with some exterior girders at W18x35 and the rest between

W21x44 to W21x68, with beams increasing in size as follows W12x19, W16x26, and W18x35. Around the stairs and the center of the building the beams and girders vary slightly from those found in the wings of the building. The columns are spliced at the top of the 3rd floor for the penthouse above certain sections of the building. The columns decrease in size to HSS6x6x1/2 to HSS8x8x1/2 or decrease to W8x67. The beams carrying the roof loads range in size from W18x40 to W18x46, with girders varying in size from W21x44 to W21x93 in the NE wing. In the South wing, the beams increase in size as follows W12x26, W16x26, and W18x46, with girders ranging in size from W21x44 to W21x83. The steel construction uses Moment Frame connections.

Fire Protection:

A wet pipe sprinkler system is provided throughout the Science and Technology Building. Provided in each stairwell is a 2-1/2" fire hose valve at the landing of every floor. There are 2 hour rated requirement for shafts and exit stairwells, while also there for separation between the two occupancies B & A-3. There is a requirement for a 2 hour rated system for the floor construction and supporting structure for chemical control zones within the building. The fire alarm system contains manual pull stations, smoke detectors, and water flow detection within the sprinkler system.

Telecommunications:

The project includes the relocation of the Nortel Telephone System, previously housed in the original building on the site. Within the new Science and Technology Building the telecom system will include voice, data, and CATV in all laboratories and classrooms, with only voice and data in offices. A duct bank connects all buildings on the Clarion University campus with fiber optics and cable wires.

Transportation:

The Science and Technology Building contains one passenger elevator along with three stairwells located at the end of each wing and the center of the building (main entrance).

Security:

The control system for the all access controlled and monitoring openings will implement the current campus-wide Johnson Controls CardKey access system in the Science and Technology Building. Access to the elevator will be controlled by the card reader on floor's elevator lobby in order to be able to call the elevator to that particular floor.

Mechanical System Existing Conditions

Introduction:

The Grunenwald Science and Technology Building is a 3-story, 108,560 square foot, university laboratory and classroom building on Clarion University's campus. The building is comprised of approximately 50 percent laboratories, 20 percent classroom, and 10 percent offices. The laboratories are served by a 100 percent outdoor air VAV system, while the other spaces are served by a conventional VAV system. It is designed to achieve a LEED Gold rating through the use of sustainable technologies and innovative design approaches.

Design Objectives and Requirements:

The main design objective for the Science and Technology Building was to focus on sustainability and a reduction in energy consumption while obtaining a LEED certification and meeting the ASHRAE Standards. In order to meet the standards, the building must meet specific energy, ventilation, equipment, and temperature requirements. With these both in mind the designers produced a VAV system using 100 percent outdoor air for the zones handling the laboratory spaces, and used a conventional VAV system for the classrooms and offices. The mechanical system consists of high efficiency chillers and cooling towers, while using the central campus plant steam to pass through a plate and heat exchanger to heat the water used in the heating coils in the systems. The 100 percent outdoor units utilize a glycol runaround coil to pre-treat air entering the AHU's, while the all the systems use energy recovery wheels to pre-treat the air using either the exhaust air or the heat produced by the on-site micro turbine.

Site and Budget:

The site for the Grunenwald Science and Technology Building is located on the campus of Clarion University in Clarion, PA. At Clarion University, the new building was built on the same site as the previous Pierce Science Building constructed in 1968. In the center of the building, the newly renovated planetarium was preserved from the previous Pierce Science Building along with a large lecture hall located on the first floor, directly below the planetarium. The building sits on the same footprint of the previous building and the location of a faculty parking lot as it did not add more impermeable surfaces than what was previously on the site. The building was awarded for $34 million, which was within the established budget for the university. One item that was nearly left out due to budget concerns was the micro turbine as the calculated payback period exceeded 30 years. The university was able to obtain a government grant for the micro turbine allowing the design team the ability to use this technology with no cost to the university who began seeing savings upon installation into the building.

Mechanical System Initial Cost:

The estimated final cost including change orders for the mechanical system for the Grunenwald Science and Technology Building was $6.25 million. This number includes the plumbing that is associated with the HVAC systems. The calculated cost per square foot of the building floor area is $57.57. The total cost of the mechanical system accounts for 18.4 percent of the total construction cost for the building.

Energy Sources:

The campus does utilize district steam which is produced at a central plant that is delivered to the building and is passed through a plate heat exchanger with water that then runs through the heating coils. The electricity for the campus is provided by Allegheny Power. The costs were 4.8 cents/kWh for electricity and 1.195 $/therm for the purchased steam from the central campus steam plant, as was used for the analysis for Technical Report Two.

Design Indoor and Outdoor Air Conditions:

Grunenwald Science and Technology Building is located on the campus of Clarion University in Clarion, PA. The city that has similar weather conditions and location to the Science and Technology Building was Erie, PA. The design outdoor air conditions for Erie, Pa were obtained from the ASHRAE Handbook of Fundamentals 2009. The heating design month was July, while the cooling design month was January, and can be seen in the following table. The data was used for the 0.4 percent and 99.6 percent design conditions.

Table 1- Outdoor Air Design Conditions

Summer		Winter
DB (F)	MCWB (F)	DB (F)
85.8	72.7	2.9

The indoor design conditions were obtained from the design documents and can be seen in the following table.

Table 2- Indoor Air Design Conditions

Cooling Set Point	75 F
Heating Set Point	68 F
Relative Humidity	50%

Ventilation Requirements:

All (5) systems were analyzed with the results for each of the systems contained within Appendix A and Appendix B. The calculations were completed using the ASHRAE Standard 62.1 User Manual, which includes a Microsoft Excel based spreadsheet. The spreadsheet has inputs such as; type of space, assumed population, and square footage of the room. For the purpose of this study all spaces were analyzed for the (3) 100 % outdoor air units. The ventilation rate was found to always meet the minimum requirement of outdoor air provided to each space except for two spaces which are labeled as the critical spaces for the analysis of AHU-1, 2, 5. The two spaces that do not comply with Section 6 are a Clean Room and Cold Room as they do not receive the minimum ventilation rate.

The VAV systems were analyzed using the same process as the 100 % outdoor air units, and all spaces in the VAV system comply with the minimum ventilation rates stated in Section 6 of ASHRAE Standard 62.1- 2007. The ventilation system efficiency (E_v) can be found on in the spreadsheet highlighted in blue for the VAV system. The VAV systems as designed is greater than the CFM required of outdoor air when the calculation requires 11,500 CFM, therefore it complies with Section 6. This can be seen in the Table 3, that all of the air handling units do comply with the ventilation requirements.

Table 3- Ventilation Requirements

Unit	Design Max CFM	Design Min OA	ASHRAE 62.1 Min OA	Compliance
AHU-1	40,890	100 percent	100 percent	Achieved
AHU-2	41,735	100 percent	100 percent	Achieved
AHU-3	27,500	13,000 CFM	9,500 CFM	Achieved
AHU-4	24,000	4,553 CFM	2,000 CFM	Achieved
AHU-5	22,450	100 percent	100 percent	Achieved

Annual Energy Use:

The following table shows the comparison in energy consumption between the design calculation and the block load model calculation. All the data in the table was obtained from the LEED submission for the design values and Trane Trace 700 for the modeled loads.

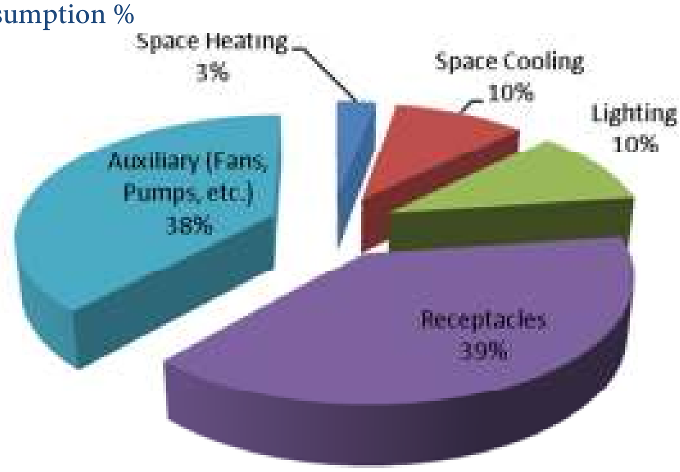
Table 4- Annual Energy Consumption Comparison

Energy Use	Modeled	Designed
Space Heating	334,000 (kBtu)	448,521 (kBtu)
Space Cooling	289,042 (kWh)	252,002 (kWh)
Auxiliary (Fans, Pumps)	1,132,269 (kWh)	1,188,325 (kWh)
Lighting	302,358 (kWh)	558,189 (kWh)
Receptacles	1,153,669 (kWh)	608,648 (kWh)
Cogeneration	Not Modeled	-1,515,247 (kBtu)

The differences seen in the receptacle consumption may be due to the assumptions made in the W/sf that were used while the designer had specific data on the equipment that was used in each space.

The cogeneration was not modeled in Trace due to user knowledge of modeling a micro turbine and photovoltaic solar panels in order to be able to calculate an energy savings from these energy producing products. The largest producer of electricity in the Science and Technology Building is the receptacles followed by the fans and pumps for the systems in the buildings. The space heating consumptions differ due to difficulty modeling the heating system with the use of a plate frame heat exchanger between steam and water for use in the heating coils. The cogeneration is on site produced energy that will be used for heating and electricity throughout the building. The figure below shows the energy consumption percentage for each use for the Science and Technology Building. The Receptacles use 39 percent, while the Auxiliary energy accounts for 38 percent of the energy consumption each.

Figure 1- Energy Consumption %

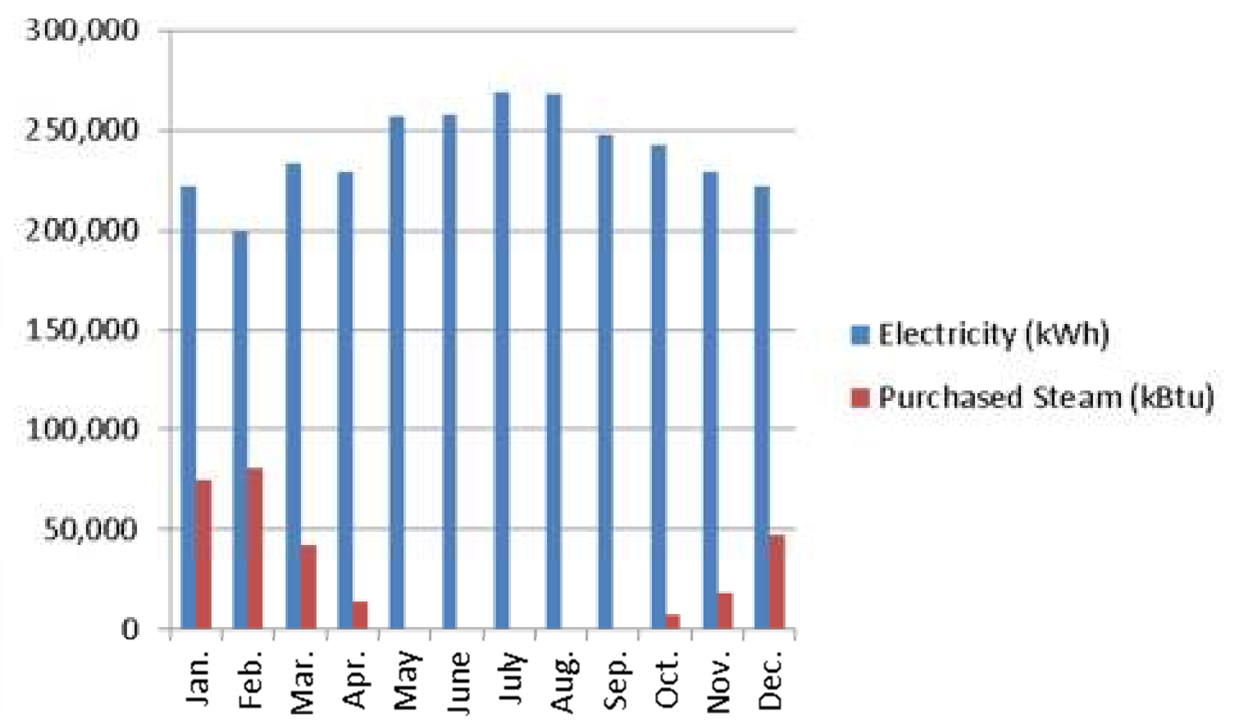


Using Trane Trace 700 the monthly energy consumption was calculated for electricity use and purchased steam total, these values can be seen in Table 5 and in Figure 2. Figure 2 is a graphical representation for usage per month.

Table 5- Monthly Energy Consumption Electricity & Purchased Steam

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Electricity (kWh)	222,089	199,515	233,795	229,135	256,651	257,323	269,448	268,688	247,377	242,935	228,835	222,047
Purchased Steam (kBtu)	75000	80400	42500	14100	900	400	200	400	500	7700	18500	47400

Figure 2- Monthly Energy Consumption



As can be seen in the graph the purchased steam has a near zero energy consumption during the summer months since it is used for heating only. The electricity is at its highest during the summer months as this is the peak cooling load for the Science and Technology Building.

Energy Costs:

The energy cost calculations were done in Trace using the cost rates provided by the designer in the LEED EA CR-1 submission. The cost for the individual energy consumptions can be seen in Table 6, and the percent of total cost is the same as the energy consumption percentage. This occurs since all the energy uses are based on the same cost, except for the space heating which depends on the cost of steam and does not affect the overall percentage. The results obtained from Trace are nearly identical to those calculated by the design engineer for total energy cost for electricity and purchased steam as can be seen in Table 7. The percentage of total cost for each use can be seen where receptacles are 39 percent with space heating the lowest percent at 2.8. A monthly cost analysis can be seen in Figure 3 including both the cost of electricity and steam. Table 8 has the calculated cost per month for electricity and purchased steam.

Table 6- Energy Cost per Year Each Load Type

Energy Use	Modeled	Cost	% of Cost
Space Heating	334,000 (kBtu)	$3,996	2.8
Space Cooling	289,042 (kWh)	$13,874	9.8
Auxiliary (Fans, Pumps)	1,132,269 (kWh)	$54,349	38.2
Lighting	302,358 (kWh)	$14,513	10.2
Receptacles	1,153,669 (kWh)	$55,376	39.0

Table 7- Energy Cost Building Total Comparison

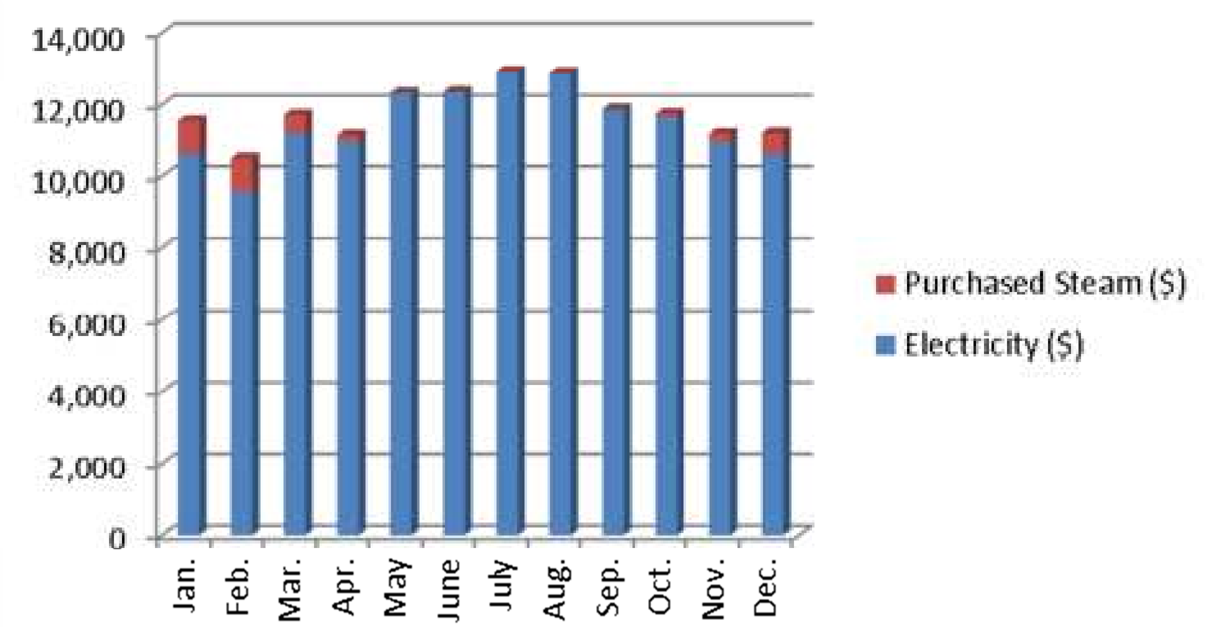
Utility	Modeled Building Energy Cost	Designed Building Energy Cost
Electricity	$ 138,143	$ 134,949
Purchased Steam	$ 3,965	$ 10,893
Total	$ 142,108	$ 145,842
Cost per Square Foot	$ 1.39	$ 1.43

The total energy cost for the building is similar, but individually the electricity is slightly more than as-designed since the receptacles and space cooling have greater energy consumption. The reduced cost of steam is due to the energy consumption of the heating being less than the design value calculated by the engineer. The total cost per square foot for the Grunenwald Science and Technology Building came out to $1.39 similar to the design value of $1.43. The integration of the micro turbine and photovoltaic panels saves on average $6,800 dollars a year as calculated by the design engineers, even offsetting the cost of purchasing natural gas to operate the micro turbine.

Table 8- Monthly Cost Electricity and Purchased Steam

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Electricity ($)	10,660	9,577	11,222	10,998	12,319	12,352	12,934	12,897	11,874	11,661	10,984	10,658
Purchased Steam ($)	896.25	960.78	507.875	168.495	10.755	4.78	2.39	4.78	5.975	92.015	221.075	566.43

Figure 3- Monthly Cost Analysis



The cost for the steam is shown to be nearly negligible compared to the cost for electricity for the entire building. During every month the electricity dominates the cost of the total energy consumed in the building. The highest monthly cost is in July at $12,936, with the lowest monthly cost occurring in February at $10,538.

LEED Assessment for Mechanical System

A LEED assessment was done by the design engineers using LEED-NC 2.1 for the Grunenwald Science and Technology Building. There are two areas of LEED that are relevant to assessing the buildings mechanical system, which are Indoor Environmental Quality, and Energy and Atmosphere categories. LEED-NC 3.0 was used for the evaluation of the criteria based on calculations made by the design engineers. The changes that were made to LEED include an increase in the emphasis on the reduction of energy consumption and greenhouse gas emission for the various credits that can be achieved. The Indoor Environmental Quality (IEQ) has 2 prerequisites and 5 mechanical system applicable areas to earn credits; while Energy and Atmosphere (EA) has 3 prerequisites and 6 areas that possible credits can be earned. The credits that are associated with the mechanical system for IEQ are credit 1, 2, 6.2, 7.1, and 7.2, as the rest are related to construction practices, electric, and day lighting systems.

Indoor Environmental Quality:

IEQ Prerequisite 1requires the design to meet Sections 4-7 of ASHRAE Standard 62.1 and is required for this section, which was met based on the calculations done for the previous version of LEED by the engineers. The calculated values for Technical Assignment 1 were not 100 percent accurate as the engineers did not have two critical spaces that did not meet the ventilation requirements.

IEQ Prerequisite 2 is to prevent or minimize exposure to environmental tobacco smoke (ETS) and is required for this section. This was achieved since the Grunenwald Science and Technology Building is non-smoking.

IEQ Credit 1is the installation of permanent monitoring systems to ensure that the ventilation systems maintain the specified design requirements. This was achieved by installing devices to measure the CO_2 differentials in all of the return ducts for the laboratory, classroom, and office spaces. The measured differential controls the dampers for the economizer and verified through air flow meters in order to maintain the minimum differential. This was worth one point for achieving the credit.

IEQ Credit 2 is to provide additional outdoor air ventilation to improve the indoor air quality; this was not done for the building as this would have increased the energy consumption.

IEQ Credit 6.2 is to provide 50 percent of the building with comfort controls. This was not achieved as the building has set temperature controls for the different spaces, and is an educational building with constant changeover of occupants.

IEQ Credit 7.1 is the design of thermal comfort by meeting the requirements of ASHRAE Standard 55- 2004. The calculations done by the design engineers do comply with the standard, therefore one point can be earned for this credit.

IEQ Credit 7.2 is the verification of thermal comfort in the building. The engineers have put into place a permanent monitoring system to ensure that the thermal comfort designed is being met. This is worth one additional point.

Energy and Atmosphere:

EA Prerequisite 1 is the fundamental commissioning of building energy systems, which is required for EA credits. This was done by the design engineers to achieve this prerequisite.

EA Prerequisite 2 is the minimum energy performance for the building, which was achieved by the design engineers as the building does comply with all the required sections in ASHRAE Standard 90.1-2007 and all energy costs were included.

EA Prerequisite 3 is the CFC reduction in the mechanical system which is achieved since no CFC based refrigerants where used.

EA Credit 1 is the optimization of energy use in the building using the described method used in prerequisite 2. The engineers were able to reduce the energy consumption by 40.9 percent over the baseline design which would earn 15 points for this credit.

EA Credit 2 is the on-site renewable energy percentage. The Grunenwald Science and Technology Building does have photovoltaic panels, and the points for this category range from 1 to 7 based on the percent of the total energy produced. The percent produced by the photovoltaic panels is less than 1 percent therefore no points were earned for this credit.

EA Credit 3 is the enhanced commissioning of the building worth a total of 2 points. The Science and Technology Building will only use basic commissioning practices not achieving this credit.

EA Credit 4 is the enhanced refrigerant management to help prevent the depletion of the ozone, which is achieved since the buildings mechanical system does not use refrigerants.

EA Credit 5 is the measurement and verification of the building energy consumption over time. At this time the 3 additional points were not required, therefore the engineers did not pursue them for their LEED certification.

EA Credit 6 is the owner's choice to purchase over 35 percent of the buildings electricity from renewable resources for at least 2 years. This is worth 2 points, but Clarion University does not plan on entering into a contract to purchase renewable energy.

System Operations

Schematics:

The water sided cooling is shown in Figure 4 through the use of 2 cooling towers, that feed in to the condensers of the centrifugal chillers shown in Figure 5. These two make up the water side cooling schematic while Figure 6 is the water side heating along with the campus steam loop used with the plate and frame heat exchanger.

Figure 4- Cooling Tower Schematic

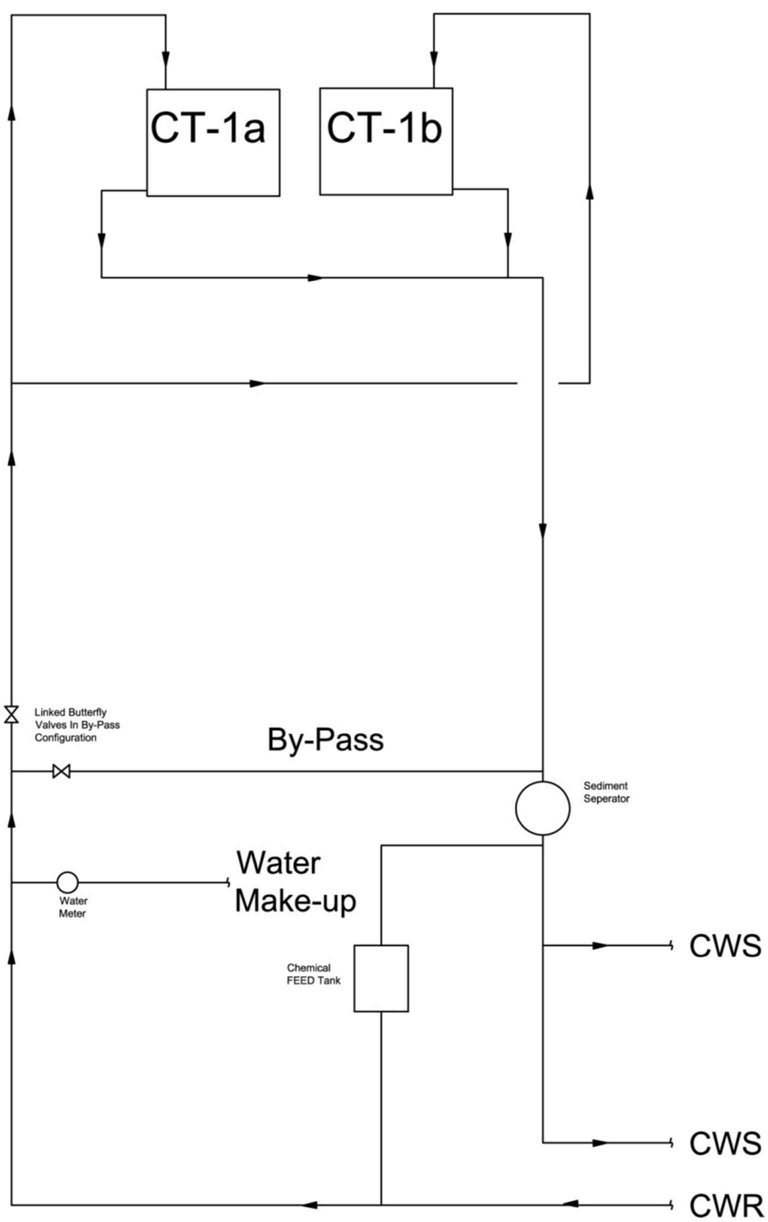


Figure 5- Chiller Schematic

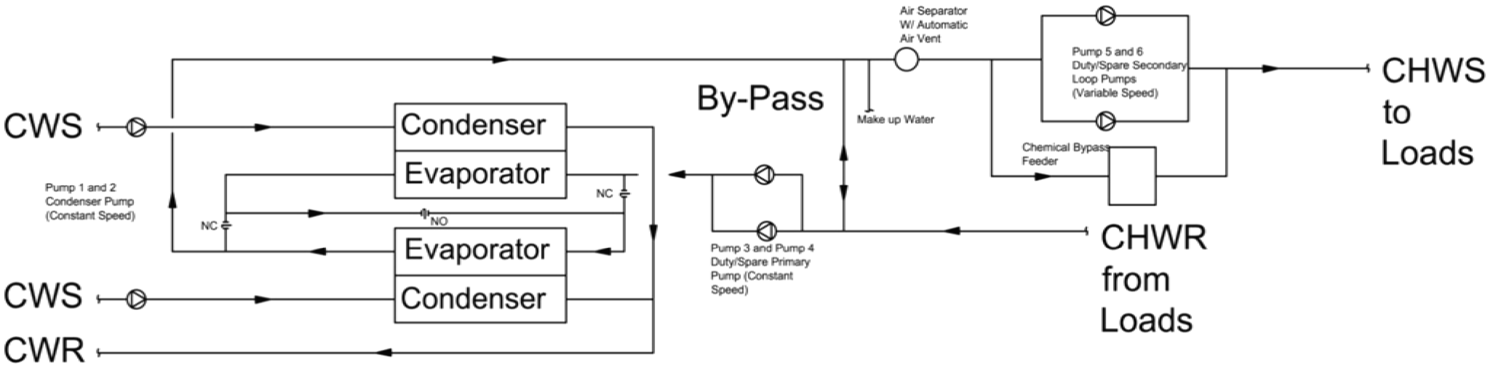
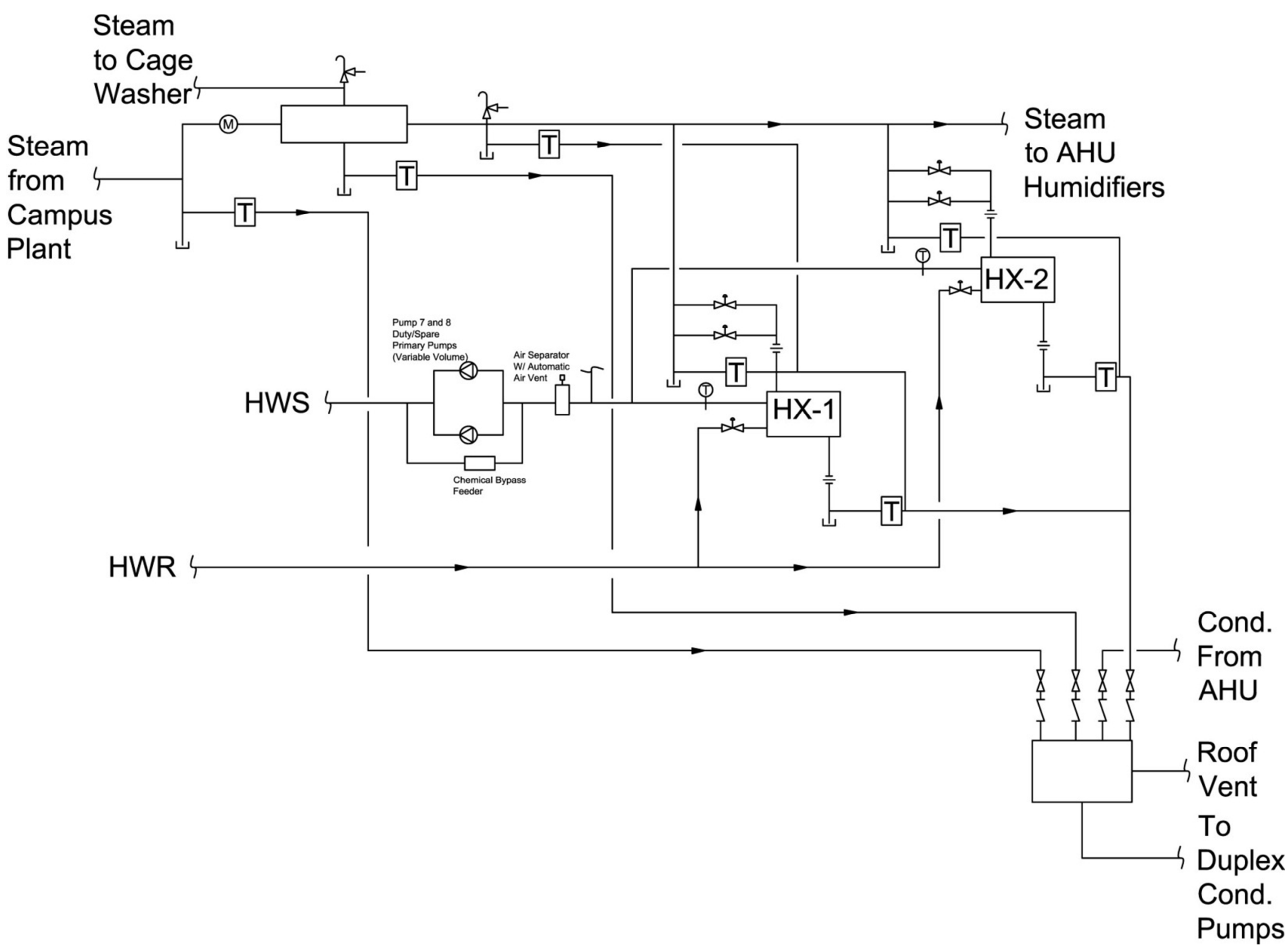


Figure 6- Hot Water & Steam Schematic



Air Side:

The Grunenwald Science and Technology Building utilizes VAV systems for air delivery to zones. All of the VAV terminal units are supplied with air from the modular AHU's that are located on the roof. The use of a BACnet control system allows for the system to start based on the optimum time for heating or cooling associated with the occupancy schedule for the building. The pressure for the building is important to not allow transfer of contaminants from the laboratory spaces, which is controlled by varying the supply and exhaust fans to obtain negative or positive pressure for the correct spaces. The zones use both humidity and temperature sensors that allow the BACnet system to modulate the supply air in either heating or cooling mode. The heating and cooling coils are fed by hot or chilled water which is produced by the processes shown in Figures 2 and 3. Through the use of CO2 meters and flow meters, economizer dampers vary to allow more outside air in as needed to meet the higher CO2 concentrations. This allows for the minimum outdoor air in the building to always be met with additional outdoor air being delivered as required.

The outdoor air for the VAV systems is pretreated by energy recovery wheels that use exhaust air from the two systems in a counter flow to the outdoor air. In the 100 percent outdoor air VAV systems the outdoor air is pretreated by a glycol runaround coil that exchanges heat with the exhaust plumes from the laboratory spaces. The exhaust air from the labs that could contain contaminants is thrown at high velocity so that neighboring buildings or the Science and Technology Building are not affected.

Water Side- Chilled:

The chilled water in the Grunenwald Science and Technology Building is obtained by the use of centrifugal chillers. The chilled water system utilizes a primary/secondary pump flow system, which is shown in Figure 2. The primary pumps on the chilled water system supply the evaporator, while the secondary pumps distribute the chilled water throughout the system to the loads. As can be seen in Figure 2, the chillers are set up to be in series to provide energy savings as each of the chillers will only need to lower the temperature of the water by 6 degrees Fahrenheit. The BACnet sequences and controls the final chilled water temperature out of the second chiller in series is 44 degrees Fahrenheit. When the load is quite small one chiller is shut down, since each chiller was sized to meet the full load and is not efficient when operating at part loads. This can be seen in the piping configuration in the schematics where the piping from the evaporators has valves that can be closed.

The system has redundancy built in with the use of duty and spare pumps. Upon failure of the duty pump the space pump is automatically turned on and is sized to meet the full load. This is done for the primary and secondary loop pumps. The condenser pumps do not have redundancy built.

The cooling towers seen in the schematic in Figure 1 cools the condensate water to 65 degrees Fahrenheit from the exit temperature of the Condenser of 95 degrees Fahrenheit. The chilled water is used in the cooling coils in each of the modular air handling units.

Water Side- Hot:

The hot water for the heating coils is produced by the campus supplied steam, which is produced by natural gas boilers. The steam from the campus supply is passed through a pressure reducing station that is shown on Figure 3. This steam is stepped down in pressure and then is used for either the humidification of air in AHU's 1, 2, and 5 or it is passed through the plate and frame heat exchanger. The water leaves the exchanger at a maximum temperature of 180 degrees Fahrenheit and a passes the temperature sensor in the hot water supply adjusts the total steam into the exchanger allowing for the lower hot water temperatures. The temperature sensor can be seen on the schematic after both of the exchangers in the supply water line. The pumps use redundancy with the duty and spare alignment discussed in the previous system.

Mechanical System Overview

The mechanical system for the Grunenwald Science and Technology Building serves approximately 50 percent university laboratories, 25 percent classrooms, and 25 percent faculty offices. The laboratory spaces are served from one of three VAV 100 percent outdoor air units, of various sizes ranging from 24,000 cfm to 45,000 cfm. One of these air handling units serves only an Organic Chemistry Lab due to the high loads and need for ideal control over the temperature and humidity in the space. The offices and classrooms are served from one of two VAV modular units both similar in size of about 25,000 cfm. All of the air handling units are modular and are located in the penthouse of the building. The use of 2 energy recovery wheels helps to offset the large energy consumption associated with the 100 percent outdoor air. The exhaust air from the fume hoods, and snorkels located in the labs is used along with the waste heat from the micro turbine, producing on-site energy for the building, in the recovery wheels to pretreat the air entering into the system. Economizers are used on the VAV systems to supply additional energy savings associated with heating and cooling the mixed air.

Chilled water is produced on site by two 250 ton centrifugal chillers located in the mechanical room on the first floor of the Science and Technology Building. The building uses campus generated steam and does not have a boiler located onsite. The steam is passed through a plate frame heat exchanger to produce the needed hot water for the heating coils and domestic uses.

The water enters the heat exchanger at a temperature of 140 degrees Fahrenheit and leaves to be used in the heating coils at a temperature of 180 degrees Fahrenheit. The building exhaust air from the potentially contaminated lab spaces through the use of three 40,000 cfm fans which throw the air out 26 foot stacks located on the roof with high velocity. With the high velocity the effective height of 69 feet with high wind speeds of approximately 15 mph. The reason for the discharge air to be at a high velocity is so that exhausted air reentering the building or providing problems for the surrounding campus and community of Clarion. The mechanical system does use two 750 gpm cooling towers.

The micro turbine used in the building supplies some of the energy needed to power specific equipment located in the Science and Technology Building. The turbine is operated by natural gas which does produce emissions that will be calculated later in this report. The use of the turbine was not seen by the designers to be optimal as the payback period was near fifteen years, but the university was able to obtain a grant enabling the turbine to begin to pay for itself as soon as it was installed. The use of on-site generated energy was important to Clarion University as can be seen not only in the use of a micro turbine, but the use of large array of photovoltaic panels covering a large area of the roof plan.

Mechanical System Evaluation

The mechanical system for the Grunenwald Science and Technology Building is well designed and implements various sustainable technologies. The use of energy efficient equipment keeps the energy consumption of the mechanical system to a minimum. The use of high efficiency chillers, along with the VAV systems can be very effective when implemented properly. The use of produced steam from the central campus boiler plant is required by the university, and the plant has recently been upgraded to provide energy efficient boilers that burn natural gas rather than coal.

The use of economizers along with CO2 measurement devices allows the mechanical system to reduce the energy consumption further. The designers also incorporated a micro turbine into the design as the university received a grant to purchase this technology, it will provide electricity and the heat will pretreat outdoor air. The chillers used for the mechanical system are variable flow centrifugal chillers, which does make them more efficient than constant flow chillers and reduces the number of pumps along with their associated cost of installation. The cooling towers do not utilize free cooling in the initial design and if implemented savings in energy could be seen for a slight increase in upfront costs.

The VAV system used to supply the laboratories with 100 percent outdoor could work with a dedicated outdoor air system since the laboratories do not require that high of a ventilation rates. The use of the VAV systems keeps the installation and operating costs lower since it is typical of many new office buildings. If a DOAS was used only the ventilation would be provided by supply air while the rest of the load would be taken care of by radiant ceilings, chilled beams, etc., and may increase the first costs of the mechanical system. The cost of the mechanical system accounted for 18 percent of the total construction cost, and this is in the range of normal for construction projects of this type. The operational cost of the building is $1.43/sf. This is relatively low do to the on-site produced energy along with the use of energy efficient equipment.

The mechanical system utilized in the Science and Technology Building consists of chillers, cooling towers, pumps, AHU's, and VAV boxes, which is in the conventional systems installed in many of the new buildings. This will allow for many building engineers to know how to work on this system since there is no special equipment or training required to make repairs. Overall, the maintenance costs should remain low as the system is typical.

The laboratories are 100 percent outdoor air to prevent contaminants within the building, rather being captured by the large fume hoods and flexible snake exhaust ducts in each lab. There are 4 exhaust fans where redundancy is used with the implementation of an extra fan in case of failure of one of the other 3 fans. The exhaust for the building is released at high velocity to increase the throw above 60 feet to prevent contaminants to surrounding buildings.

Proposed Alternative Systems

The current mechanical system was designed to be energy efficient and has been able to aid in the project achieving a LEED Gold rating at this time. The energy savings of the building have been modeled to achieve a 40 percent reduction over the ASHRAE Baseline Building. There are other alternatives that can be implemented to provide an even larger energy reduction than the original design of the Grunenwald Science and Technology Building. These alternative designs can be implemented into the building with minor changes to the system as a whole, while their potential for improving the Science and Technology Building will be discussed further below. The alternatives to be investigated for use in the building are: exhaust fan redesign, Dedicated Outdoor Air System for laboratory wing with various radiant cooling techniques, and the use of Geothermal Heat Pumps to meet partial load.

Exhaust Fan Redesign:

The Science and Technology Building is comprised of 50 percent laboratory spaces each having multiple fume hoods and exhaust fans. The laboratories use more energy than the typical office building by nearly 4 to 6 times according to the preliminary research that was done until now.

The fans associated with the fume hoods contribute to the energy consumption of the laboratories more than most of the systems associated with the labs. In the original design, the exhaust fans where oversized and not all were designed to be VAV fans.

The fans will be resized based on the codes in place to meet the required air changes per hour for the different occupancy type labs in the Science and Technology Building. All of the fans will then be designed as VAV fans to reduce the energy consumption of the exhaust fans in the laboratory spaces. A comparison will be made between the original design and the redesign of the exhaust fans to see if the initial cost could be reduced with the use of smaller fan sizes even though they will need to be VAV. The comparison will also determine if sufficient energy savings will be seen with the redesign of the fume hood exhaust system.

Dedicated Outdoor Air System (DOAS):

The Dedicated Outdoor Air System supplies the ventilation requirement to the space with 100 percent outdoor air. The system that the labs use in the building is a 100 percent outdoor air VAV system even though the labs require only a high percentage of outdoor air to meet ASHRAE Standard 62.1. The supply of 100 percent outdoor air was done to prevent cross contamination between the various laboratory spaces. The use of this system will allow for the supply ducts to be reduced in size along with the supply fan, when compared to the VAV system being used in the original design.

The ventilation air will be treated by both an enthalpy wheel and an AHU to meet the latent load attributed with that space. This allows the sensible load to be treated completely separate from the latent load by using a parallel system such as: fan-coil units, radiant panels, chilled beam, etc. The outdoor air that is being introduced into the system will need to be pretreated which requires the use of a heat recovery system. At this time the laboratory spaces do use an enthalpy wheel to pretreat the outdoor air by using both the exhaust air from these spaces and the waste heat from the onsite micro turbine. This was required by ASHRAE 90.1 for the 100 percent outdoor air VAV system since the air also needed to be pretreated before the coils as there was no mixing in the system. This allows the energy of the exhausted air from the lab spaces to be exchanged with the outside air based on the overall efficiency of the heat recovery system.

The use of this type of system to meet the requirements for the Science and Technology Building may provide additional energy savings according to the preliminary research, since the building is comprised of 50 percent laboratories. Along with the energy savings associated with the AHU fan will be savings associated with the reduced load on the coils. There will also be inherent energy increases when using a DOAS system and these will have to be taken into account when calculating the total energy usage of the DOAS system. The results will be compared with the current 100 percent outdoor air VAV system used in the Science and Technology Building.

Geothermal Heat Pumps:

At Clarion University, the buildings are supplied steam to meet the heating loads of all the buildings on the campus using natural gas boilers to generate the steam at the central plant. Any renewable resources that could help to reduce the load of the Science and Technology Building on the central plant may be able to reduce the energy consumption of the building. The Geothermal heat pump will be looked to be a variable method used in conjunction with the campus steam already used in the building to ensure full load is meet and using a supplemental cooling tower.

The area needed for the geothermal heat pump system can be provided in the adjacent quad at the center of the university as there is a considerable amount of open land. The geothermal system could provide energy savings for the university building when compared to the VAV systems in use in the building as a result of the near constant temperature of the ground in Clarion, PA is approximately 52 degrees Fahrenheit. The use of the geothermal heat pumps will be explored in aiding the systems that serve only the offices and classrooms with the VAV system that is used in the original design. In addition to this it will be integrated into the proposed Dedicated Outdoor Air System serving the laboratory spaces comparing the energy consumption of the DOAS with and without the geothermal heat pumps and the associated cost savings that may be obtained through the two separate designs.

The initial cost of the geothermal system can be high, but the maintenance costs are relatively low with a long system life. The geothermal system will add to the construction schedule based on the number and depth of wells that would need to be drilled to meet either the full or part load of the building. This will have to be analyzed to optimize the size of the geothermal field based on the overall cost and energy savings obtained by the design. The construction process associated with the geothermal system will be analyzed in further depth as part of the breadth studies.

Exhaust Fan Redesign- Mechanical Breadth

The occupancy type was determined for the laboratory spaces in the Grunenwald Science and Technology to be type B, as it is a university lab. The code then states that based on the volume of the spaces and the types of contaminants in the space the air change rate can be determined instead of using the rules of thumbs. The reason that this was investigated was that with lowering the air change rate would allow for the fan size to be reduced saving energy in the exhaust system. The problem that was discussed as part of the LABS21 initiative was that the rules of thumbs that were used in most building designs where causing additional energy to be used when it was not necessary for the space being exhausted. The rules of thumbs that were used are typically between 10-12 air changes per hour for all laboratory spaces.

The minimum air change rates where determined using the process outlined in the International Mechanical Code which happened to be the exact calculations done by the design engineers. Using this some of the spaces were calculated to have 4 air changes per hour to 6 air changes per hour required based on the size of the laboratory space in the Grunenwald Science and Technology Building. Each of the spaces calculated was designed at the minimum level that was calculated for the various Laboratory spaces, therefore no further analysis could be performed to reduce the energy associated with the exhaust fans. If the design would have not met the minimum air change rates then the exhaust fans could have been reduced in size along with the a reduction in the duct size used to exhaust the air out of the stacks located on the roof of the Science and Technology Building. Along with the reduced equipment costs the building would have seen a savings in the electricity bill with the smaller fan sizes.

Dedicated Outdoor Air System (DOAS) Design- Mechanical Breadth

Introduction:

The use of DOAS was examined for use in the Grunenwald Science and Technology Building Laboratory Wing. The analysis was run for only the labs in the building as they do have a high requirement of outdoor air. The DOAS along with a parallel system will replace the (3) modular air handling units which supply the laboratories of the building. The parallel system will be chosen based on the available ceiling space in the labs along with the most cost effective solution for the mechanical system. The parallel systems that will be analyzed include radiant panels, active chilled beams, and standard chilled beams. With using a parallel system humidity concerns are apparent as the design does not want to create condensation in the zones.

DOAS Roof Top Unit:

The DOAS roof top units will not affect the structural design of the buildings as these roof top units will replace the modular AHU-1, 2, and 5 located on the roof of the building. The first step that was taken to size the units was to take the total outdoor air required for each of the three systems that serve the laboratories in the building. The systems were kept as three smaller units to reduce the length of ducts (pressure drop) that needs to be overcome as compared to if only one roof top unit was used. Another reason that the AHU's were split into three separate units was for the ease of maintenance. If one of the units were to fail part of the building would still be receiving the required ventilation air by ASHRAE Std. 62.1. The three roof top DOAS units were sized and selected from Semco. The information for each of the roof top DOAS units is provided in the following three tables. The EPC-9 Unit has a minimum CFM of 4500 and a max of 8000, which puts the outdoor air requirements of the system 1 unit within the operating range of the unit. The EPC-13 as the range for this unit is from 6000 to 10000 CFM with the highest computed air flow of 8800 CFM is within the range of the unit's capacity. The unit will be able to handle this capacity without any problems. The unit that will be used for system three is a smaller EPC-3 unit with a range of 2000 to 3000 CFM.

Table 9- System 1DOAS Rooftop Units

System 1 CFM	7450
Model Number	EPC-9
Unit Dimensions (w x l x h)	98"x 206"x 72"
Weight (lbs)	8350
Roof Opening Supply (w x l)	20"x 46"
Roof Opening Return (w x l)	20"x 34"
Static Pressures at the Following:	
OA Hood	0.02
EA Hood	0.17
Damper	0.34
OA Filters (Assuming 2" 30% Filters)	0.32
EA Filters	0.49
Enthalpy Wheel	0.67
Casing Losses	0.3
Finned Height Opening for the Cooling Coil	54"
Finned Width Opening for the Cooling Coil	42"

Table 10- System 2 DOAS Rooftop Units

System 2 CFM	8800
Model Number	EPC-13
Unit Dimensions (w x l x h)	98"x 224"x 72"
Weight (lbs)	10800
Roof Opening Supply (w x l)	26"x 46"
Roof Opening Return (w x l)	26"x 34"
Static Pressures at the Following:	
OA Hood	0.02
EA Hood	0.15
Damper	0.17
OA Filters (Assuming 2" 30% Filters)	0.42
EA Filters	0.55
Enthalpy Wheel	0.60
Casing Losses	0.3
Finned Height Opening for the Cooling Coil	66"
Finned Width Opening for the Cooling Coil	42"

Table 11- System 3 DOAS Rooftop Units

System 3 CFM	2100
Model Number	EPC-3
Unit Dimensions (w x l x h)	86"x 198"x 48"
Weight (lbs)	5650
Roof Opening Supply (w x l)	20"x 24"
Roof Opening Return (w x l)	20"x 24"
Static Pressures at the Following:	
OA Hood	0.02
EA Hood	0.09
Damper	0.18
OA Filters (Assuming 2" 30% Filters)	0.26
EA Filters	0.17
Enthalpy Wheel	0.69
Casing Losses	0.3
Finned Height Opening for the Cooling Coil	33"
Finned Width Opening for the Cooling Coil	30"

Parallel System:

The system that is going to be analyzed for placement into this building based on design and feasibility is a radiant ceiling. To be able to find the required CRCP area a manufacturer's data had to be referenced to find the design cooling capacity per unit panel area (BTU/hr*ft^2). For the manufacturer's data obtained from Airtite Radiant Ceilings the approximate cooling capacity per unit panel is 30 Btu/hr*ft^2. This was obtained by assuming the outdoor air from the DOAS system was entering the space using conventional supply air diffusers at 59.8˚F, and that the average glass for the systems was about 25%. This gave a difference in the room and supply temperatures of 15˚F, and the 25% glass is where the data that the cooling capacity was q_{panel}= 30 Btu/hr*ft^2. The total ceiling area for each of the three laboratory systems was calculated and can be seen in Table 12, 13, and 14.

Table 12- System 1 Radiant Panel Area

$Q_{hydronic}=Q_{sensible}=1.08*CFM*(T_{room}-T_{supply})$
$Q_{hydronic}=1.08*(12,950\ CFM)*(75-51)$
$Q_{hydronic}=335,664$ BTU/hr
Area of Panels Required=$A_p=Q_{hydronic}/q_{panel}$
$A_p=335664/30$
$A_p=11189\ ft^2$
% of Ceiling Area=(A_p/Floor Area for System1)*100
% of Ceiling Area=(11189/20400)*100
% of Ceiling Area=54.8%

Table 13- System 2 Radiant Panel Area

$Q_{hydronic}=Q_{sensible}=1.08*CFM*(T_{room}-T_{supply})$
$Q_{hydronic}=1.08*(16680\ CFM)*(75-51)$
$Q_{hydronic}=432346$ BTU/hr
Area of Panels Required=$A_p=Q_{hydronic}/q_{panel}$
$A_p=432346/30$
$A_p=14412\ ft^2$
% of Ceiling Area=(A_p/Floor Area for System1)*100
% of Ceiling Area=(14412/16653)*100
% of Ceiling Area=86.5%

Table 14- System 3 Radiant Panel Area

$Q_{hydronic}=Q_{sensible}=1.08*CFM*(T_{room}-T_{supply})$
$Q_{hydronic}=1.08*(1830\ CFM)*(75-51)$
$Q_{hydronic}=47434$ BTU/hr
Area of Panels Required=$A_p=Q_{hydronic}/q_{panel}$
$A_p=47434/30$
$A_p=1581\ ft^2$
% of Ceiling Area=(A_p/Floor Area for System1)*100
% of Ceiling Area=(1581/2130)*100
% of Ceiling Area=74.2%

The use of radiant ceiling panels would therefore not be feasible since the panel area requirement for each of the system is greater than 50 percent of the ceiling area. The three separate systems range from 54 percent to 86.5 percent of the ceiling area. The use of these panels may not be feasible since other components are typically located on the ceiling of a space, such as supply and return diffusers, lights, and fume hoods in the laboratory spaces.

With radiant panels not being feasible active chilled beams were analyzed to see whether the remaining sensible load could be met while occupying less of the ceiling area with the parallel system. For this analysis the Semco IQFC-240 6 foot active chilled beam was used with a total area of 12 ft^2 per each unit. For this chilled beam the chilled water temperature is 58 $^{\circ}$F and it has a flow rate of the air of 65 CFM. Even with the fans being placed into each zone the measured decibel level is 25 and should not pose a sound level problem within the laboratories. The manufactured data obtained from Semco for the cooling effect of each chilled beam will be approximately 3400 Btu/hr. Tables 15, 16, and 17 show the calculations for the ceiling area that the chilled beams will occupy in each of the systems.

Table 15- System 1 Active Chilled Beam Area

$Q_{hydronic}$=335,664 BTU/hr
Number of Panels Required=N_p=$Q_{hydronic}$/q_{panel}
A_p=335664/3400 Area of Panel= 12
N_p=99*12=1188 ft^2=Total Area
% of Ceiling Area=(Area/Floor Area for System1)*100
% of Ceiling Area=(1188/20400)*100
% of Ceiling Area=5.82%

Table 16- System 2 Active Chilled Beam Area

$Q_{hydronic}$=432346 BTU/hr
Number of Panels Required=N_p=$Q_{hydronic}$/q_{panel}
N_p=432346/3400 Area of Panel= 12
N_p=128*12=1536 ft^2=Total Area
% of Ceiling Area=(Area/Floor Area for System1)*100
% of Ceiling Area=(1536/16653)*100
% of Ceiling Area=9.22%

Table 17- System 3 Active Chilled Beam Area

$Q_{hydronic}$=47434 BTU/hr
Number of Panels Required=N_p=$Q_{hydronic}$/q_{panel}
A_p=47434/3400 Area of Panel= 12
N_p=14*12=168 ft^2=Total Area
% of Ceiling Area=(Area/Floor Area for System1)*100
% of Ceiling Area=(168/2130)*100
% of Ceiling Area=7.89%

With the use of active chilled beams the remaining sensible load in each of the systems will be able to be met with less ceiling area being needed for the chilled beams when compared to the radiant panels. The ceiling area for each of the three systems was calculated to be less than 10 percent of the total ceiling area making the application of chilled beams feasible. With the percentage of the ceiling being used remaining below ten percent for active chilled beams lead to passive chilled beams being looked at. The ceiling percentage for passive chilled beams should be between the radiant panels and active chilled beams. For the analysis the QPBA chilled beam from Semco was used to determine the Btu/hr supplied by the chilled beam. With a difference in temperature of 12 degrees Fahrenheit the cooling effect is 1700 Btu/hr for a beam length of 8 ft that is 1.5 ft in width. The calculations for the passive chilled beams can be found in the following three tables.

Table 18- System 1 Passive Chilled Beam Area

$Q_{hydronic}$=335,664 BTU/hr
Number of Panels Required=N_p=$Q_{hydronic}$/q_{panel}
A_p=335664/1700 Area of Panel= 12
N_p=198*12=2376 ft^2=Total Area
% of Ceiling Area=(Area/Floor Area for System1)*100
% of Ceiling Area=(2376/20400)*100
% of Ceiling Area=11.6%

Table 19- System 2 Passive Chilled Beam Area

$Q_{hydronic}$=432346 BTU/hr
Number of Panels Required=N_p=$Q_{hydronic}$/q_{panel}
N_p=432346/1700 Area of Panel= 12
N_p=255*12=3060 ft^2=Total Area
% of Ceiling Area=(Area/Floor Area for System1)*100
% of Ceiling Area=(3060/16653)*100
% of Ceiling Area=18.4%

Table 20- System 3 Passive Chilled Beam Area

$Q_{hydronic}$=47434 BTU/hr
Number of Panels Required=N_p=$Q_{hydronic}$/q_{panel}
A_p=47434/1700 Area of Panel= 12
N_p=28*12=336 ft^2=Total Area
% of Ceiling Area=(Area/Floor Area for System1)*100
% of Ceiling Area=(336/2130)*100
% of Ceiling Area=15.8%

The results for the passive chilled beams double the percentage of the ceiling used compared to the active chilled beams, but passive chilled beams are still much less than the radiant panels on the ceiling. The energy analysis was done and can be found later in this report. The energy analysis was used to make the determination of which of the chilled beam parallel systems would be used in the design.

Geothermal Heat Pumps Design- Mechanical Breadth

Introduction:

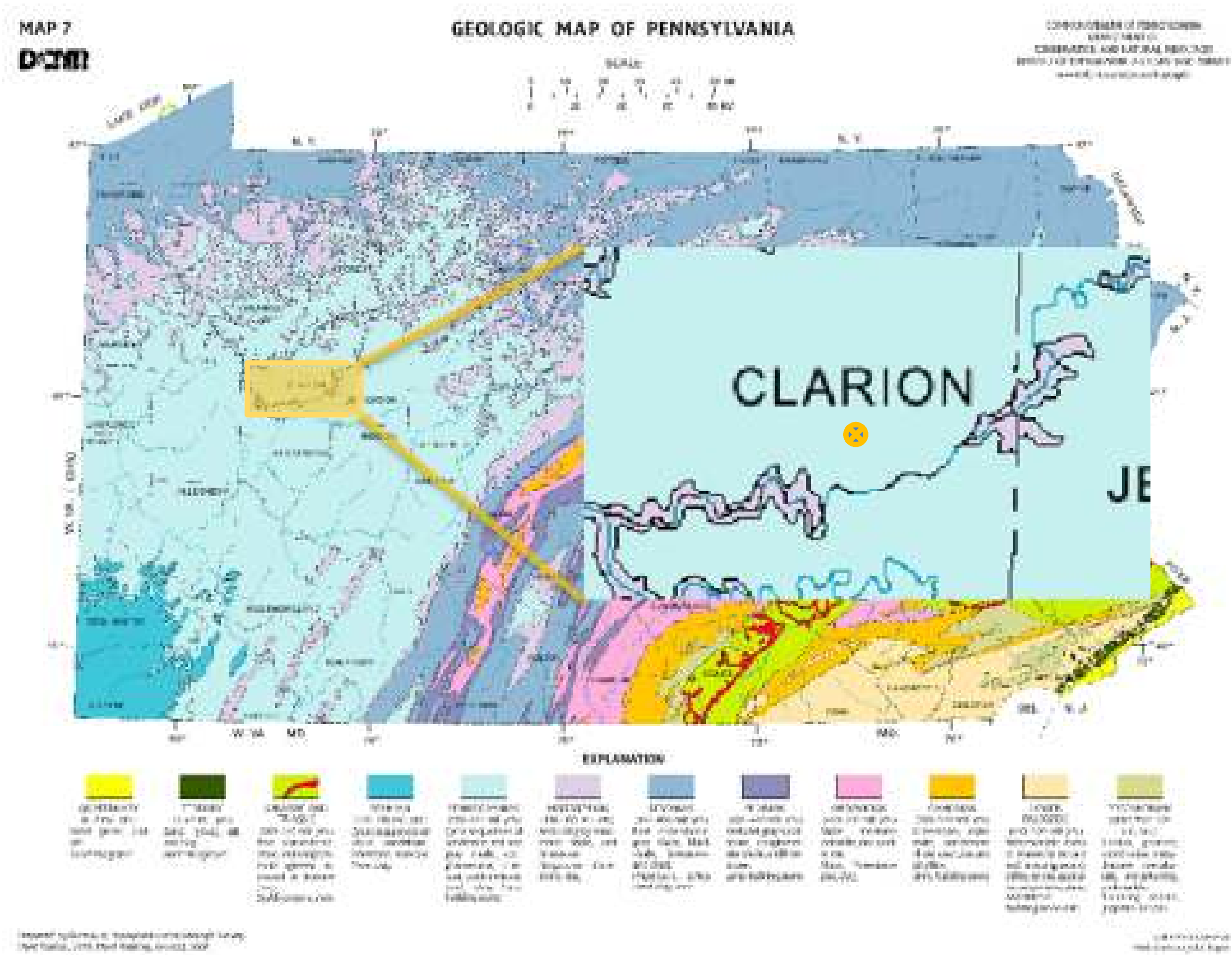
The majority of the space heating, cooling and ventilation is handled by the (5) modular air handling units located in the penthouse. The hot water used for heating the building uses a plate and frame heat exchanger with the campus generated steam from the central boiler plant. The central boiler plant uses (4) natural gas boilers to meet the heating and hot water demand of the Clarion University campus. This section discusses the proposed design of the geothermal heat pumps to supply chilled water to the air handling units located in the penthouse replacing the current system employed by the building. The system that will be analyzed will be a water to water ground source heat pump. The current system to create the needed chilled water is (2) 250 ton centrifugal chillers. The geothermal heat pump system will consists of vertical drilling due to the limitation of the space in the quad that will be utilized. The vertical drilling will be based on Figure 7 for piping and location for each borehole.

Figure 7- Vertical Piping Layout

Site Geology Analysis:

The site geology affects the design of the ground source heat pump, as the various soils and rock types located underground will affect the thermal properties of the ground. These thermal properties are used to determine the heat transfer between the water and the ground. In the determination of the soil properties borehole testing would need to be done to properly size the system. As part of the study borehole testing is not possible for the project to determine the rock and soil types where the loops would be located on the Clarion University campus. Rather a detailed analysis was performed to determine the geology of the construction site. The map that was used to determine the geology of the site in Clarion, PA is located below in Figure 8. The map of Pennsylvania was obtained from the United States Geological Survey.

Figure 8- Geologic Map of Pennsylvania- Expanded for Clarion, PA



Using the map above the soil type found in Clarion, PA was found to consist of cyclic sequences of the following: red and gray shale, coal, limestone, clay, and sandstone. This data was then compared to Table 5 of the ASHRAE Handbook 2007: HVAC Applications to determine the conductivity and diffusivity of the soil and rock types. Since the ground in Clarion, PA consists of different layers the average was taken to represent the conductivity of the ground due to the clay, shale, limestone, and sandstone. These value can be seen in Table ##, where the midpoint was taken for each using heavy clay 15 percent water as an assumption along with the other three rock types. The averaged conductivity for the soil came out to be 1.3 BTU/hr*ft*°F. The conductivity will be needed to determine the bore length for the cooling demand of the building. The conductivity of the fill and of the pipe was determined by Table 5 and 6 respectively from

Chapter 32 of the ASHRAE Handbook 2007: HVAC Applications. The grout and backfill was assumed to be 15% bentonite/85% SiO_2 sand, which results in a thermal conductivity of approximately 1.0 BTU/hr*ft*˚F. The pipe was assumed to be one inch in diameter with a borehole diameter of six inches. Using the pipe and borehole diameter along with the fill conductivity the thermal resistance can be found in Table 6 from Chapter 32 of the ASHRAE Handbook 2007: HVAC Applications, This gives a thermal resistance for the borehole of 0.10 hr*ft*˚F/BTU, where the table from the ASHRAE handbook can be seen in Figure 9. The average diffusivity was determined the same way as the conductivity with the midpoint of the values shown in Table 21 and averaged these together to get the grounds total diffusivity. The average diffusivity was calculated to be 0.86 ft^2/day.

Table 21- Soil & Rock Thermal Properties

Category	Type	Conductivity, Btu/hr*ft*˚F	Diffusivity, ft^2/day
Soil	Heavy Clay, 15 % Water	0.8-1.1	0.45-0.65
Rock	Limestone	1.4-2.2	0.9-1.4
	Sandstone	1.2-2.0	0.7-1.2
	Shale	0.8-1.4	0.7-0.9
Grout/Fill	15% bentonite/85% SiO_2 sand	1.0-1.1	-

Figure 9- Thermal Resistance of Boreholes

	Bore Fill Conductivity,* Btu/h·ft·°F					
	4 in. Diameter Bore			6 in. Diameter Bore		
U-Tube Diameter, in.	0.5	1.0	1.5	0.5	1.0	1.5
3/4	0.19	0.09	0.06	0.23	0.11	0.08
1	0.17	0.08	0.06	0.20	0.10	0.07
1-1/4	0.15	0.08	0.05	0.18	0.09	0.06

*Based on DR 11, HDPE tubing with turbulent flow

Bore Length Calculation:

The method used to appropriately size the geothermal heat pumps was followed from the ASHRAE Handbook 2007: HVAC Applications. The equation, Figure 10, was used to determine the bore length that would be required to meet the cooling load associated with the Grunenwald Science and Technology Building is from Chapter 32 of the ASHRAE Handbook 2007: HVAC Applications. This equation takes into account the associated heat pulses and thermal resistance of pipe wall and the between the pipe and fluid/ground. In order to calculate the value for the Length (LC) the equation was solved using Excel, and the results along with the inputs for each variable can be found in the appendix.

Figure 10- Equation to Calculate Bore Length

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41\ W_c)(R_b + \mathrm{PLF}_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

where

F_{sc} = short circuit heat loss factor
L_c = required bore length for cooling, ft
L_h = required bore length for heating, ft
PLF_m = part load factor during design month
q_a = net annual average heat transfer to the ground, Btu/h
q_{lc} = building design cooling block load, Btu/h
q_{lh} = building design heating block load, Btu/h
R_{ga} = effective thermal resistance of ground (annual pulse), h·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_b = thermal resistance of pipe, h·ft·°F/Btu
t_g = undisturbed ground temperature, °F
t_p = temperature penalty for interference of adjacent bores, °F
t_{wi} = liquid temperature at heat pump inlet, °F
t_{wo} = liquid temperature at heat pump outlet, °F
W_c = power input at design cooling load, W
W_h = power input at design heating load, W

The modular air handling units require a chilled water supply temperature of 44 degrees is needed to meet the loads. With the ground temperature being higher than this the best solution for the design is to use heat pumps to cool the chilled water temperature to the required 44 degrees Fahrenheit. The data for the heat pumps was obtained from McQuay using a water to water floor mounted unit. The model that was used for the analysis and implementation into the design was the GCW 420, with a source EWT of 85˚F and LWT of 93.7˚F. The load LWT is 44˚F with a EWT of 50˚F, while the source gpm is 75 and the load gpm is 90. The total capacity of each individual heat pump is 258,748 Btuh. The total load of the building is 4,235,700 Btuh, which means that to be able to meet this load 17 heat pumps would have to operate in the system. The ground temperature for Clarion, PA was determined to by 51˚F, all of the temperatures needed are outlined in Table 22. The temperature penalty was found to be 2.4˚F from Table 7 of Chapter 32 of the ASHRAE Handbook 2007: HVAC Applications.

Table 22- Temperature for Bore Length Equation

t_g	t_{wi}	t_{wo}	t_p
51˚F	85˚F	93.7˚F	2.4˚F

The ground source heat pumps rely on minimizing the thermal resistance between the ground and the water this will increase the transfer of heat with the ground. In order to calculate the thermal resistances for the appropriate heat pulse the following equations in Figure 11 where used to determine the three resistances. To calculate the Fouriers number for each heat pulse the τ, measured in days, were set to 10 years, a month, and 6 hours as is suggested in the ASHRAE Handbook 2007: HVAC Applications. The calculated Fourier numbers are then used with Figure 15 from Chapter 32 to find the associated G-factor's. Once the G-factors are known along with the thermal conductivity of the ground the resistances of the three heat pulses can be solved for in the equations as seen in Figure 11.

Figure ##- Equations for Fouriers Number and Pulse Resistances

$$\mathrm{Fo}_f = 4\alpha\tau_f/d_b^2$$
$$\mathrm{Fo}_1 = 4\alpha(\tau_f - \tau_1)/d_b^2$$
$$\mathrm{Fo}_2 = 4\alpha(\tau_f - \tau_2)/d_b^2$$

$$R_{ga} = (G_f - G_1)/k_g$$
$$R_{gm} = (G_1 - G_2)/k_g$$
$$R_{gd} = G_2/k_g$$

The power input at the design cooling load was assumed to be 50,000 Btuh. While the value for the short circuit heat losses was assumed to be 1.04. The part load factor was assumed to be 1.0 to ensure that the geothermal heat pump was sized to meet the full cooling load. Table 23 shows the variables that were found or solved for in order to find the borehole length that would be required to meet the cooling load of the building.

Table 23- Variables for Bore Length Equation

List of Variables needed to Solve for L_c					
F_{sc}=	1.04	t_g=	51˚F	d_b=	0.5 ft
PLF_m=	1	t_{wi}=	85˚F	τ_1=	3650 days
q_a=	-4235700 Btu/hr	t_{wo}=	93.7˚F	τ_2=	3680 days
q_{lc}=	-4235700 Btu/hr	t_p=	2.4˚F	τ_f=	3680.25 days
R_{ga}=	0.292 hr*ft*˚F/BTU	W_c=	50000 W	G_f=	0.93
R_{gd}=	0.169 hr*ft*˚F/BTU	Fo_f=	50640.24	G_1=	0.55
R_{gm}=	0.254 hr*ft*˚F/BTU	Fo_1=	416.24	G_2=	0.22
R_b=	0.10 hr*ft*˚F/BTU	Fo_2=	3.44	k_g=	1.3 BTU/hr*ft*˚F
α=	0.86 ft^2/day				

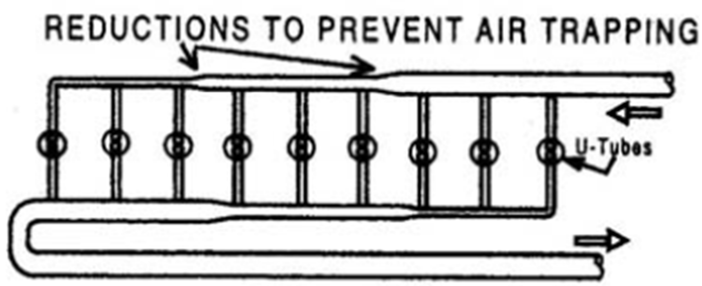
Plugging the variables into the above equation in Figure 10 solves for the length of the piping which was calculated to be 87,458 ft.

System Layout:

The site for the geothermal wells was chosen based on several variables which are the drilling cost, construction schedule, and construction impact on the campus. The Construction Breadth includes a section which considered the variables to obtain an optimal design for the geothermal system. This variables lead to the design to consist of 270 boreholes drilled at 324 ft.

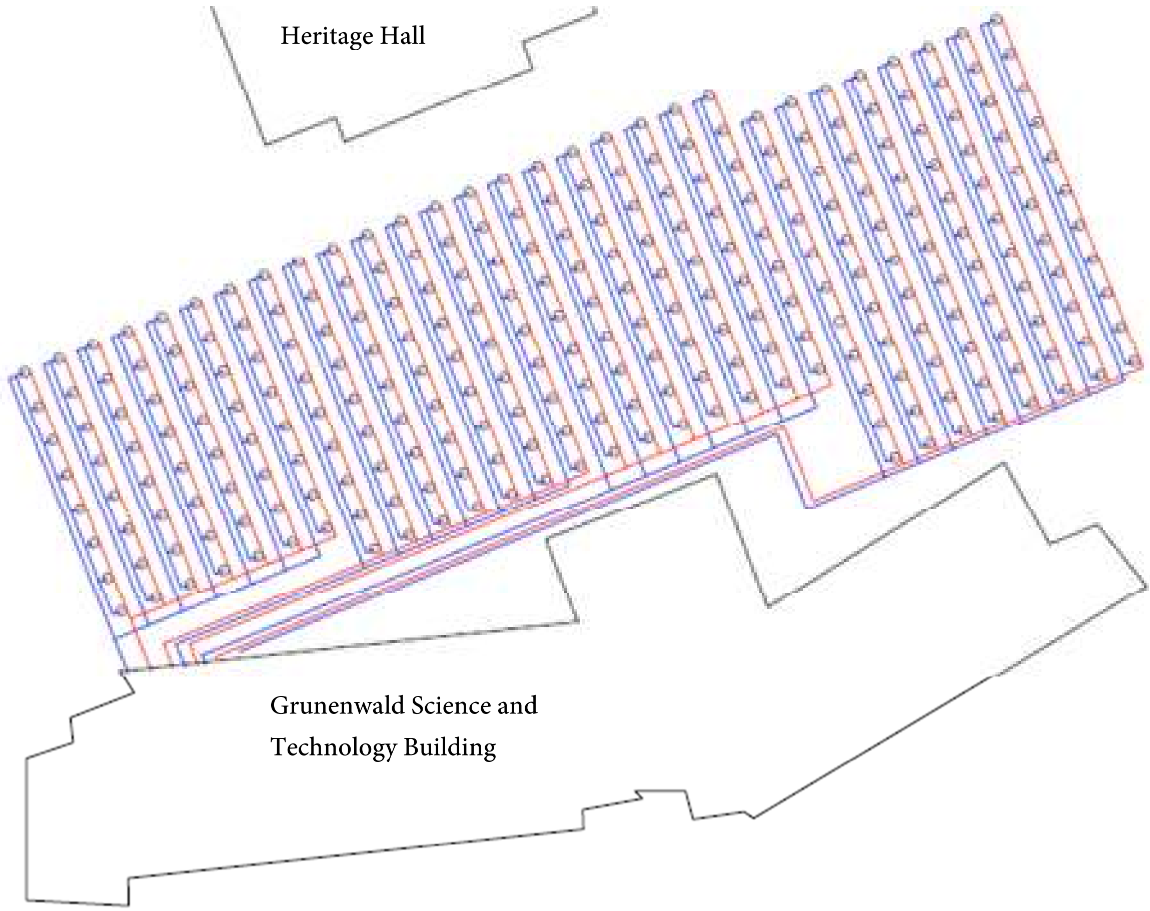
The loops where arranged into subgroups to make each set more manageable and allows for each subgroup to have its own header. Each header will be supplied from the pump room and will have its own butterfly type isolation valve. Using subgroups reduces the pipe size needed for the headers, and will be designed in a conventional reverse-return set-up illustrated in Figure 12. This design will aid in preventing the system from trapping air by stepping down the size of the header over the pipe length.

Figure 12- Header Conventional Reverse Return



The layout of the system was split into 4 subgroups of various sizes to utilize the size of the north quad adjacent to the Grunenwald Science and Technology Building. The smallest of the four subgroups consists of 7 sets of 8 boreholes, while the two medium sized subgroups each consists 7 sets of 9 boreholes. The largest subgroup located to the right in Figure 13 consists of 8 sets of 11 boreholes. This layout utilizes a 15 foot by 15 foot grid to space the boreholes as needed to not increase the ground temperature overtime, while allowing each borehole to dissipate the required heat to the ground efficiently.

Figure 13- Proposed Geothermal Borehole Layout

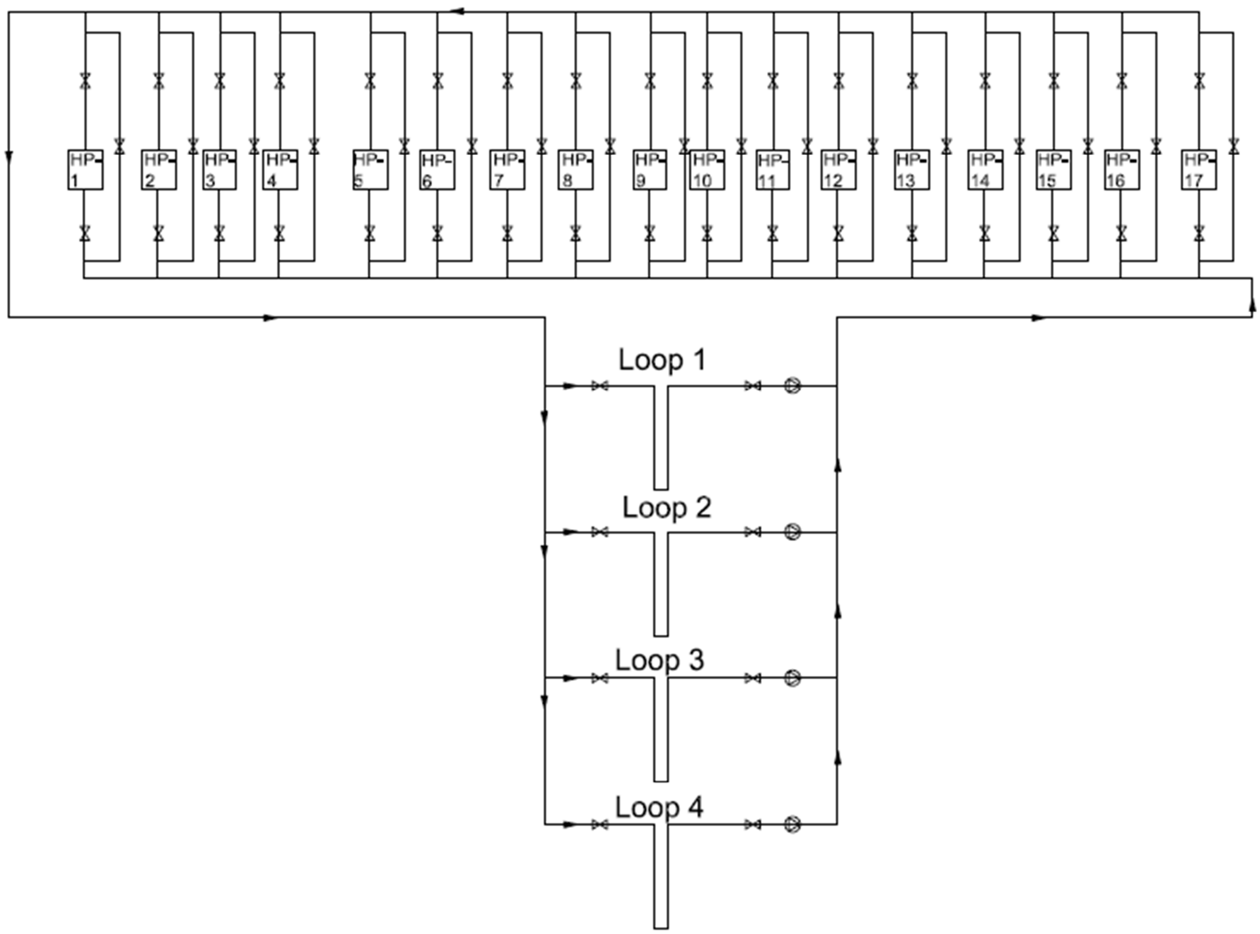


Geothermal Pump Requirements:

The geothermal system was split into four separate loops, which does enable the system to meet various cooling part loads of the building. If this was designed as only one loop the geothermal system would operate at part load for a majority of the cooling hours reducing the efficiency of the pumps and the capacity of the geothermal load. There are several advantages of creating three separate loops. First is that at part load the heat transfer rate to the ground will remain maximized as the flow remains non-laminar. This is achieved by having the pumps operate on their own loop, as the demand increases the next loop will activate in another loop increasing the capacity of the system. The control system will operate the isolation valves to activate the loops and pumps in that run. The loops will also be cycled through when operating at part load to decrease the rise in ground temperature over time and allowing the system to respond at a greater rate to changes in the chilled water need. The separate headers discussed previously will also aid in system flushing.

The ground water schematic can be seen in Figure 14, the loops can be seen with their independent pumps along with the heat pumps used to transfer energy to the chilled water system. The chilled water system will remain the same as seen in Figure 5 other than that where the chillers in series are located heat pumps in parallel will now be used to lower the temperature of the chilled water to 44 ˚F from 50 ˚F. The pumps on the chilled water system may remain the same as the total head due to the heat pump is less than that of the series chillers.

Figure 14- Groundwater System Schematic



The longest equivalent lengths were determined for each of the loops 1, 2, 3, and 4 as seen in the previous figure. The equivalent lengths were determined by the length of each diameter of pipe along with the fittings in the various sections of the piping. The elbow was assumed to be normal and the locations varied to the 4" pipe to the 1" pipe for the greatest equivalent length of each loop. Isolation valves were also used in the calculation with two located near the heat pump and two located in each set of bore holes in case a problem was detected in the loop at any location the whole loop would not have to be shut down. The calculations can be found in Table 24, with an assumed flow rate of 3 gpm/ton (as recommended by McQuay) to determine the flow rate needed by each pump.

Table 24- Total Head and Flow Rate for Each Loop Pump

Loop	Length 4 " Pipe	Length 2" Pipe	Length 1" Pipe	Elbow Eq. Legth	Head Heat Pump	Isolation Valve Eq. Length	Total Length	Head loss /100ft	Total Head	Pump Flow Rate
1	137.4	60	920	66.2	16.7	4.8	1205.1	4	48.2	220
2	238	60	935	66.2	16.7	4.8	1320.7	5	66.0	247
3	460	60	935	66.2	16.7	4.8	1542.7	5	77.1	247
4	715	60	1027	102.2	16.7	4.8	1925.7	6	115.5	345

The four ground loop pumps were then sized using pump curves from Bell and Gossett. The plots on the pump curves can be found in the appendix. The plots resulted in 4 base mounted, end suction Series 1510 pumps as can be seen in Table 25.

Table 25- Pump Selections

									Motor Data			
Unit	Manu.	Frame Size	Type	GPM	Total Head	VFD	Emergency Power	Impellor Diameter	HP	RPM	Volts	Phase
GWSP-1	Bell & Gossett	184 T	End-Suction	220	48	Yes	Yes	8"	5	1700	480	3
GWSP-2	Bell & Gossett	213 T	End-Suction	245	66	Yes	Yes	9"	7.5	1700	480	3
GWSP-3	Bell & Gossett	213 T	End-Suction	245	77	Yes	Yes	9.5"	7.5	1700	480	3
GWSP-4	Bell & Gossett	254 T	End-Suction	350	115	Yes	Yes	11"	15	1700	480	3

The pipes that will be used in the ground will be HDPE (High Density Polyethylene Pipe) since it is thermally fused and will allow for the best heat transfer with the ground. Each of the pumps will be VFD to maintain a minimum flow rate while in operation.

Construction Breadth- Geothermal Installation

Introduction:

The construction of the geothermal system requires an investigation into the upfront costs of installing the large geothermal field and replacing the equipment of the original design. The schedule will also be looked at to lower the disruption of university activities, with the best time for installation occurring during the summer semesters where the number of students on campus is at its lowest. The study that was performed investigated the cost of the system and the impact that it may have on the construction schedule. The mechanical performance of the system is the driving factor, with the drilling and location being evaluated in the optimization of the depth and number of boreholes needed to meet the cooling load of the Grunenwald Science and Technology Building. All of the estimated costs were obtained from RS Means Mechanical Cost Data-2010.

Location of Boreholes:

The space needed for the required number of boreholes to meet the load varied since with greater bore depth the # of bores was decreased. For the purpose of this project the area that could be utilized for the placement of the bores was in two quads adjacent to the building, one to the north and the other to the south of the building. The goal was to be able to utilize the space provided without causing a major impact to campus life for the students at Clarion University. The most number of bore holes that could fit into just one of the quad areas was found to be 270 through design layouts in Autocad, which occurred in the north quad. This worked well as it was in the second tier of drilling cost as each borehole depth was only needed to be 324 feet. Any more than 270 the entire campus would have been affected more as the construction site would have needed to grow to keep the same size staging area on site. This lead to the decision that the south quad would not be used for the geothermal system and only the north quad would be utilized with 270 boreholes at a depth of 324 feet.

Table ##- Construction Borehole Selection Guide

Length (ft)	# of Bores	Bore Depth	ft/day	day/Bore	Days	Weeks	Drilling Cost	Location of Site
87458	170	514	900	0.572	97.2	19.4	$329,619.48	N Quad
87458	210	416	900	0.463	97.2	19.4	$329,619.48	N Quad
87458	250	350	900	0.389	97.2	19.4	$329,619.48	N Quad
87458	270	324	1200	0.270	72.9	14.6	$216,312.79	N Quad
87458	310	282	1200	0.235	72.9	14.6	$216,312.79	N&S Quad
87458	350	250	1200	0.208	72.9	14.6	$216,312.79	N&S Quad
87458	380	230	1200	0.192	72.9	14.6	$216,312.79	N&S Quad
87458	390	224	1800	0.125	48.6	9.7	$118,457.00	N&S Quad
87458	430	203	1800	0.113	48.6	9.7	$118,457.00	N&S Quad

Cost:

The costs for the geothermal heat pump system includes the drilling cost, which was based on three different auger depth prices including the equipment rental and labor needed for the installation. All of the costs that were obtained from RS Means Mechanical includes the labor to install the equipment. The multiplier for Erie, PA is 0.94, which was then multiplied with each cost to get the geographical cost of the equipment and labor. The price for the HDPE piping that was used in the geothermal field is priced per linear foot. The price for 1" HDPE piping used for the borehole piping is $0.65/LF, while the 2" HDPE piping is $1.36/LF, and 4" HDPE piping is $2.75/LF. The 2" and 4" piping were used in the headers for the geothermal field. The piping also requires that every 40 feet of pipe be welded together and the welding equipment needed is $55/day. For the welding labor the cost is $8/weld for 1" pipe, $17.05/weld for 2" pipe, and $25.38/weld for 4" pipe. The grout cost to fill the the boreholes was found to be $0. The pump cost varied based on the horsepower with the 5 hp pump costing $14,852, and the 7.5 hp pumps costing $16,755.50. The 15 hp pump cost is $23,782 according to RS Means Mechanical. The design consists of 17 water to water floor mounted heat pumps with a total cost of $448,800, obtained through research of cost per ton for a water to water heat pump. This was done since RS Means does not include prices for water to water heat pumps. The total cost of the geothermal heat pump system can be found in the following table.

Table 27- Increase in Initial Cost over Original Design for Geothermal

New Equipment		Replaced Equipment	
Equipment/Material	Cost for Location	Equipment	Cost for Location
Drilling	$216,312.79	(2) Centrifugal Chillers	$209,244.00
Grout	$196,019.48	Cooling Tower	$54,000.00
Heat Pumps	$448,800.00		
Piping	$78,967.52		
Pumps (Hydraulic)	$55,389.50		
Welding	$3,774.10		
		Initial Cost Increased by	$736,019.37

The initial cost increased by a total of $736,019. This value calculated for additional cost was used in the potential energy savings section of this report to determine the payback period when using a geothermal heat pump system with water to water heat pumps over the use of centrifugal chillers and a cooling tower to supply chilled water to the AHU's.

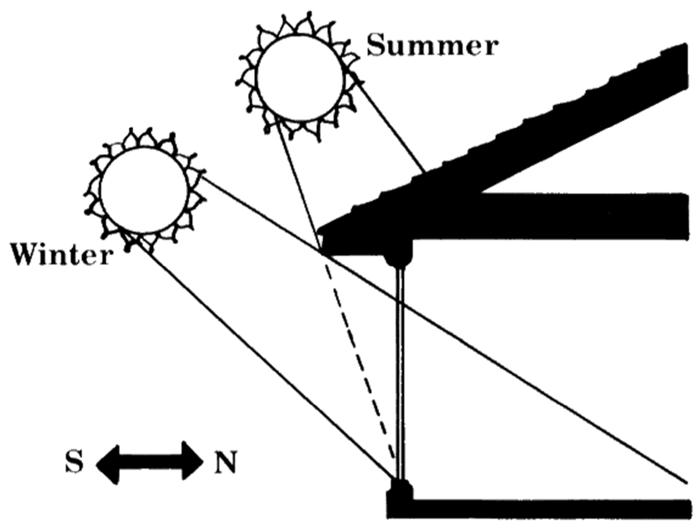
Schedule:

The majority of the schedule needed for the installation of the geothermal system is the number of days needed to drill the 270 boreholes, which was 14.6 weeks. The installation of the heat pumps will occur at the same time as the drilling for the well field. The piping and grouting of the boreholes occurs directly after the well has been drilled. The only problem that can occur is that if all boreholes have been grouted the groundwater pressure has nowhere to go and may blow out a few of the boreholes in the surrounding area. To prevent this from happening the piping and grouting will start a week later than the drilling to allow for unfilled boreholes around the drilling rig to release the groundwater pressure. The total schedule for the geothermal field and equipment installation will be 15.6 weeks. The summer semester break at Clarion University is a total of 14 weeks long, which means that this construction schedule will not affect the students during the Spring and Fall semesters for more than a couple of weeks.

Architectural Breadth- Solar Shade Design

The use of the solar shades in the design is to limit the heat gain from the direct solar radiation into the space in the cooling months, while allowing the solar radiation into the space when heating is necessary. Through research of the various methods of limiting the solar radiation it was determined that interior shades are not as effective as the external shades. This is due to the fact that the external shades block the radiation before entering through the glass, while the internal shades do not block the radiation until it is in the space. The internal shades would allow for the space to experience near the same cooling loads in the summer months. For these reasons external shades were analyzed to determine if energy could be saved once the shades were properly sized for the windows on the South and Southwest facing walls of the Grunenwald Science and Technology Building. The goal of adding the overhang can be seen in the following figure.

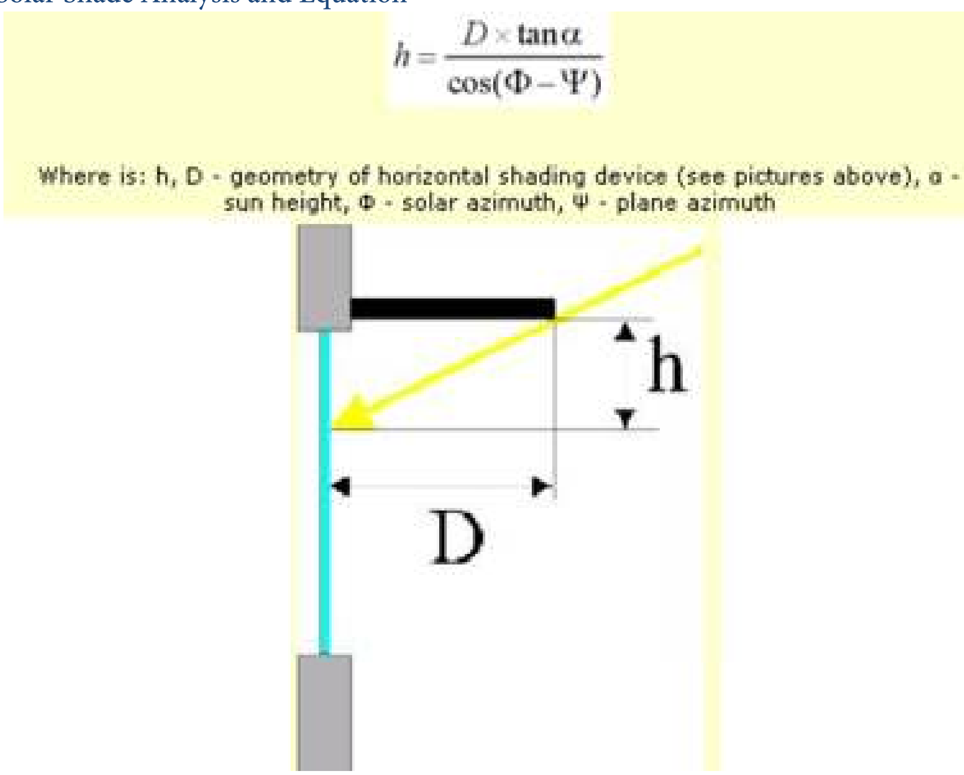
Figure 15- Solar Shade Summer & Winter Solstice



The calculations needed to determine the proper depth of the shade when positioned above the window use trigonometry properties with the azimuth and other solar angles. The latitude for Clarion, PA is 41.2 degrees. The shade will be attached to the wall 6 inches above each of the windows, with the height each of the window equal to 5' 4". The solar height for Clarion, PA on the summer solstice is 72.3° while the solar azimuth that will be used for each of the calculations will be 0˚ since the analysis only looks at solar noon on the summer and winter solstice. The winter solstice has a solar height of 25.3˚ and will be analyzed to insure that the maximum heat gain is achieved with the minimum heat gain during the summer months. For the South facing wall the plane azimuth will be 0˚ while for the Southwest facing wall azimuth will be 45˚ to determine the shade dimensions for each wall. Other information that is needed for this analysis is that the window is set into the wall 4" and the shading device has a thickness of 3".

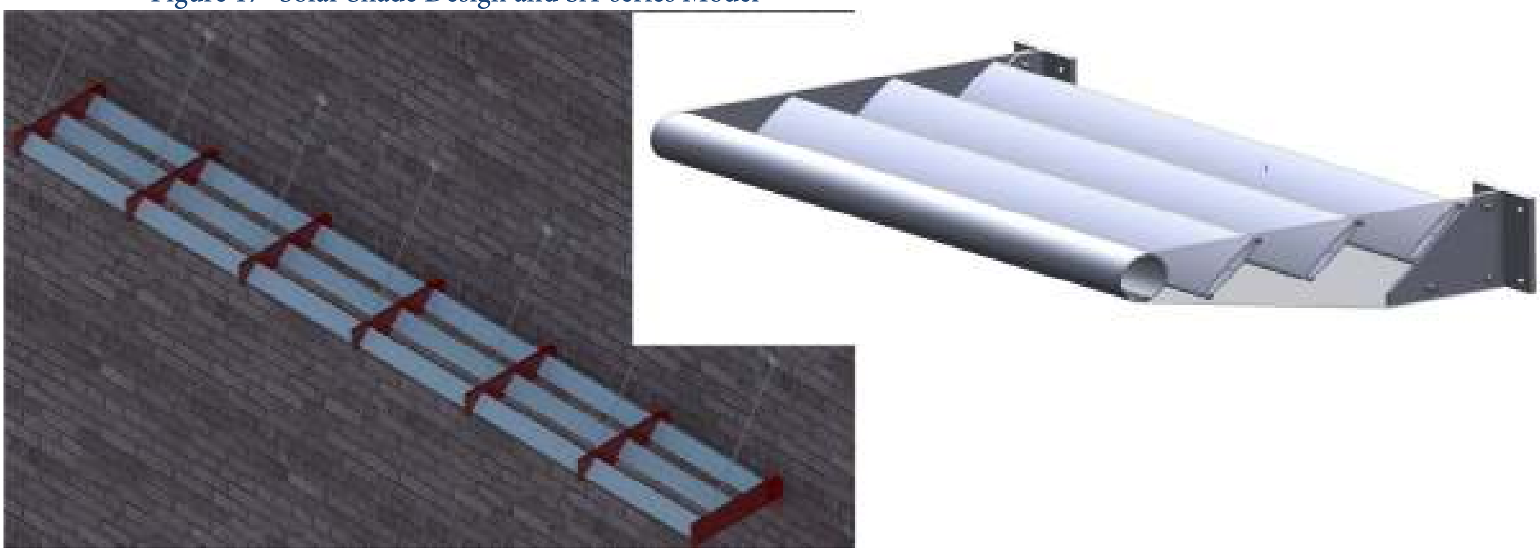
The following figure shows the terms of the equation used to solve for the depth needed to block solar radiation and there relation to the window sizes. The equation below was manipulated to solve for the depth of the shade rather than the height since all components of the height are known.

Figure 16- Solar Shade Analysis and Equation



The equation determined that the depth of the solar shades on the south wall needed to be 1' 7" to completely block the direct solar radiation from the window. With this depth of the solar shade on the winter solstice only 5" of the window is blocked by the solar radiation. For the shades on the southwest wall the depth was determined to be 1', which on the winter solstice blocked 5" of the window from solar radiation. The calculations for both the summer and winter solstices for both the south and southwest facing walls can be found in the Appendix of the report. Along with the calculations, REVIT models were made to show the solar radiation entering the space for the solstices and equinoxes. The potential energy savings can be found in the following section of this report, as it discusses all of the potential energy savings associated with each alternative design used. The exterior shade that will be used in the design uses aluminum as the louvers and the cooper as the frame to tie into the aesthetics of the rest of the building. The shade can be seen in Figure 17 with the aluminum louvers with red paint of where the frame would be the pre-patina colored cooper. The design allows for the shade to be constructed into the various sizes needed for the Science and Technology Building. The model that was found to be similar to that in Revit was the SA-series model for solar shades from Industrial Louvers Inc.

Figure 17- Solar Shade Design and SA-series Model



Potential Energy Savings with Alternative Designs

Introduction:

For analysis of each of the alternatives a model was created using Trace 700 with different systems created for a comparison to the original design. This includes the DOAS with 2 different parallel systems, geothermal heat pump for cooling only, and solar shade added on the south and southwest facing facade of the building. All of the obtained results from the energy calculations and other calculations based on the payback period will be discussed in the results section.

DOAS:

Based on the percent of ceiling area needed for the parallel systems only the passive and active chilled beams where analyzed for savings in energy and cost. The passive chilled beams saved more energy than the active chilled beams as the passive do not have additional fan energy consumption. The passive chilled beams has an energy consumption of 2,684,445 kWh when compared to the original design of 2,962,304 kWh there is a savings of 277,859 kWh. This corresponds to a savings of $13,177 dollars each year. The savings seen for the passive chilled beams are associated with the smaller supply fans needed as well as having the sensible and latent loads being separated. Active chilled beams had a total energy consumption of 2,744,816 kWh, which is a savings of $10,284. The energy savings and cost savings for active and passive chilled beams can be seen in the following table, while the two figures show the reduction in electricity and natural gas used each month for the DOAS systems against the original design.

Table 28- DOAS Energy Comparison

	Original Design (VAV)	DOAS with Passive Chilled Beams	DOAS with Active Chilled Beams
Energy Consumption (kWh)	2,962,304	2,684,445	2,744,816
Electricity Cost	$138,141	$125,877	$128,741
Natural Gas Cost	$3,444	$2,531	$2,560
Total Saving (Energy)		277,859 kWh	217,488 kWh
Total Cost Saving per Year		$13,177	$10,284
Payback Period (Years)		2.48	6.45

Figure 18- Electricity Cost Comparison per Month for DOAS

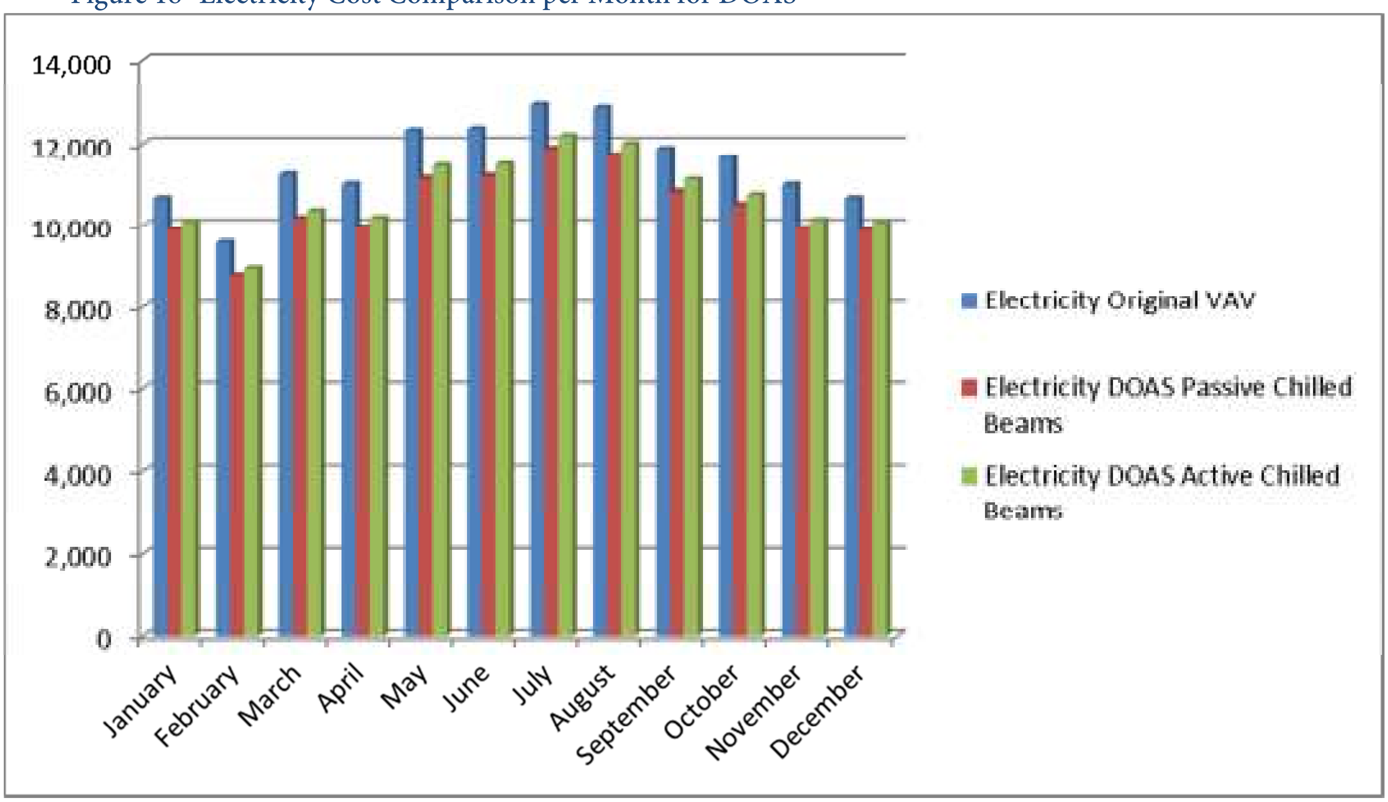


Figure 19- Natural Gas Cost Comparison per Month for DOAS

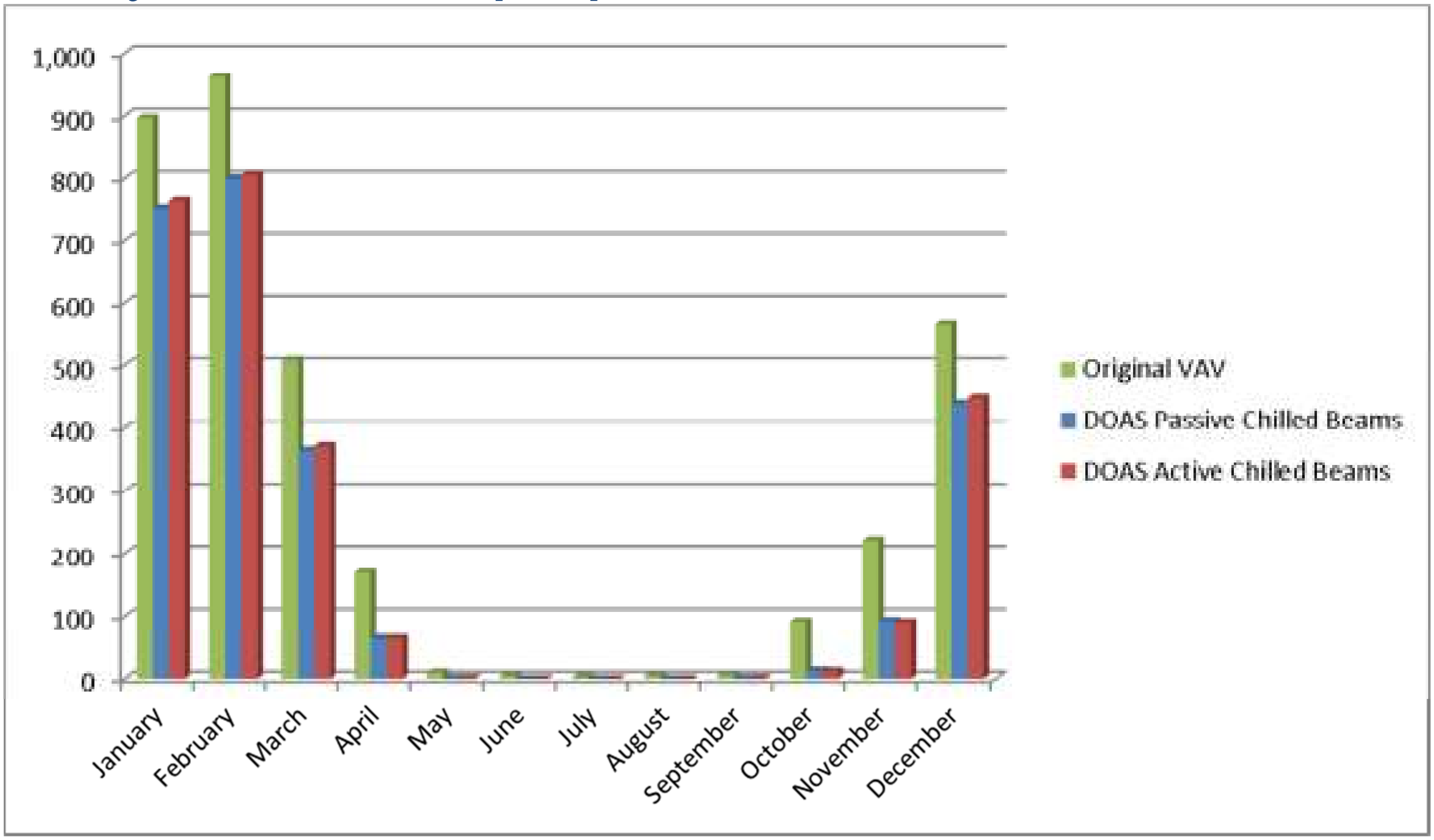


Figure 20- Energy Consumption %- Passive Chilled Beams

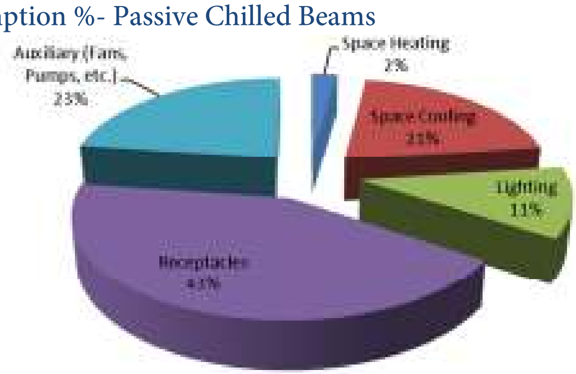
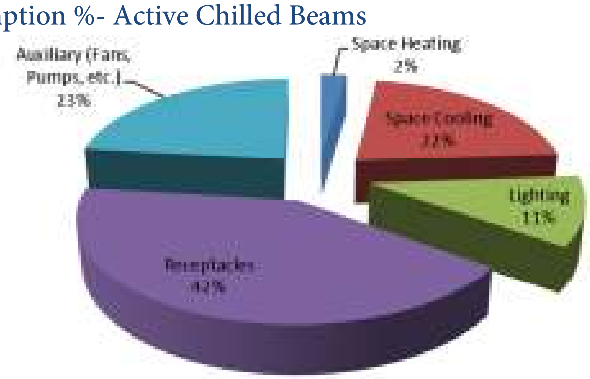


Figure 21- Energy Consumption %- Active Chilled Beams



The payback period for this alternative could not be determined using RS Means as all of the cost data was not available in the resources that could be obtained. The cost for the chilled beams would raise the initial cost, but are an item that is not listed in RS Means Mechanical and could not be found in a reliable source. Along with the chilled beam and the installation of the unit, additional chilled water piping and pumps will be needed to supply each of the chilled beam units. The item that could be replaced in the original cost analysis is the (3) modular AHU's which were found to cost a total of $151,223. The DOAS rooftop units were found to add an additional $36,778 to the systems first cost. There will also be savings seen in the downsizing of fans, and ducts due to the lower flow required.

In order to obtain a simple payback period, a Semco sales representative was contacted to determine the initial installation cost of both the active and passive chilled beams. For this payback calculation the additional chilled water piping and pump cost was assumed to be offset by being able to decrease the fan sizes and the duct sizes in the system. The active chilled beams were found to cost $0.22/Btu/h, while the passive chilled beams cost $0.18/Btu/h for each installed units. The additional first cost was found to be $66,305 for the DOAS with active chilled beams, and $32,721 for the DOAS with passive chilled beams. The simple payback results were obtained using the additional first costs and the energy savings seen in the Trace 700 model. The results of the calculations for the payback period can be found in the table on the previous page. The passive units cost less than half of the active chilled beam units while requiring double the amount of units. Further discussion on the benefits of each will be discussed in the overall results section.

Geothermal Heat Pump:

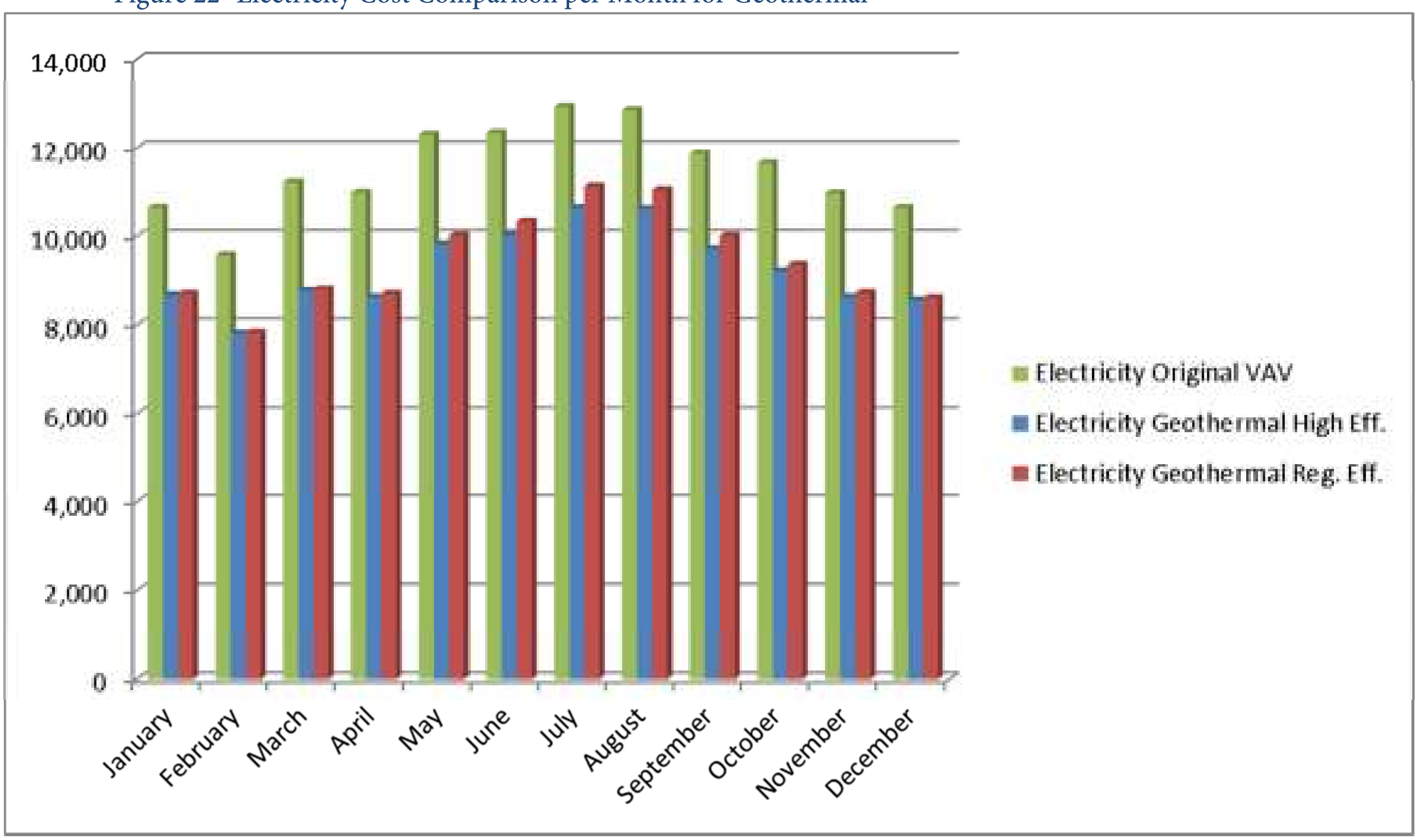
The geothermal heat pump system was modeled in Trace 700 using the User Manual to setup the system. The system was used for cooling only therefore there is no cost or energy savings associated with the heating as this is still supplied by the campus natural gas boilers. The first modeled system was a heat pump with a ground water loop with high efficiency rather than regular efficiency. The total energy consumption for the Grunenwald Science and Technology Building operating the geothermal heat pump for cooling only with the campus supplied steam for heating is 2,400,184 kWh compared to the original design of 2,962,304 kWh. The total cost per year for energy is $114,602.38, which results in a savings of $26,982.62 each year in utility costs. For the second modeled system was a heat pump with ground water loop with regular efficiency. The total energy for this system was calculated to be 2,445,493 kWh with a yearly savings of $24,807.23.

To calculate the simple payback period the added initial cost calculated in the construction breadth was divided by the savings seen per year for the operation of the geothermal heat pump system. The payback period was calculated to be 27.28 years for the high efficiency system while the payback period for the regular efficiency was 29.67 years. All of the data can be found in the following table comparing the two geothermal systems with the original design used in the Grunenwald Science and Technology Building. The two different efficiencies for the geothermal loops do not provide large differences in energy consumption each year. The following figure shows the cost of electricity each month for each of the alternative geothermal systems. The comparison of the used purchased steam was not compared as the heating system was unchanged, and the assumption that the heating load remained the same keeping the cost the same as the original VAV system used in the building.

Table 29- Geothermal Energy Comparison

	Original Design (VAV)	Geothermal High Efficiency	Geothermal Regular Efficiency
Energy Consumption (kWh)	2,962,304	2,400,184	2,445,493
Electricity Cost	$138,141	$111,158.38	$113,333.77
Total Saving (Energy)		562,120 kWh	516,811 kWh
Total Cost Saving per Year		$26,982.62	$24,807.23
Payback Period (years)		27.28	29.67

Figure 22- Electricity Cost Comparison per Month for Geothermal



Solar Shade Addition:

The solar shades were added into the Trace 700 model with all of the settings and templates of the original design, with the exception of having the calculated depth of as a fixed horizontal overhang. The overhangs were only added 6 inches above the windows located on the south and southwest walls with an extension of 1 foot on each side of the windows. The total energy consumption that was calculated with the addition of the solar shades was 2,946,597 kWh compared to 2,962,304 kWh for the design with no solar shades. The cost saving associated with the reduction in the energy consumption for an entire year was found to be $. The results of this calculation can be seen in the following table along with figures comparing the two designs with the electricity and natural gas cost for each month of the year.

The cost for the SA-series was found to be on average $15/sf, which was obtained through contacting an Industrial Louver Inc. sales representative. With this value the total cost of installing the SA-series aluminum louvers on the building was found to be $22,380 for the 1,492 sf of fixed horizontal aluminum shades. The simple payback period was calculated using the additional initial cost and the energy savings per year. The calculation results can be found in the following table.

Table 30- Solar Shade Energy Comparison

	Original Design (VAV)	Original Design With Added Solar Shades
Energy Consumption (kWh)	2,962,304	2,946,597
Electricity Cost	$138,141	$137,198
Natural Gas Cost	$3,444	$3,605
Total Saving (Energy)		15,707 kWh
Total Cost Saving per Year		$782
Payback Period (Years)		28.62

Figure 23- Electricity Cost Comparison per Month for Solar Shades

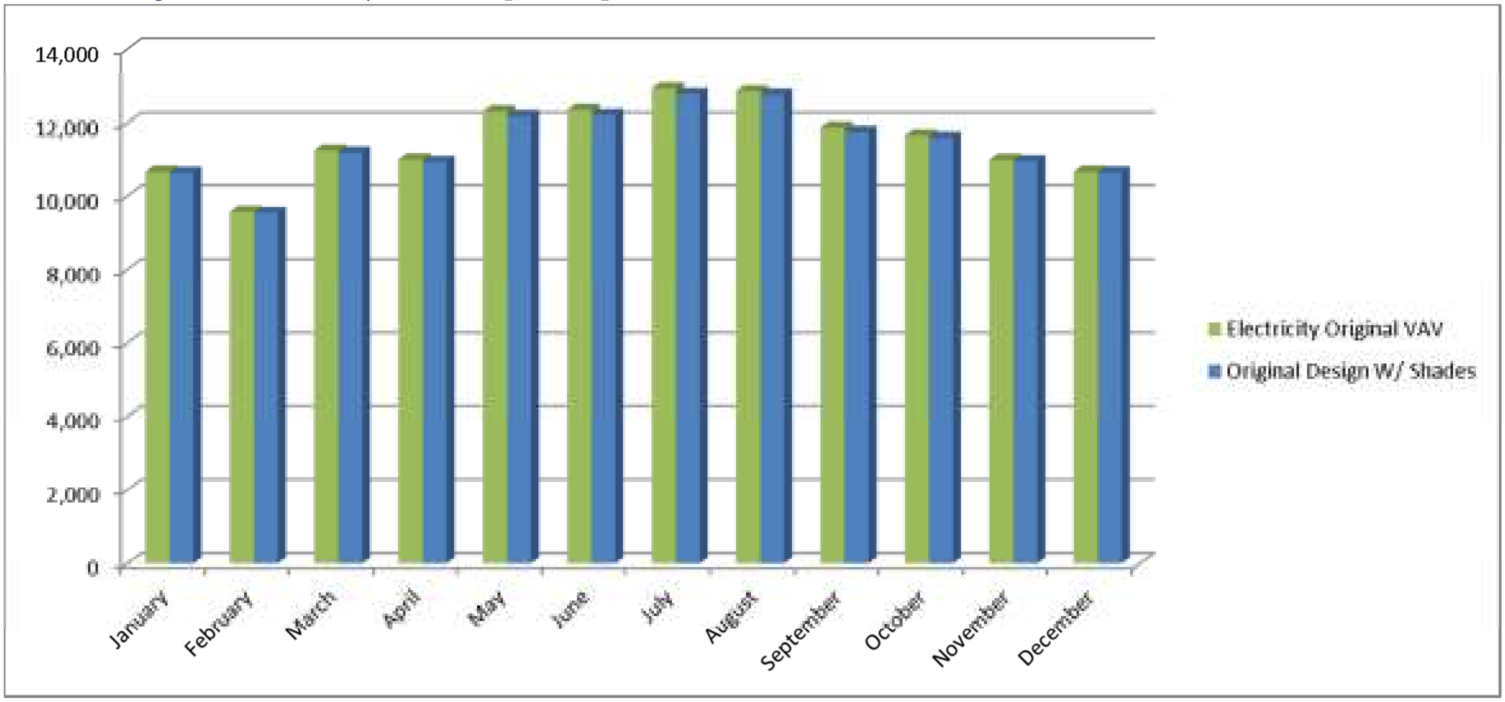
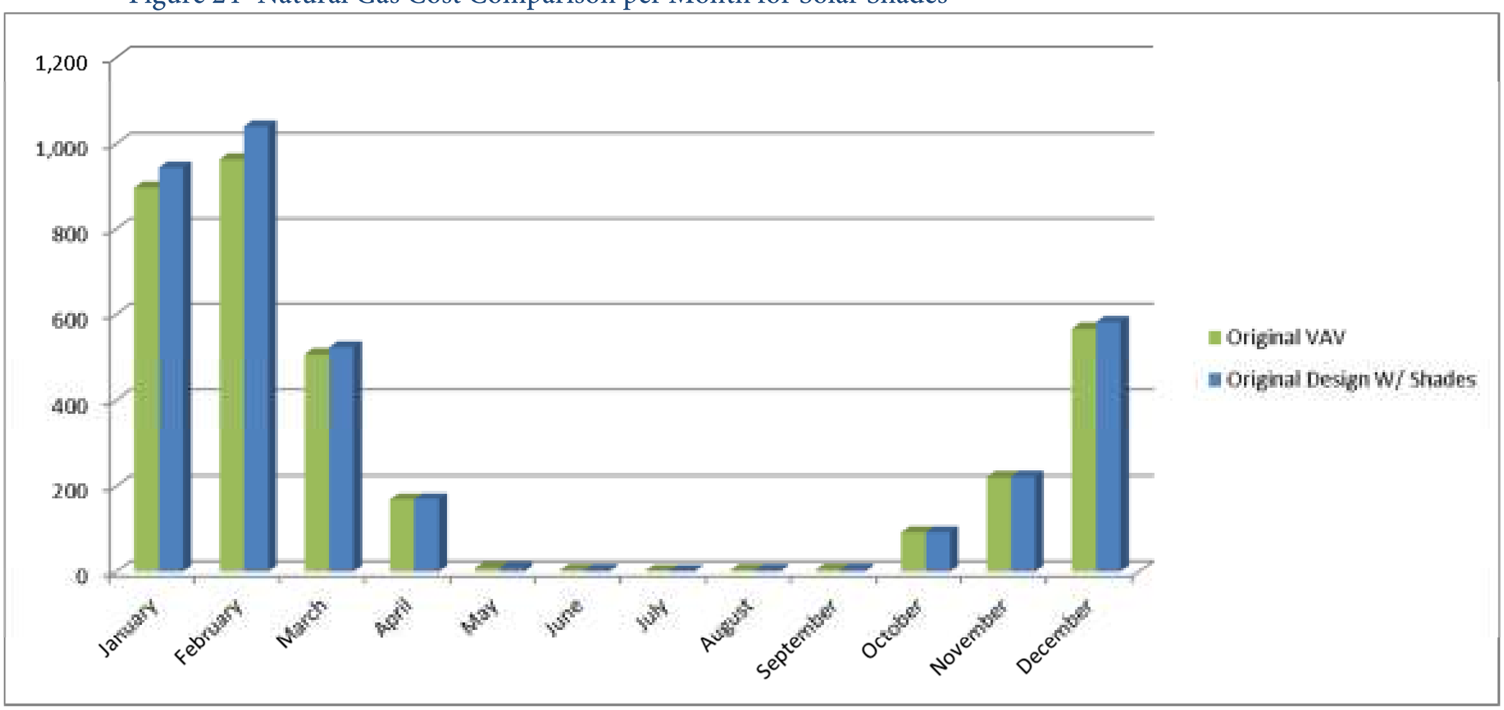


Figure 24- Natural Gas Cost Comparison per Month for Solar Shades



Discussion of Obtained Results:

The investigation of the DOAS with parallel systems did have pros and cons associated with the use of this system in the Grunenwald Science and Technology Building. With the parallel systems it was found that the radiant ceiling was not feasible as the percent of the ceiling area required to meet the sensible load that was not covered by the roof top DOAS unit were above 50 percent of the area. This is not feasible as the ceiling is used for the lighting systems and for the diffusers in each of the zones. This led to the selection of the chilled beams that did not require more than 20 percent of the ceiling area for the passive units and less than 10 percent for the active units. The initial cost for either of the chilled beam units was found to be greater than that of the original VAV system, with payback periods of between 2.48 and 6.45 years. These payback periods are low and could be a system that would be able to provide savings to the owner in a reasonable time frame. The passive did have a lower payback period even though there were twice as many units that had to be used in the laboratory zones. This is due to the lower initial of each unit of $306 compared to the initial cost of $750 for the active chilled beams. The lower additional costs combined with the larger energy savings seen in the passive chilled beam parallel system led to the payback period being shorter by nearly 4 years over the use of the active chilled beam parallel system.

The payback periods that were found through the above calculations for the two different fluids used in the Geothermal Heat Pumps. The payback periods were over 27 years which is not reasonable for a return on the additional first costs of the system. Even though the energy savings for this system was the greatest, but the first cost for the geothermal system was high due to the additional site work and equipment needed for the system. The high first cost lead the payback period to be very high. Most owners would not consider the system since the return on their investment is just about as long as the life of some of the systems used in the building or even the building itself. The same is true for the fixed horizontal solar shades in which the payback period was over 28 years due to the energy savings each year being minimal.

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Appendix

Pump Selection:

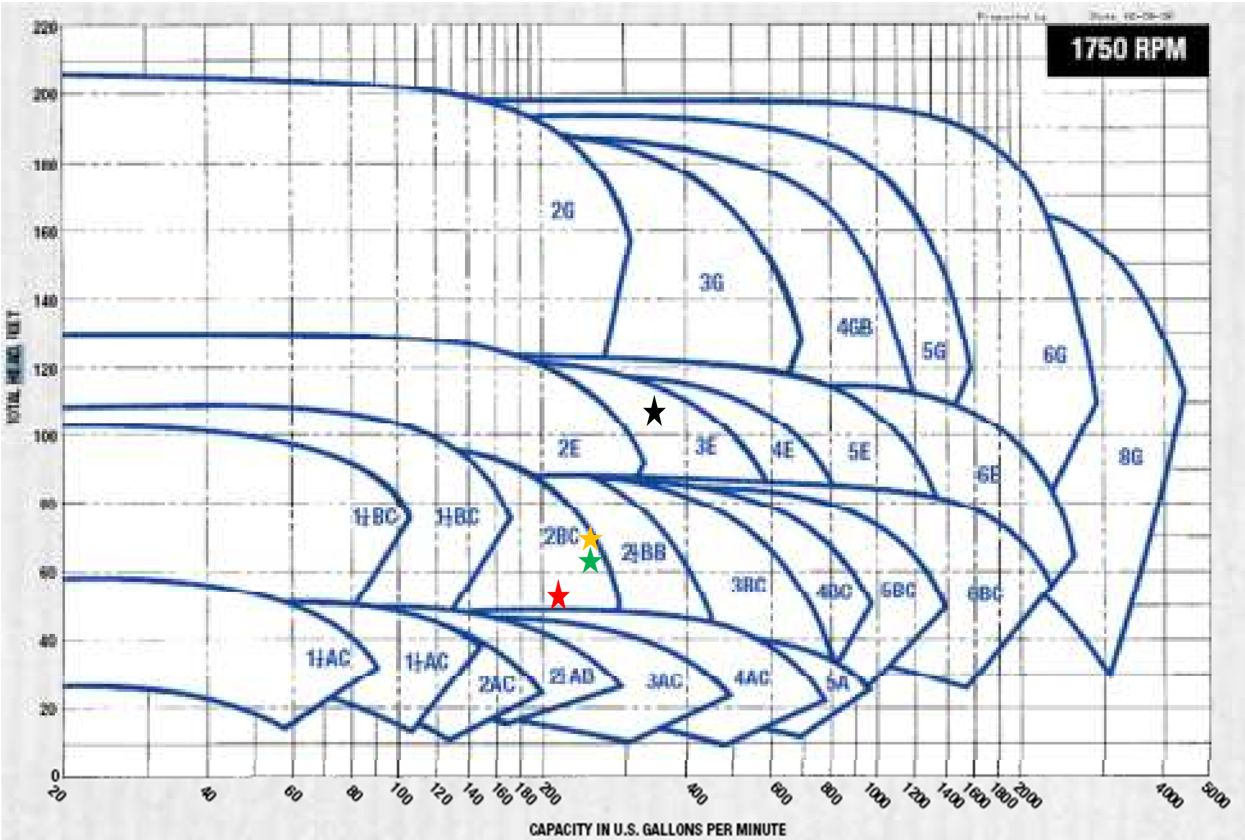
Loop- Pump Selection

Loop 1- Red

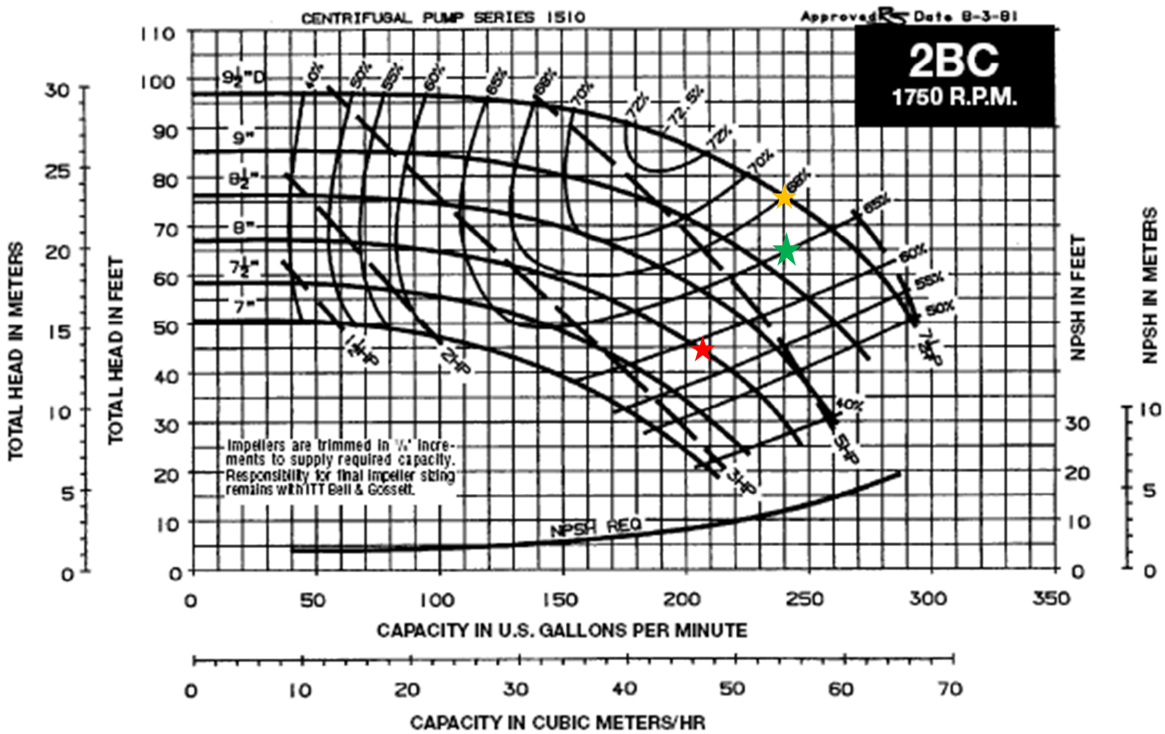
Loop 2- Green

Loop 3- Yellow

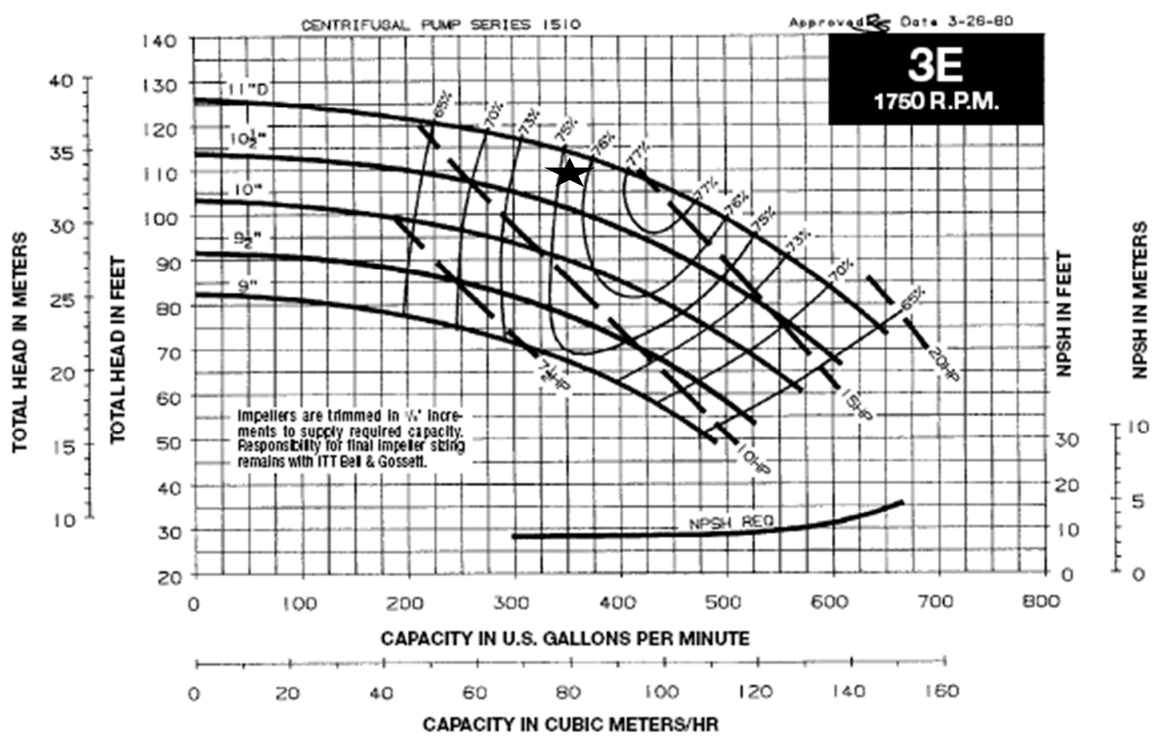
Loop 4- Black



Pump 2BC:



Pump 3E:



Solar Shade Calculations:

Solar Shade Depth Calculations

α - Solar Height or Solar Altitude

ϕ - Solar Azimuth

ψ - Plane Azimuth

For South Facade

Summer Solstice - Block entire window

$$h = \frac{D \times \tan\alpha}{\cos(\phi - \psi)} \longrightarrow D = \frac{5.833' \cos(0)}{\tan(72.3)}$$

$$D = 1.86 \text{ ft}$$

Window inset 4" So Depth of Shade

$$D_s = 1.86' - 4'' = 1.53 \text{ ft}$$

$$\boxed{D_s = 1'\text{-}7''}$$

Winter Solstice - Check with 1.86' overhang total

$$h = \frac{1.86' \tan(25.3)}{\cos(0)} = 11'' - 6'' = 5''$$

Distance Above Window

$\therefore$ 5" of window blocked on Winter Solstice

For Southwest Facade

Summer Solstice - Block entire Window

$$D = \frac{5.833 \cos(45)}{\tan(72.3)} = 1.33' - 4'' = 1 \text{ ft}$$

Window overhang

$$\boxed{D_s = 1 \text{ ft}}$$

Winter Solstice - check total overhang 1.33 ft

$$h = \frac{1.33' \tan(25.3)}{\cos(45)} = 0.89' = 11'' - 6'' = 5''$$

Distance Above Window

$\therefore$ 5" of window will be shaded in Winter Solstice

Solar Shade As-Designed Revit Renderings:

South Facade Space- Summer Solstice:

South Facade Space- Winter Solstice:

South Facade Space- Equinox:

Southwest Facade Space- Summer Solstice:

Southwest Facade Space- Winter Solstice:

Southwest Facade Space- Equinox: