FINAL REPORT

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Mechanical

This document contains the results of several studies conducted as a requirement of the Pennsylvania State University Architectural Engineering Program. Found within are proposed design modifications to the St. John Student Center located on McDonogh's campus in Owings Mills, Maryland. This report was created for speculation only and should not be used as a basis for actual changes to the current systems at the Student Center.

The Pennsylvania State University
Architectural Engineering
Advisor: Dr. Bahnfleth
07 April 2011

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McDonogh School Campus Green Project

Owings Mills, MD

Project Information:

Delivery Method - Design-Bid-Build
Operational Date - September 2012
Occupancy - K-12 Boarding School
Size - 68,000 SF
Cost - $16,000,000

Primary Project Team:

Owner - McDonogh School
Architect - Bowie Gridley Architects
Civil Engineer - Matis Warfield
MEP Engineer - James Posey Associates, Inc
Structural Engineer - Linton Engineers, LLC

Lighting:

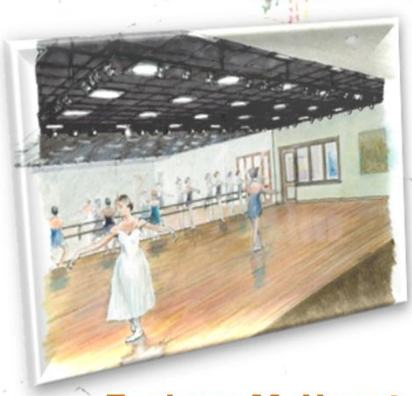
Each space will be tailored with its own unique lighting. Large "breath-taking" suspended fixtures combined with daylight will provide the perfect proportions of light to accommodate dining halls. Conference rooms will be well equipped with an array of lighting fixtures for different control configurations. Offices will receive recessed fixtures and the lecture hall will be furnished with dimmable house lights and regular stage lighting.

Electrical Systems:

Both 480V-3 phase and 120V-1 phase services will be used to energize the building. An emergency generator will serve multiple buildings including the St. John Student Center in order to prevent power loss. Certain lighting fixtures and the smoke exhaust system will remain active should power loss occur.

Mechanical System:

The St. Johns Student Center will have an HVAC system primarily comprised of multizone and single-zone Variable Air Volume (VAV) air handling units with chilled water cooling coils and hot water heating coils. There will be 5 single zone VAV air handling units and 1 Constant Volume air handling unit for a total of 6 units. These units will receive chilled and heating water from a new central plant. A tremendous amount of thought has gone into the location of the units due to architectural concerns.



Structural System:

The overall structural system is an all concrete building with self supporting 2-way slabs. Concrete beams and columns are used in order to support the longer spans. In an effort to decrease the size of the concrete beams, supplemental steel was implemented. Custom made, prefabricated light gauge steel trusses top the building in order to support the roofs and attic spaces.

Architecture:

The student center is to become the hub of McDonogh campus. It will be tailored with a 3 story lobby/atrium that will require smoke exhaust, chimneys will be used for building exhaust and the beautiful copula will allow for air intake thus hiding all mechanical equipment. The dining room interior is to be architecturally classic, having high ceilings and large windows, maximizing the amount of light being able to enter.

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Mechanical

www.engr.psu.edu/ae/thesis/portfolios/2011/zmh5001

Executive Summary

The St. John Student Center is being constructed on the existing campus of McDonogh School located in Owings Mills, Maryland. The Student Center is one of several new buildings being added to the campus. The Center is a 3 story, 68,000 square foot facility that houses a 3 story lobby/atrium, dining halls, commercial kitchens, a grand auditorium, a dance studio, and classrooms that range from art and photo to general seminar.

The mechanical system that was designed for the Center uses a combination of VAV and CAV technologies. The AHUs supply air to remote VAV and CAV boxes located throughout the building which provides occupancy control. The central plant located elsewhere on the campus produces both heating and chilled water. The chilled water in the plant is produced via electricity while the heating water is produced via natural gas.

Several alternatives were selected to be analyzed to meet the goals of reducing the peak energy consumption with a reasonable payback period. The alternative design options that were selected to be analyzed were implementing a geothermal well field, upgrading the glazing to Solarban 70XL glass, and adding a total energy wheel to the AHU that serves the art classrooms. A geothermal well field can reduce energy consumption by a great deal due to the consistency of the grounds temperature being held at 55°F. Improving the glazing of the building is a highly beneficial way to improve on the buildings overall energy consumption level. The improved glass offers a superior U-value and shading coefficient at a reasonable price. The addition of a total energy wheel on the art classrooms will be a great addition. With the amount of exhausted air produced by these classrooms it is expected to be able to recover a substantial amount of valuable air.

Due to the increased complexity with a ground source heat pump or (GSHP) a reallocation of the budget, time, and manpower must be made in order to accomplish a successful installation. The total energy wheels will increase the size of the AHU located in the attic. The attic will need to be tailored to fit a larger such unit. This tailoring would include possibly resizing the structural support members. In order to ensure proper support a full structural check was performed.

After the analysis was performed a combination of all three upgrades was selected due to its relatively low payback period of 12 years. If the owner was working with a tight budget and could not afford to initial upfront costs of the GSHP but still wanted be energy conscious they could elect to upgrade the glass and install a total energy wheel to yield a 2.5 year payback period. This combination does not save as much energy but is a very cheap upfront cost and still yields a substantial energy savings.

Mechanical System Description

Overview:

The St. John Student Center is one of several new buildings being added to McDonogh School. The building is a 3 story, 68,000 square foot facility that houses various types of spaces. This Student Center has a 3 story lobby/atrium, dining halls, commercial kitchens, an auditorium and dance studio, offices, conference rooms, and classrooms that range from art and photo to general seminar. The Center is to become the hub of McDonogh campus. An aerial view of the campus can be seen in Figure 01 on the right with the Student Center being located in the bottom left corner of Figure 01. The Center was to blend in with the existing buildings so all HVAC equipment was not to be visible from the outside. Special considerations have been taken into account to place things like exhaust and outdoor intakes. Several outdoor air intakes have been places inside of the cupola located on the main roof of the Student Center to comply with this request.

Figure 01 – McDonogh Campus

Mechanical Design Objectives:

McDonogh is a school that embraces diversity of background, culture, and thought. The school was founded in 1873 as a farm school for poor boys; the school is now situated on nearly 800 pastoral acres in Owings Mills, Maryland. Special considerations were taken into account during the design of The Student Center in order to complement the surrounding buildings. This includes special considerations for the mechanical designs as well.

An effective Heating, Ventilation, and Air Conditioning (HVAC) system was designed to be installed in the new Student Center in order to provide a more productive, comfortable and nontoxic environment for all the building occupants. The HVAC system was designed to meet all International Building Codes (IBC) and all International Mechanical Codes (IMC). The system was also designed to meet the minimum ventilation rates prescribed in ASHRAE Standard 62.1. Since there are classrooms located in the Center, the mechanical system designed will be very reliable to ensure a proper learning environment.

Due to the dense population of this building the occupants are at a much higher risk of obtaining an illness. This increased chance of illness means that the indoor air quality must be a high concern. Building pressurization and envelope construction quality help to ensure the quality of air found within the various spaces by preventing unconditioned air from leaking in through the envelope and becoming a place for mold and other bacteria's to grow.

Equipment Summary:

The Student Center utilizes two different types of air systems. The majority of the building is conditioned by Variable Air Volume units, and the remainder of the Center is conditioned by a Constant Volume unit.

The HVAC system receives heating and chilled water from a new central plant. A tertiary pumping system will be utilized for distribution within the building. The system will be designed by taking load diversity into consideration. The total cooling load from the Center's HVAC system is approximately 400 tons, while the heating load is approximately 3300 MBH. Tables-01 through 04 shows summaries for the AHUs, fans, VAV boxes, and unit heaters.

Table 01 – Air Handling Unit Specifications

	Unit Airflow (CFM)	Outdoor Airflow (CFM)	Filter Rating
AHU-1	10,000	3,500	7
AHU-2	4,000	800	7
AHU-3	7,400	1,700	7
AHU-4	11,400	3,500	7
AHU-5	11,400	3,500	7
AHU-6	4,000	1,500	7
AHU-7	15,605	9,480	7
AHU-8	**15,535**	**12,535**	**7**

Table 02 – Exhaust Fan Specifications

Fan	Duty	CFM	SP (IN WC)	Fan RPM	HP (Watts)	Wheel DIA (IN)
EF-4	Exhaust	1,500	0.75	969	1/2	18.25
EF-5	Exhaust	750	1	1464	1/2	13.5
EF-6	Exhaust	3,510	2	1273	3	22.25
EF-7	Exhaust	9,685	1.75	940	7.5	36.5
EF-8	Exhaust	4,300	1.5	1366	3	22.25
EF-9	Exhaust	1,750	1.5	1600	2	16.5
EF-10	Exhaust	500	0.75	1579	1/2	10.5
EF-19	Smoke Exhaust	54,000	2.5	787	40	60
EF-20	Smoke Exhaust	54,000	2.5	787	40	60
RF-5	Return	9,000	1.5	678	5	36.5
RF-6	Return	9,000	1.5	678	5	36.5
RF-7	Return	6,075	1.5	825	5	30
RF-8	**Return**	**3,200**	**1.25**	**1043**	**2**	**22.25**

Table 03 – VAV Box Specifications

	Max Airflow (CFM)	Min Airflow (CFM)	MBH	EWT (°F)	EAT (°F)	LAT (°F)
VAV 7-1	1,845	1,645	79.9	180	55	100
VAV 7-2	300	300	14.6	180	55	100
VAV 7-3	1,160	1,160	81.4	180	55	120
VAV 7-4	1,250	1,250	60.8	180	55	100
VAV 7-5	400	400	19.4	180	55	100
VAV 7-6	1,400	1,200	58.3	180	55	100
VAV 7-7	2,050	650	31.6	180	55	100
VAV 7-8	1,500	600	35.6	180	55	110
VAV 7-14	1,200	500	24.3	180	55	100
VAV 8-1	200	100	4.9	180	55	100
VAV 8-2	1,000	600	29.2	180	55	100
VAV 8-3	800	300	14.6	180	55	100
VAV 8-4	**1,700**	**550**	**26.7**	**180**	**55**	**100**

Table 04 – Cabinet Unit Heat Specifications

Unit Heater	CFM	MBH	GPM (At 180°F)	Max Head (Ft)
CUH-1	345	22.6	3	5
CUH-2	345	22.6	3	5
CUH-3	345	22.6	3	5
CUH-4	345	22.6	3	5
CUH-5	495	45.2	2	5
CUH-6	495	45.2	2	5
CUH-7	345	22.6	3	5
PUH-1	630	25.5	3	5

System Operation:

- ### Airside System Operation:

For the VAV system, anytime an AHU is demanded to run a supply fan is started. The fan VFD speed will modulate to maintain the duct static pressure set point. Consequently the return fan will run anytime the supply fan is running. Both the supply and return fan VFDs are modulated together. Like all buildings both fans are set to produce a net positive building pressure.

There are multiple VAV boxes located throughout the facility that will then receive the conditioned air and disperse accordingly to the individual rooms. The initial start command is sent to the AHUs based on the occupancy schedule. The VAV box will modulate depending on what room needs more air or less air.

Exhaust fans located in the atrium are triggered to go off in the event of smoke detection in the space. The smoke control system will include exhaust fans located on the Lobby roof with make-up air provided through all entrance doors at grade (doors will automatically open during smoke control operation). These exhaust fans have been carefully located to not recirculate smoke into the AHUs intakes.

- ### Waterside System Operation:

The central plant mechanical equipment and associated systems will be provided with a web based direct digital control (DDC) system, using native BACnet protocol. The central plant will include both chilled water generation and high temperature hot water generation equipment. High temperature hot water will be produced in the central plant and distributed to the Student

Center this process can be seen in Figure-04. The Center also houses converters that will also be fed the high temperature hot water. These converters will be high temperature, hot water to low pressure steam feeding unfired steam generators. The low pressure steam will be distributed to the existing campus until renovation of the facilities is completed.

Chilled water will be distributed from the central plant to the Student Center as well which is illustrated in Figure-02 below. The main distribution piping is sized to include the future expansion of the campus. The chillers will be utilized to generate chilled water at 42°F. The chilled water pumping systems will be designed for a 16°F temperature drop. Chiller 1 is a 300 ton electrical water cooled centrifugal chiller with an evaporator flow of 450 GPM and a condenser flow of 900 GPM. The evaporator is to have an EWT of 58°F and thus a LWT of 42°F and a 15 feet maximum pressure drop. The condenser will have an EWT of 85°F and a LWT of 95°F and a 15 feet maximum pressure drop.

The cooling towers are induced draft and will run whenever a chiller is called upon to run. Figure-03 below shows this process. The cooling tower VFD fans maintain a set point of 85°F for the condenser water supply temperatures.

Schematics:

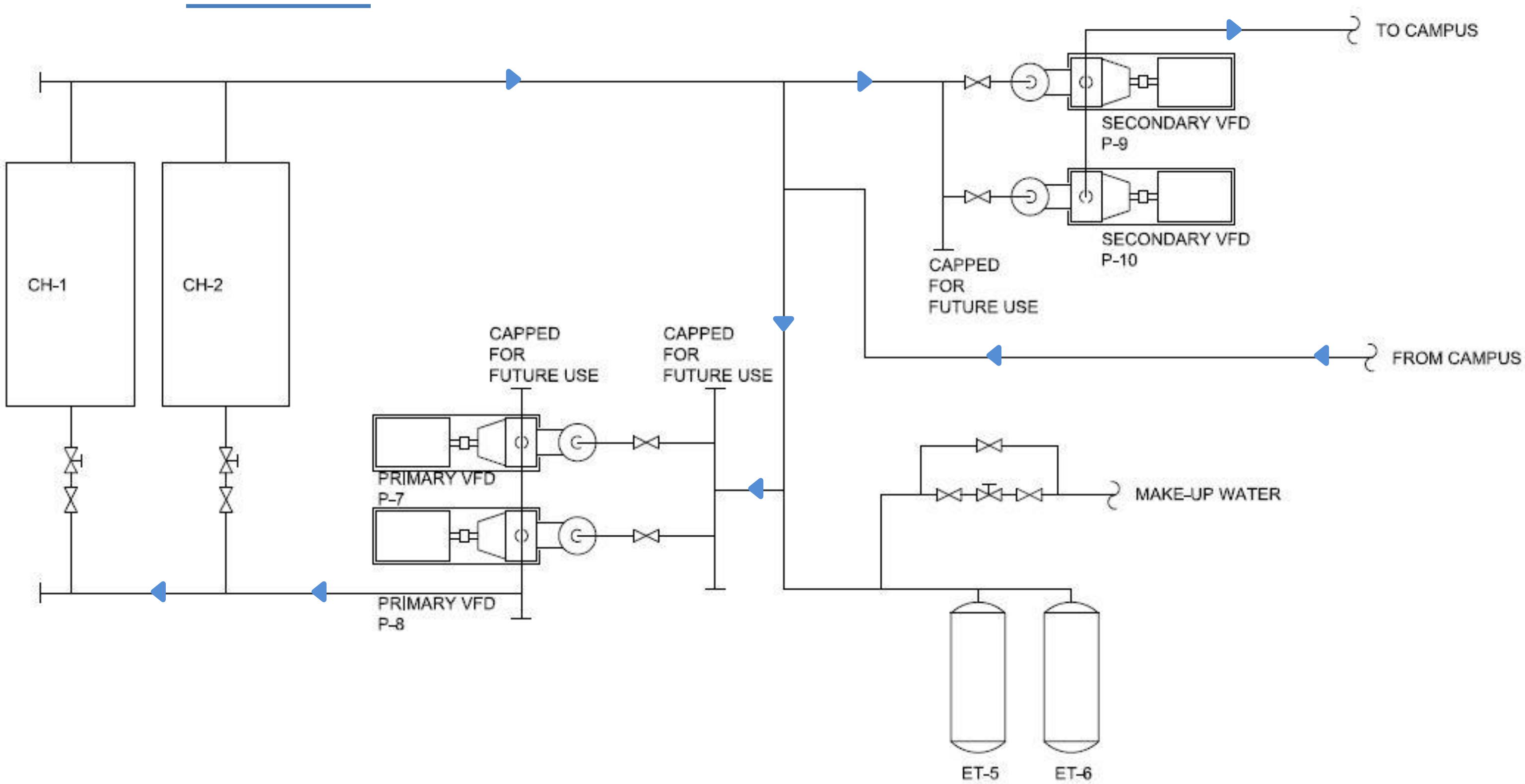


Figure 02 - Chilled Water System Schematic (Primary/Secondary Pumping)

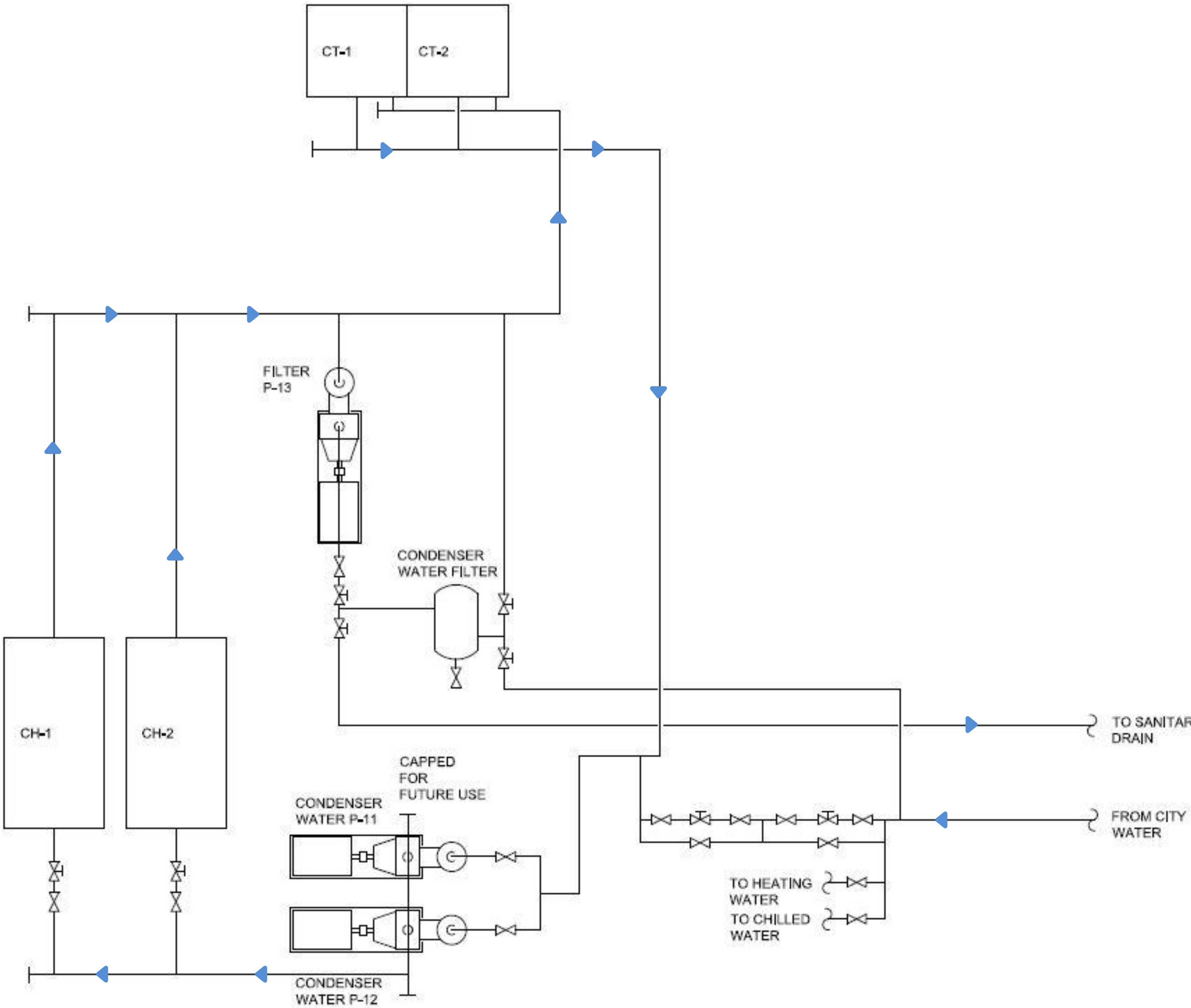


Figure 03 – Condenser Water System Schematic

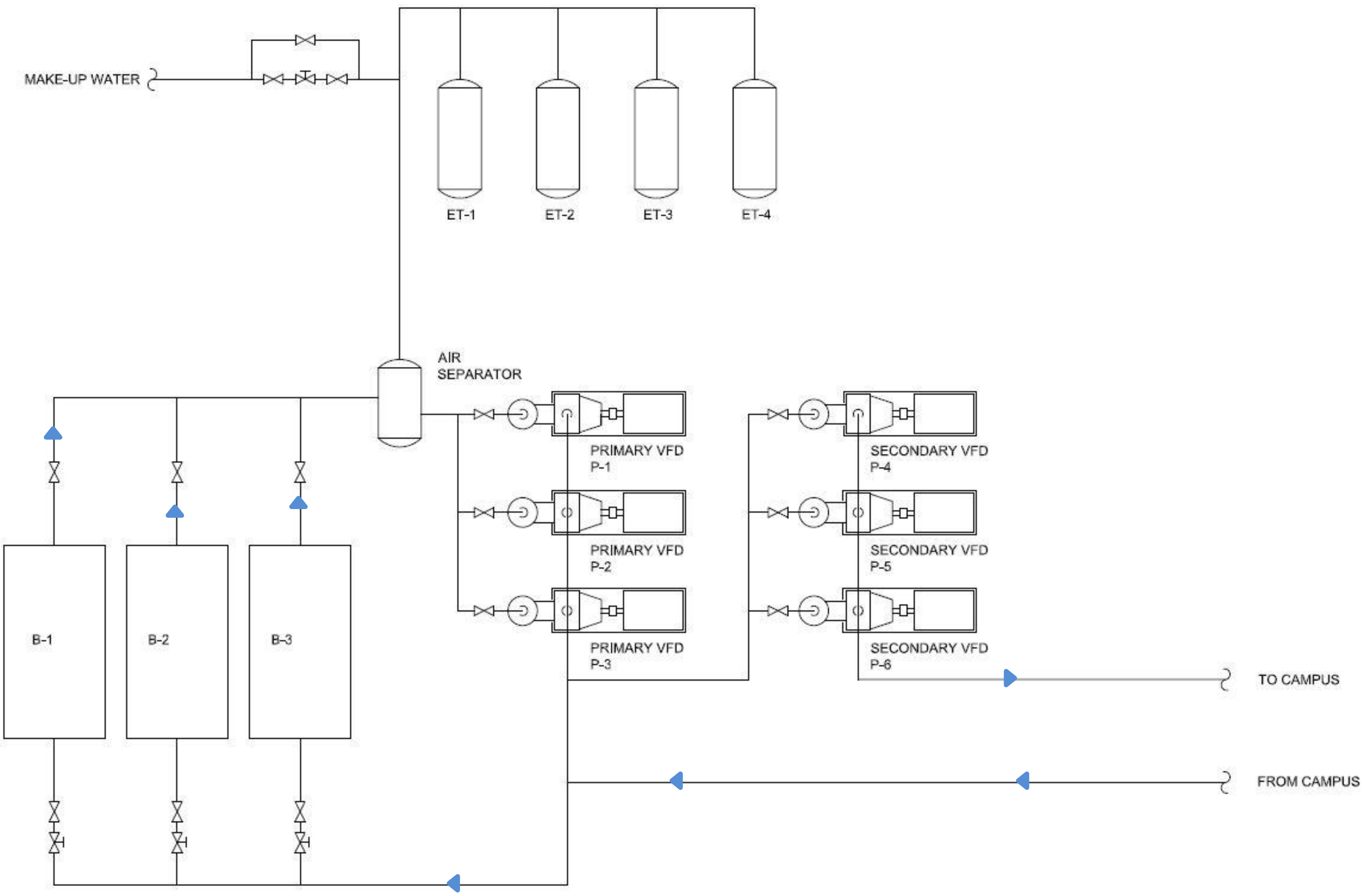


Figure 04 – Heating Water System Schematic

Energy Sources:

Possible energy sources that the Center is able to utilize include electricity, natural gas, and fuel oil. The fuel oil is to only be used as a back-up to the natural gas. The electricity and natural gas are provided by Baltimore Gas and Electricity and the rates for both can be found below in Table-05.

Table 05 – Energy Rates

Utility Energy Rates	
	Local Rate
Electricity Costs ($/kWh)	0.12
Natural Gas Cost ($/Therm)	1.11

Design Conditions:

The outdoor design conditions that were used for this site as well as the indoor design conditions for each space type can be found in Tables 06 and 07. The outdoor deign conditions were taken from either the ASHRAE Handbook of Fundamentals or from the weather data that was loaded within the Hourly Analysis Program (HAP). The indoor design conditions were taken from the mechanical design documents, both winter and summer seasons are listed.

Table 06 – Outdoor Design Conditions

Outdoor Design Conditions		
	Dry Bulb	Wet Bulb
Summer	95°F	78°F
Winter	0°F	-

Table-07 – Indoor Design Conditions

Indoor Design Conditions		
	Dry Bulb	Relative Humidity
Summer	75	50%
Winter	70	-

Mechanical System Cost:

The total mechanical system cost is approximately $4,000,000. This is a total price for the entire HVAC system. Breaking this system cost down on a per square foot basis it yields a cost of $58.82/SF. The mechanical system cost is lower then other building types due to the simplicity of the systems.

Design Factors:

The only design conciderations were to complement the surrounding buildings and to have no visible HVAC equipment. Chimneys are to be used for building exhaust and the copula will allow for air intake thus hiding all mechanical equipment. Other design factors could be obviously observed. The Center is located in Owings Mills, Maryland which is defined by having mixed weather conditions that can have periods of high humidity. For obvious reasons humidity will be a high concern. The buildings façade design includes only 22% glazing so heat loss durning the winter should not be much of a concern. Consequently solar heat gain during the summer should not be much of a concern either.

Design Ventilation Requirements:

Minimum ventilation rates that need to be supplied to all occupied spaces were determined by doing an analysis of ASHRAE Standard 62.1. The HVAC system supplies a large amount of art classrooms and these spaces must be exhausted. Due to the high amount of exhaust requirements the minimum ventilation rates prescribed by ASHRAE Standard 62.1 will always be exceeded.

A ventilation calculation was performed and then they were compared to the ventilation rates that were calculated by the design engineer. The ventilation rates that were calculated by the design engineer and within the Standard 62.1 analysis are shown below in Table-07. As you can see the results are nearly identical. The results vary slightly most likely due to different assumptions and the design engineer most likely used safety factors.

Table-08

Design Ventilation Requirements	
	CFM
Standard 62.1 Minimum	38177
Designed	38315
Percent Difference	0.36%

Estimated Design Loads:

Carriers Hourly Analysis Program (HAP) was used in order to predict the annual energy consumption. Table-09 below summerizes the total cooling MBH, heating MBH, supply air CFM, and ventilation CFM for each AHU.

Table 09 – System Load Analysis

System Load Analysis									
		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	AHU-6	AHU-7	AHU-8
Cooling (MBH)	Modeled	427	154	156	49	275	298	277	577
	Designed	1194	208	319	166	503	543	543	1025
Heating (MBH)	Modeled	160	118	67	41	114	142	148	286
	Designed	662	173	320	173	432	492	492	672
Supply Air (CFM)	Modeled	14064	4057	3303	701	5833	5886	5245	17572
	Designed	15335	4000	7400	4000	10000	11400	11400	15555
Ventilation (CFM)	Modeled	2436	1652	1456	701	2743	3277	3277	4247
	Designed	12335	3500	1700	800	3500	3500	3500	9480

There is some discrepencies when comparing the design versus the modeled cooling loads. As you can see from Table-08 the modeled loads are much less than the design loads. This is most likely attributed to the fact that a default chiller had to be used in the energy model because the chillers have not been finilized at this point. The mechanical designer most likely used safety facors while designing which would lead to a greater total MBH.

The total heating loads were also much lower when modeled versus designed. This again can be attributed to the fact that a default boiler was selected to do the energy model and that the mechanical designer most likely used safety factors again.

In general the modeled building was fairly different then what was designed. The Student Center was not required to have an energy model which is where these differences can largely be attributed to. Also because the boilers and chillers had to be defaults in HAP, thus creating discrepancies between what was modeled and what was designed. Finally the last source of error could be attributed to the fact that the model was done by block analysis and is less accurate then a room by room analysis.

Annual Energy Use:

As previously stated the Student Center was not required to perform an energy model and thus a comparison between what was modeled versus what was designed cannot be done. Table-09 below shows the annual energy consumption in both kBTU and kWh. Because the annual energy consumption was calculated in kBTU the number could be compared to the 2003 Commercial Buildings Energy Consumption Survey (CBECS). The average educational building for CBECS in 2003 had approximately 83.1 kBTU/SF. The Student Center came in at 25 kBTU/SF. The numbers in the model were most likely lower than the average because the Student Center is not a typical educational facility. This Center does have classrooms located within; however it has been tailored with a variety of different spaces as well. Some unique spaces found within the Student Center include but are not limited to; a 3 story lobby/atrium, conference rooms, dance studio, and a café. Referencing Figure-05 it is clear to see that the building lights consume the most energy. This is due to the fact that the lighting was designed for a much more aesthetically pleasing interior.

Table 10 – Annual Energy Consumption

Annual Energy Consumption		
	Energy (kBTU)	Energy (kWh)
Cooling	294,192	98,572
Heating	931,417	19,995
Pumps	211,009	61,995
Cooling Tower Fans	87,962	26,527
Lights	489,285	197,905
Electrical Equipment	81,657	86,267
Grand Total:	**2,095,522**	**491,261**

As shown above the largest consumer of energy is the lights, followed by cooling. The cooling load is also greater than the heating load which makes sense due to the location of the Student Center. Figure-05 below shows the annual energy consumption as an overall percentage.

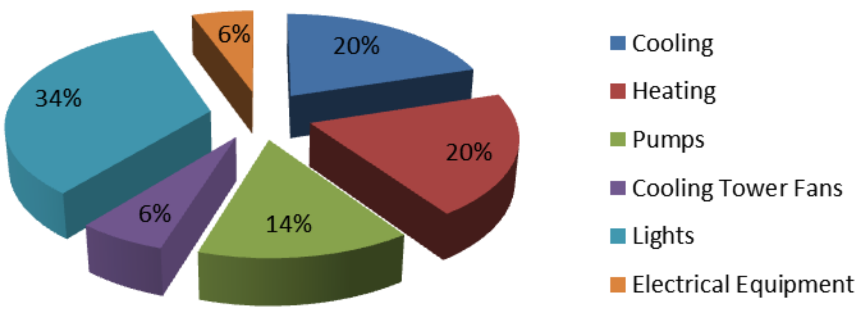


Figure 05 – Annual Energy Consumption

In addition to the annual consumption, a monthly consumption was also computed. Figure-02 illustrates the monthly energy consumption by energy type. In the Figure it is clear to see that it makes sense that the heating load will be lower during the summer months and higher in the winter months as seen in the figure.

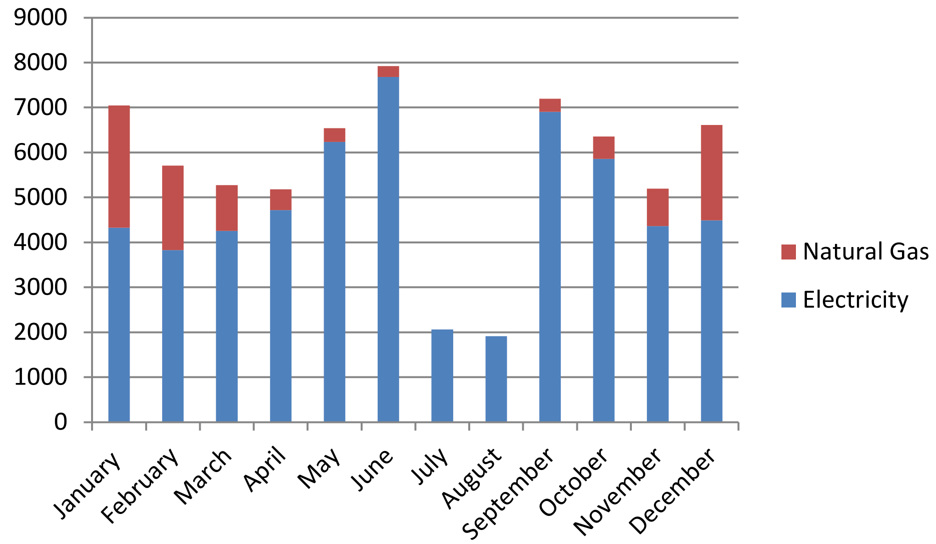


Figure 06 – Monthly Energy Consumption

Mechanical Systems LEED Analysis:

The Leadership in Energy and Environmental Design (LEED®) was created by the United State Green Building Council (USGBC) to help designers and building owners realize how important it is to practice energy efficient and environmentally friendly construction techniques. There are two categories within LEEED that are influenced directly by the mechanical design engineer. These two categories are; Energy and Atmosphere (EA) and Indoor Environmental Quality (IEQ). The Student Center is not currently seeking any LEED status. This analysis only considers potential credits from both of these categories.

- ### Energy & Atmosphere:

EA Prerequisite 1: Fundamental Commissioning of Building Energy Systems - Complies

Intent: To ensure that the mechanical systems are installed, and calibrated to perform according to the mechanical design engineers specifications.

Student Center: A commissioning authority will perform a full controls and mechanical system run through. All results gathered will be directly turned over to the owner.

EA Prerequisite 2: Minimum Energy Performance – N/A

Intent: To establish the minimum level of energy efficiency for the building and systems to reduce enviromental and economical impacts associated with excessive energy use.

Student Center: Because the building was not looked at for achieving LEED status this credit can not be accounted for. The mechanical design engineer has full confidence that this credit would be achieved if the Center was opting for LEED status.

EA Prerequisite 3: Fundamental Refrigerant Management – Complies

Intent: To reduce stratospheric ozone depletion by eliminating the use of chlorofluorocarbon (CFC)-based refrigerants in the buildings HVAC systems.

Student Center: The refrigeration used within the Center is R-134a, which is an HFC refrigerant.

EA Credit 1: Optimize Energy Performance – N/A

Student Center: Because the building was not looked at for achieving LEED status this credit can not be accounted for. The mechanical design engineer has full confidence that this credit would be achieved if the Center was opting for LEED status.

EA Credit 2: On-site Renewable Energy – Noncompliant

Intent: To reduce the impacts that fossil fuel energy sources create.

Student Center: Renewable energy sources such as; wind, solar, geothermal, or biomass was not used thus the Center did not receive any points for this credit.

EA Credit 3: Enhanced Commissioning – Complies

Intent: To begin the commissioning process early in the design process.

Student Center: The specifications state that the owner will have a separate commissioning authority. All results will be turned over to the owner.

EA Credit 4: Enhanced Refrigerant Management – N/A

Intent: To reduce ozone depletion and support compliance with the Montreal Protocol.

Student Center: Since refrigerants have been selected to be used within the Center the following formula must be followed. A refrigeration calculation cannot be completed because the equipment has not been fully scheduled at this point.

$$\mathbf{LCGWP + LCODP \times 10^5 \leq 100}$$

Where:

LCODP = [ODPr x (Lr x Life +Mr) x Rc]/Life

LCGWP = [GWPr x (Lr x Life +Mr) x Rc]/Life

LCODP: Lifecycle Ozone Depletion Potential (lb CFC 11/Ton-Year)

LCGWP: Lifecycle Direct Global Warming Potential (lb CO2/Ton-Year)

GWPr: Global Warming Potential of Refrigerant (0 to 12,000 lb CO2/lbr)

ODPr: Ozone Depletion Potential of Refrigerant (0 to 0.2 lb CFC 11/lbr)

Lr: Refrigerant Leakage Rate (0.5% to 2.0%; default of 2% unless otherwise demonstrated)

Mr: End-of-life Refrigerant Loss (2% to 10%; default of 10% unless otherwise demonstrated)

Rc: Refrigerant Charge (0.5 to 5.0 lbs of refrigerant per ton of gross ARI rated cooling capacity)

Life: Equipment Life (10 years)

Once the refrigerants have been fully scheduled this calculation would need to be done. The corresponding value would need to be less than 100 in order to achieve compliance.

EA Credit 5: Measurement and Verification – Noncompliant

Intent: To provide for the ongoing accountability of building energy consumption over time.

Student Center: This project was not required by any contract to perform an energy model, nor was it required to monitor the energy use for an entire year after occupancy occurs. The result is that this project does not receive any points for this credit.

EA Credit 6: Green Power – Noncompliant

Intent: To use renewable energy technologies on a net zero pollution basis.

Student Center: The Student Center will not be purchasing any of its power through a program that generates electricity using green power. Due to this the result is that the project does not receive any points for this credit.

- ## Indoor Environmental Quality:

IEQ Prerequisite 1: Minimum Indoor Air Quality Performance – Complies

Intent: To establish minimum indoor air quality (IAQ) performance.

Student Center: Sections four through seven found in ASHRAE Standard 62.1-2007 have been met and detailed in Technical Report 1. Minimum mechanical ventilation rates were determined and have designed using the ventilation rate procedure outlined in ASHRAE Standard 62.1-2007.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control – Complies

Intent: To prevent or minimize exposure of building occupants to ETS.

Student Center: Due to the Student Center being an educational building smoking is not permitted indoors. Air intakes have been placed on the roof and therefore exceed the minimum distances prescribed in ASHRAE Standard 62.1.

IEQ Credit 1: Outdoor Air Delivery Monitoring – Complies

Intent: To promote occupant well-being through the ventilation system.

Student Center: The system is not 100% outdoor air and therefore CO_2 concentrations within the spaces are to be monitored. The result is that the Center receives one point for this credit.

IEQ Credit 2: Increased Ventilation – Complies

Intent: To supply additional outdoor air to improve the indoor air quality (IAQ).

Student Center: The ventilation rates supplied to each occupied zone exceed the 30% increase that ASHRAE Standard 62.1-2007 requires. The design engineer realized that due to the high amount of art classrooms that each space needed to far exceed the minimum ventilation rates. The result is that the Center receives one point for this credit.

IEQ Credit 3.1: Construction Indoor Air Quality Management Plan (During Construction) – Complies

Intent: To reduce IAQ problems resulting from the construction process.

Student Center: The International Mechanical Code is to be adhered to. Thus Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines will be met. Typical practice for the mechanical design engineers is to protect stored on-site and installed absorptive materials from moisture damage. The result is that the Center receives 1 point for this credit.

IEQ Credit 3.2: Construction Indoor Air Quality Management Plan (Before Occupancy) - Noncompliant

Intent: To reduce IAQ problems resulting from the construction process.

Student Center: Because the Center was not trying to achieve LEED status a total building flush out will not be performed. The result is that the Center does not receive a point for this credit.

IEQ Credit 4.1: Low-Emitting Materials Adhesives and Sealants – Complies

Intent: To reduce the quantity of indoor air contaminants that hinder the comfort of the building occupants.

Student Center: All adhesives that are to be used in the building are expected to meet or exceed the maximum VOC limits that are stated within this section. The result is that the Center receives one point for this credit.

IEQ Credit 6.2: Controllability of Systems (Thermal Comfort) – Complies

Intent: To provide a high level of thermal comfort control for individuals.

Student Center: Wall-mounted temperature sensors that are adjustable by the room occupants were put in all spaces. The temperature sensor controls the variable air volume terminal unit and associated reheat coil to maintain the space temperature set point.

IEQ Credit 7.1 Thermal Comfort (Design) – Complies

Intent: To promote occupant productivity and well-being by providing a confortable thermal environment.

Student Center: The HVAC systems that were designed meet the requirements stated by ASHRAE Standard 55-2004. The result is that the Center receives one point for this credit.

IEQ Credit 7.2: **Thermal Comfort (Verification) – Noncompliant**

Intent: To provide an assessment of the building occupant thermal comfort over time.

Student Center: To achieve compliance of this credit a thermal comfort survey must be given within 6-18 months after occupancy. There is no plan to have this survey take place and the result is that the Center does not receive a point for this credit.

Mechanical Systems LEED Conclusion:

The Student Center achieved a total of 11 points between the two mechanical categories. The center was able to achieve 3 points in Energy and Atmosphere, and was able to achieve 8 points in Indoor Environmental Quality. Considering that the Student Center was not going for any type of LEED certification the buildings mechanical system faired well, results show that LEED certification should be easily attainable.

Overall Evaluation of System:

The VAV and CAV systems used in the Student Center have been implemented in buildings for several decades. The VAV system has been proven to be very effictive in most applications. Due to the various activities that take place in a student center a VAV system has many advantages.

The VAV system was most likely selected due to its lower initial costs. This system also has very low maintenance costs while maintaining a high efficiency and is easy to manage.

Operating costs for the system were estimated in the HAP model to be approximately $1.04/SF (not including maintenance costs). The cost to maintain this system should be relatively low due to how common a VAV system is. The maintenance staff should not have any problems with the repair or replacement of mechanical parts.

Indoor Air Quality can be an issue with a VAV system. The problem lies at the roots of a VAV system; the air that is delivered to the spaces is a combination of ventilation and return air. If designed, installed, or balanced incorrectly supply airflow from the VAV box can modulate with no change in the outdoor air fraction. This will result in a lower then required ventilation rate. Wrong filter placement can also cause problems in this type of system. If they are not placed in the correct location or maintained, contaminants within the building can be re-circulated to all of the spaces within the building.

The mechanical system occupies some sort of space on all floors. The first floor houses plenum space only, while the other two floors contain both mechanical rooms and plenum space. The Student Center was fortunate to have a central plant located elsewhere on the campus to free up more additional space. The Center is to accommodate AHUs and pumps only. The attic managed to be architecturally pleasing while allowing additional space for AHUs. The plenum spaces have been enlarged to accommodate both supply and exhaust ductwork to be routed simultaneously.

The use of a primary secondary system has many advantages and is very reliable. To help reduce the amount of energy consumed a geothermal well field located in the new green space would be beneficial. Using a geothermal system may be investigated further during the next assignment.

The indoor air quality throughout the Center should be slightly better than that of a similar building due to the high amount of outdoor air required for the kitchens and art classrooms. As stated before due to the system mainly being a VAV system recirculation of contaminants could be a problem.

The Centers thermal comfort and environmental control are provided by the VAV boxes located within the building. Each of these VAV boxes typically serves multiple spaces similar in occupancy. Since the spaces are served by a VAV system each space should be able to achieve the desired level of comfort.

The overall mechanical system that was designed for the Student Center uses the principle aspects of a VAV system by creating a reliable and diverse system. The Center may be lacking energy recovery but this is not a concern due to the building not striving for LEED certification. Because of this making energy improvements to this system should be fairly simple. Potential areas of redesign have already risen and will be further investigated during this report.

Proposed System Alternatives:

The current VAV and CAV system that was designed satisfies the needs of the facility owner at a reasonable system cost. Other system options which will help to reduce the initial cost, total energy cost, and decreased payback period will be investigated during the next phase of research. In order to justify these changes an in depth evaluation of possible system redesign options will be conducted.

Due to the size of the building there are only a few practical areas that can be redesigned or adjusted within the entire mechanical system. Below is a list of possible changes that could be investigated.

-Investigating the utilization of Combined Heat and Power (CHP)

-Utilizing a ground source heat pump within a geothermal well field located in the new green space

-Incorporating total energy wheels

-Upgrading the glass to Solarban 70XL

-Investigating the use of heat recovery chillers

-Investigate utilizing passive chilled beams

Three possible areas from the list above have been chosen to be further investigated. Due to these changes being made to the mechanical systems other areas have been effected. Additional studies will be performed in the end to determine the effects that these proposed changes have on each other as well as determine the best combination that provides a decrease in energy consumption combined with a reasonable payback period.

Geothermal Well Field:

One major advantage of using a GSHP is that it uses water as opposed to air to transport heat. Water transfers heat 25 times faster than air and has a higher thermal capacity than air; this simply means that much less volume of water needs to be transported than air to have the same heat transportation effects. This in turn will create a reduction in energy consumption. Water to water heat pumps will be selected which would essentially create a chiller and boiler. There would be one set of heat pumps running in one direction to produce chilled water that serves the AHUs and another set that creates the heating water. The chilled water system would then reject heat into the ground while the heating water system would absorb heat from the ground. A downside of this proposal is that the initial cost would greatly be increased, however it is expected that the payback period will be substantial enough to offset these costs.

Total Energy Wheels:

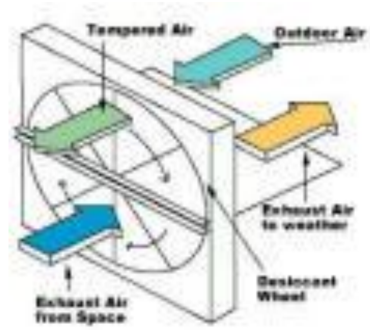


Figure 07 – Enthalpy Wheel

Total energy wheels would be an ideal installation for this student center due to the high amount of outdoor air required by code for art classrooms (0.7cm/sf exhaust). The process of how these wheels work is shown in Figure 07 on the right. Air in these classrooms is not allowed to be re-circulated by code. One minor problem that total energy wheels present is the increased size of AHUs. This building is to resemble and complement the architecture of the existing buildings. The AHUs are located in the attic space; this space is not designed for the extra height, width, and therefore weight that would be required for the new AHU. Special consideration would need to be taken into account for the structural support systems. One suggestion has been to use a dual plate heat exchanger energy recovery unit that operates at variable volume. One major downside for using a total energy wheel is yet again up-front costs. This will cause the initial cost of the buildings mechanical system to increase. However, once again it is expected to have a very lucrative payback due to the high volume of OA required for this building.

Solarban 70XL Glass Upgrade:

Upgrading the glass façade is something that has a relatively low upfront cost, lucrative payback period, and a substantial energy saver. It is expected that this upgrade will not only cut energy costs, it will cut energy consumption with a very quick payback period. This glass is also not expected to change the aesthetic appearance of the building due to the different combination of shading available.

Ground Source Heat Pump – Mechanical Depth

Redesign Objective

To design an effective GSHP in which energy reduction occurs along with a reasonable payback period. The Student Center's heating, ventilation, and cooling loads are handled by the eight AHUs located throughtout the center. These AHUs are fed by the central plant located elsewhere on McDonogh's campus. Therefore the goal for this depth is to eliminate the need of the central plant and provide year round cooling and heating with GSHPs.

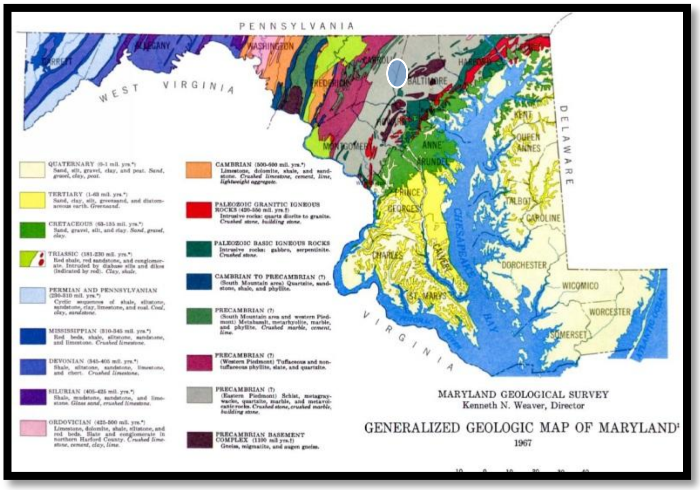


Figure 08 – Maryland Geological Survey

Site Geology Study

A proper study of the site geology is needed in order to achieve as successful design of a ground source heat pump. Both the soil and rocks located underground have varying thermal qalities that help to determine the effectiveness of the heat transfer to and from the ground. Typically, expensive borehole tests would need to be performed for a project this size in order to provide a proper analysis of the site's geology. Unfortunately the nature of this project does not allow for a test with this amount of detail, so an investigation into the known rock and soil types was performed. The map shown in Figure 08 is taken from the MGS (Maryland Geological Survey).

It depicts the geology of Maryland. The section shaded in blue in Figure 08 depicts the area shown in Figure 09. Figure 09 provides a much more clear view to the specific soil and rock type that the Student Center is situated on. The map has been color coated to depict the different soil and rock types based on location. Figure 09 shows that the Center is located in the Precambrian soil type. This area contains schist, metagraywache, quartzite, marble, and metavolcanic rocks. The soil type is listed as crushed stone, crushed marble, and building stone. These rock and soil types were then compared to those of Table 5 in Chapter 32 of the ASHRAE Handbook of HVAC Applications. The closest soil and rock types were light clay, 15% water and sandstone. When looking at the ASHRAE values the soil resistivity came out to be 0.6 BTU/hft°F.

Figure 09 – Carroll County Geological Survey

Calculations

In order to determine the number of bores and the lengths of those bores two methods were used. The first method was using a spreadsheet provided by McClure Company. The second was using the calculations found within the 2007 ASHRAE Handbook of HVAC Applications. The 0.6 BTU/hft°F value given by the 2007 ASHRAE Handbook of HVAC Applications matches the value used in the McClure spreadsheet. This spreadsheet was used to calculate the total amount of bores and the corresponding lengths of those bores. These values can be seen below in Figure 10. Once these values were determined the ASHRAE calculations, which can be found in Appendix A, were used to check these results.

GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: St. John Student Center
Job Number:
Date: 03/21/11
User: Haupt

INPUT DATA

Total Building Load (Ton)=	247.4	**Bldg Area**	68000	Sq Ft
Outdoor Design Temp. (°F)=	95	**Sq. Ft / Ton**	275	
Indoor Design Temp. (°F)=	75			
Balance Temp. (°F)=	65			
Total Heat Pump Capacity (Ton)=	247			
$COP_{COOLING}$=	3.99			
Pipe Resistance (Hr-Ft-°F/BTU)=	0.048			
Soil Resistance (Hr-Ft-°F/BTU)=	0.6			
Average Water Temp. (°F)=	70			
Mean Earth Temp.(°F)=	56			

BIN DATA

Design Month: July
Location: BALTIMORE

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

CALCULATIONS

BIN Range	Bldg Load Tons	Heat Pump Hours
95/100	395.84	0.00
90/95	333.99	8.11
85/90	272.14	15.42
80/85	210.29	75.77
75/80	148.44	58.90
70/75	86.59	43.82
65/70	24.74	14.02
		216.05

Run Fraction= 0.29
nd Loop Heat Exchanger Length(Ft/Ton)= 201.71
Total Ground Loop Length= 49904.02

Bores Required:

Depth (Ft)	Number
400	125
375	133
350	143
325	154
300	166
250	200
200	250
600	83

Figure 10 – GSHP Calculation Spreadsheet (McClure Company)

Pipe Sizing

In order to properly size the pipes in the geo field multiple parameters had to be considered, for this project the Hazen Williams Formula from ASHRAE Fundamentals was used. The first concern was the total flow rate which in this case is 750 GPM. Because there are a total of 125 bores (see Figure 10 above) each bore will have a flow rate of 6 GPM. This will mean that half of the pumps will each serve 12 bores while the other half will serve 13 bores. When calculating the overall pipe diameter the bore flow rate is used. Because the pipes are laid out in a reverse return setup, the pipes can gradually be reduced in size. The overall goal was to maintain a high efficiency and in order to do this a 0.5 – 3' pressure drop per 100' must be met.

Pump and System Layout

This redesign requires 50,000 ft of underground piping to accommodate the loads. As stated before the overall goal of this GSHP was to eliminate the need of the central plant. In order to do this the GSHP would need to make chilled water and heating water. This requires the use of water to water heat pumps that will create either chilled water or heating water. In this setup the chilled water heat pumps act like a water cooled chiller. These units will reject heat to the heat pump loop thus creating chilled water to supply to the AHUs. The heating water heat pumps operate in the reverse direction. They will be taking heat from the ground loop. This will allow for heating water to be supplied to the VAV box re-heat coils as well. Both of these processes can be seen in Figure 11 below.

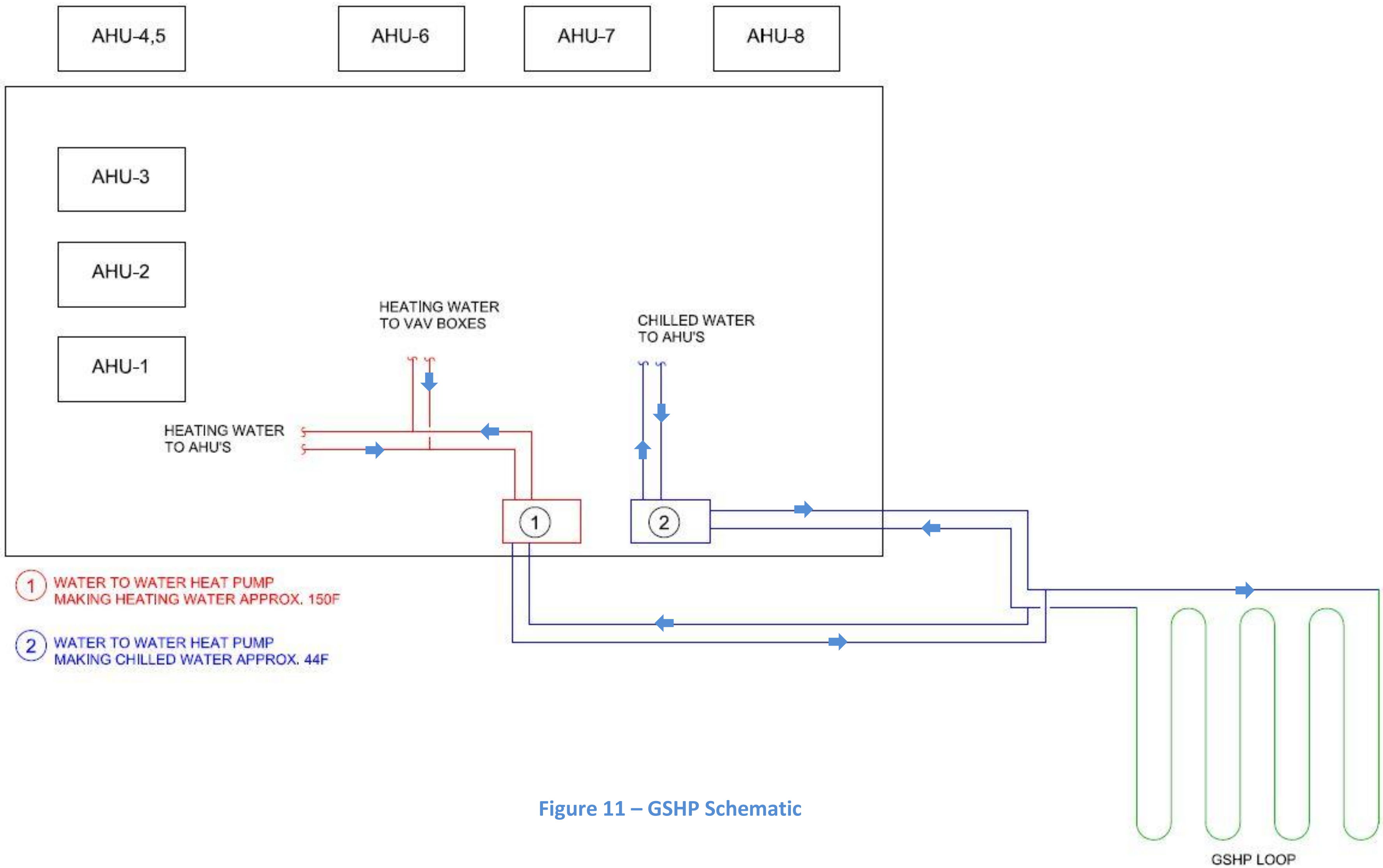


Figure 11 – GSHP Schematic

In order to ensure the ground would not gradually be cooled or heated over time due to the process, ample spacing between the bores were provided. The field available for the borehole layout was 55,296SF, this allowed for each borehole to be spaced 14.5 ft apart horizontally and 19 ft apart vertically. This spacing will avoid a rise in ground temperature overtime and will allow each borehole to absorb or dissipate heat to and from the ground effectively. The layout for this spacing can be seen in Figure 12 below. Also seen below are the existing pipe headers from the central plant. These headers go into the existing mechanical space shown in blue in Figure 11. It will be relatively easy to disconnect the pipes from the central plant and connect to the pipes from the well field.

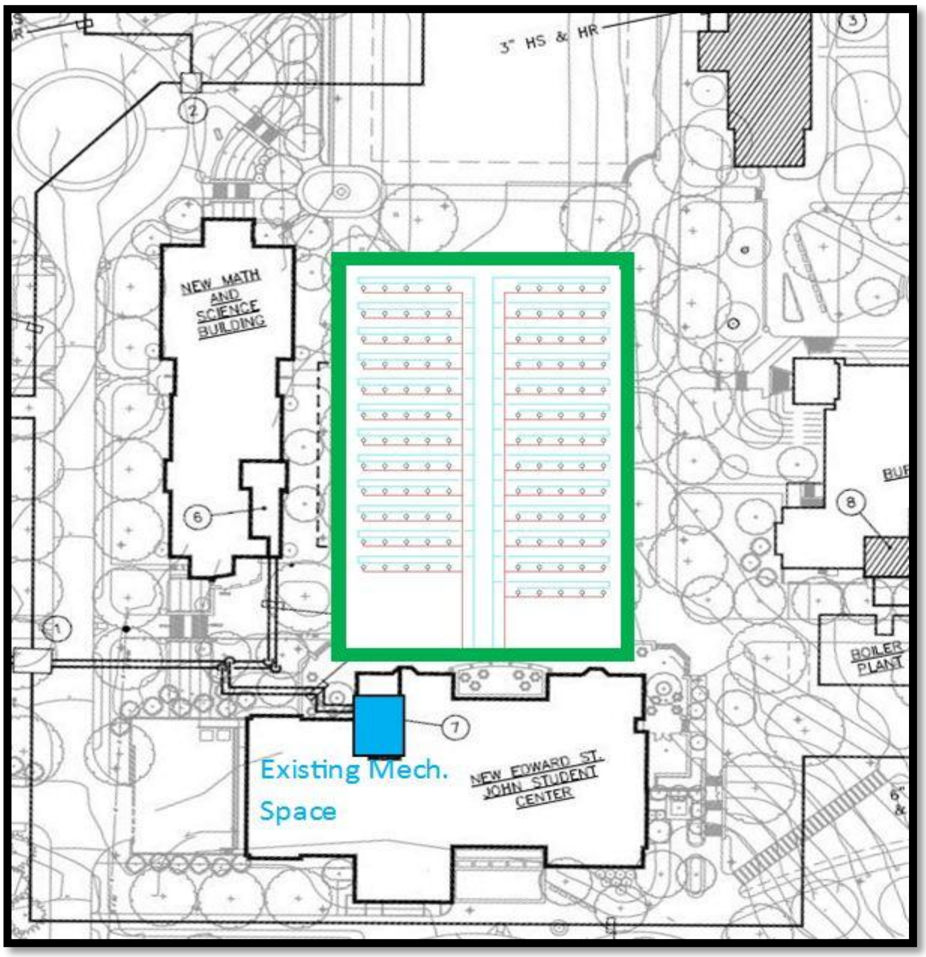


Figure 11 – GSHP Schematic

The system was determined to be 750 gpm (based on 2 gpm/ton recommendation by James Posey). The system characteristics utilized for sizing the pumps can be seen below in Table 11 below.

Table 11 – System Characteristics for Pump Sizing

	Ground Loop	CHW Loop
Capacity (GPM)	750	750
Total Head (ft h20)	204.4	204.4

The heating and chilled water ground source heat pumps were then selected using the pump information provided by Carrier. The resulting pumps are 10 Aquazone water-to-water heat pumps for chilled water and 9 pumps for heating water.

Table 12 – Selected Pump

Manufacturer	Model	TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT	EER
Carrier	50PSW360	313	16.08	367.9	61.1	19.5

Enthalpy Wheel – Mechanical Depth

Redesign Objective

The purpose of adding an enthalpy wheel is to increase energy savings and decrease the payback period. The addition of an enthalpy wheel to the AHU that serves the art classrooms was determined to save the most energy. Due to the increase in weight that the enthalpy wheel brings a structural check will need to be performed in order to ensure the proper support system will be installed.

Selection of Enthalpy Wheel

In order to select the appropriate wheel various factors needed to be looked at. The first step is to select a wheel configuration that has a face velocity as close to 800 FPM as possible. This achieves the best balance between energy recovery effectiveness, pressure loss and first cost. In order to select a wheel your total supply airflow must be known. In this case the total flow will be 15,000 CFM. When looking at SEMCO's wheel size selection, a TE3-18 wheel is the most appropriate selection. This selection process can be seen in Figure 12 on the right. Reading further down the chart the associated pressure

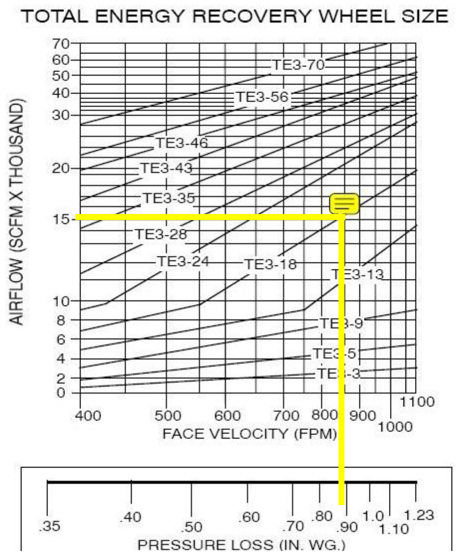


Figure 12 – Performance Chart for TE3 Series Wheels

loss can be seen, in this case it comes out to about 0.89 IN. WG.

Unit Effectiveness

The next step in the selection proccess is to calculate the units effectiveness. The calculations shown in Figure 13 below were used in order to determine the units effectiveness.

The exchanger heat transfer effectiveness e is defined as the amount of energy recovered, e.g. sensible or latent, divided by the maximum amount of energy that could theoratically be recovered.

The supply air volume heat transfer effectiveness e_s is defined as

$$e_s = \frac{V_s (X_1 - X_2)}{V_{min} (X_1 - X_3)}$$

The return air volume heat transfer effectiveness e_r is defined as

$$e_r = \frac{V_r (X_4 - X_3)}{V_{min} (X_1 - X_3)}$$

Based on the above definitions, the supply air condition X_2 can be calculated from

$$X_2 = X_1 - e_s \frac{V_{min}}{V_s} (X_1 - X_3)$$

and the exhaust air condition X_3 can be calculated from

$$X_4 = X_3 + e_s \frac{V_{min}}{V_r} (X_1 - X_3)$$

where V_s = Supply air volume, scfm
V_r = Return air volume, scfm
$V_{min} = V_r$ if V_r is smaller than V_s or $V_{min} = V_s$ if V_s is smaller than V_r
X = dry bulb temperture (°F) or moisture content (gr/lb) or enthalpy (Btu/lb)

The indices refer to the following airstreams, as indicated in the figure below:
1 = Outdoor air condition
2 = Supply air condition
3 = Return air condition
4 = Exhaust air condition

Figure 13 – Unit Effectiveness Calculations

Once all the values were entered a unit effectivenss was calculated. For our case a unit effectiveness was calculated to be about 0.85 which is a very good rating.

Implementing Enthalpy Wheels into HAP

Once the unit effectiveness was calculated the process was nearly complete. The last step was to determine the H.P. associated with the motor on the wheel. After talking to a representative at SEMCO it was determined that the motor would be approximately 0.5 H.P for this particular wheel. A simple conversion from H.P. to kW was performed and the wheel was now ready to be implemented into HAP. These values can bee seen in Figure 14 below. The final resulting wheel schedule can be seen below in Table 13 as well.

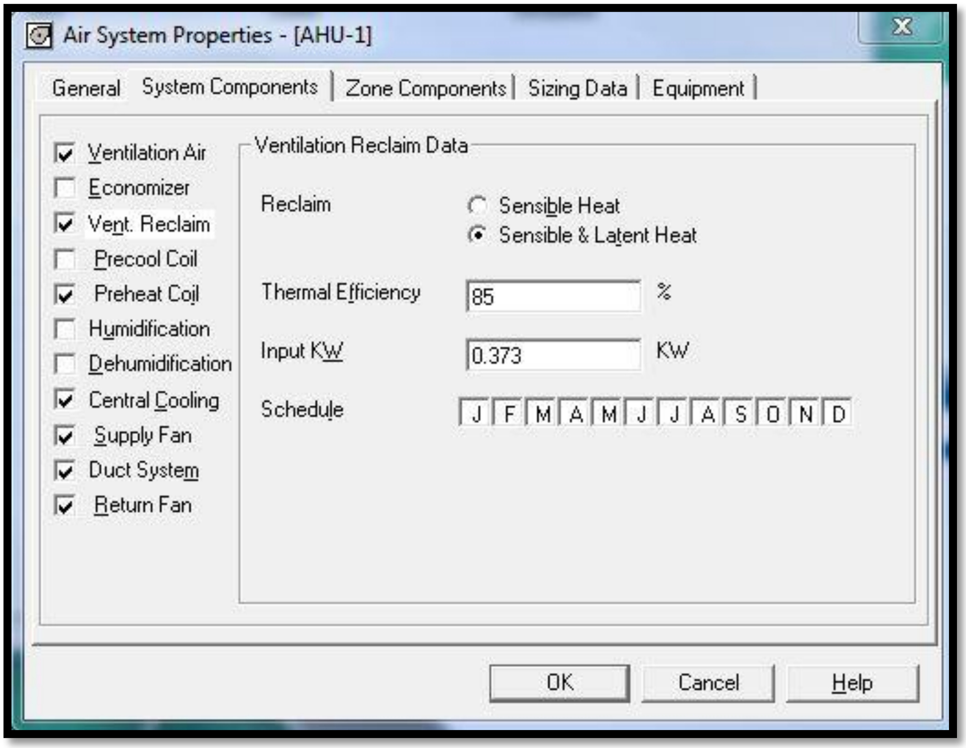


Figure 14 – Enthalpy Wheel HAP Template

Table 13 – Enthalpy Wheel Schedule

Manufacture	Model	Face Velocity (FPM)	Pressure Loss (IN. WG.)	Unit Effectiveness	Motor H.P.
SEMCO	TE3-18	840	0.89	0.85	0.5

Solarban 70XL – Mechanical Depth

Redesign Objective

By installing Solarban 70XL the goal was to provide a more energy efficient building and further reduce the payback period. Solarban 70XL glass from PPG is an innovative way to keep your building cool during summer months while minimizing the loss of daylighting. The main purpose of upgrading the glazing on the Student Center is to reduce energy consumption. Two types of PPG solar efficient glass were looked at, as well as the glass currently installed in the Student Center.

Calculating Total Amount of Glazing

In previous reports the total amount of glazing had to be calculated in order to comply with ASHRAE standards, because of this the total amount of existing glass was already calculated. Table 14 below shows how much glass the Student Center has.

Fenestration Area			
Floor	**Glass (SF)**	**Gross Wall (SF)**	**Percentage Glass**
Lower Level:	736	12992	6
First Floor:	3842	12643	30
Second Floor:	2630	7462	35
Overall Total:	**7208**	**33096**	**22**

Glazing Properties

Currently the Student Center has glazing with a poor U-value and a poor shading coefficient. A U-value is defined as "a measure of the rate of non-solar heat loss or gain through a material or assembly." A shading coefficient is defined as "A measure of the ability of a window or skylight to transmit solar heat, relative to that ability for 3 mm (1/8-inch) clear, double-strength, single glass" (online encyclopedia). The Student Center has an installed U-value of 0.588 and an overall shading coefficient of 0.811. Solarban 70XL has a U-value of 0.260 and an overall shading coefficient of 0.270. As you can see this is a tremendous improvement. Tables 15 and 16 below show the cost for the different types of glass.

Table 15 – Cost of Glazing

Type	Cost/SF	Total SF	Cost
1" clear/clear	$4.95	7208	$35,679.60
1" Solarban 60	$6.45	7208	$46,491.60
1" Solarban 70 XL	$7.45	7208	$53,699.60

Table 16 – Cost per Floor of Glazing

	1" Solarban 70 XL	1" Solarban 60	1" clear/clear
1st Floor	$5,483.20	$4,747.20	$3,643.20
2nd Floor	$28,622.90	$24,780.90	$19,017.90
3rd Floor	$19,593.50	$16,963.50	$13,018.50
Total	$53,699.60	$46,491.60	$35,679.60

Construction Management – Breadth

Objectives

The addition of a large geothermal system outlined above involves heavy construction to be added into an already time sensitive schedule. Constructing a vertical loop ground source heat pump can be very time consuming and expensive. The point of this study is to minimize added time during the construction process, and to minimize capital costs. This study evaluates the cost of testing, drilling, piping, grouting and other miscellaneous site costs incurred with drilling the boreholes. All estimated values of cost and daily outputs were taken from RS Means Mechanical Cost Data – 2009 and adjusted based on the Student Center's construction timeline of June 2011 – July 2012.

Estimated Costs

Drilling a wellfield of this size will not only increase the costs in man power but it will also increase due to renting of equipment. Table 17 below shows an estimate of the associated costs due to drilling the boreholes. Table 18 below shows the estimated cost of polyethylene piping.

Table 17 – Drilling Costs

Total Length of Pipe	Cost per Linear Ft	Total Cost of Pipe	Man Power (Ft/Day/Rig)	# of Rigs	Cost/Rig/Week	# of Bores	Bore Depth (Ft)	Bores/Day	# of Days	# of Weeks (5 days/Week)	Total Cost
50,000	$ 24.00	$ 1,200,000	400	4	$ 4,500	125	400	4	31.25	7	$ 1,231,500

Table 18 – Polyethylene Pipe Costs

Pipe Size	Length Of Pipe	Cost Of Pipe/Ft	Cost Of Pipe
3	64000	$ 0.033	$2,112
2	16000	$ 0.0275	$440
1.5	8000	$ 0.0165	$132
1.25	16000	$ 0.0125	$200
			$2,884

Site and Schedule

The construction management bids for this project were finalized in January 2011. Due to these bids being so recent, the construction schedule is not completely finalized so some assumptions had to be made. The construction process is being kicked off by the demolition of an existing building located where the geothermal well field is going to be located. Figure 15 below shows the campus plan with the existing building (shown in red) being demolished. The two buildings shown in blue are being added (Student Center shown in dark blue).

Figure 15 – Campus Master Plan

The demolition process is going to take approximately one month to complete. The excavation phase will be an ongoing process throughout this demolition and is expected to lag behind the demo phase by 2-3 weeks. The excavation phase from start to finish is to take approximately 1.5 months to complete. It is planned to phase in the borehole drilling with the excavation phase. This will fit into the schedule effortlessly due to the drilling only needing 32 days to complete which is approximately 1.5 months, when looking at only a five day work week. If the drilling, for whatever reason falls behind, working on the weekends may need to be implemented in order to stay on schedule. This minor glitch would cause the total cost of drilling to increase due to overtime hours being worked on the weekends. This however will be a last case scenario and is not expected to occur.

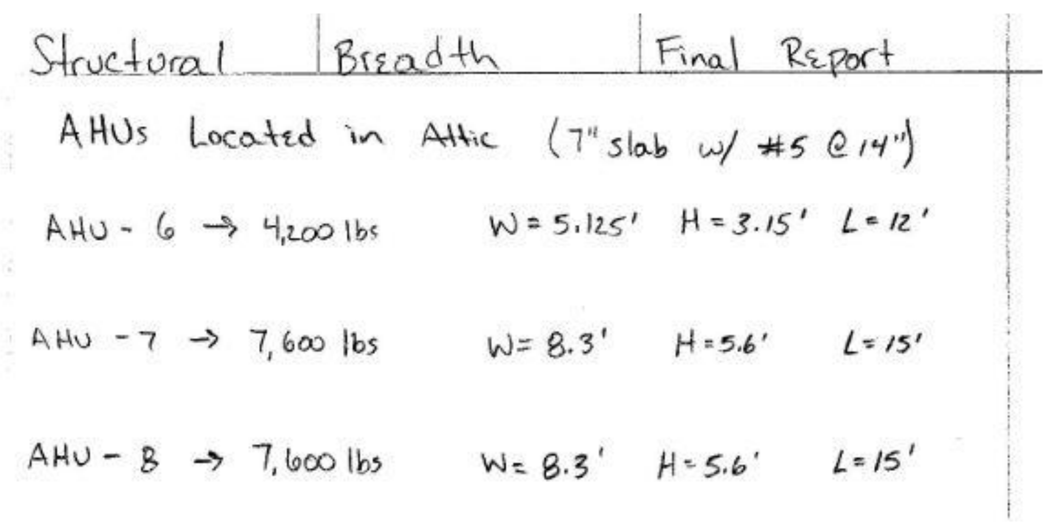
Structural – Breadth

Objectives

The added weight and size that is associated with an enthalpy wheel may cause the supporting structures to fail. In order to prevent this from occurring, a full structural analysis of the supporting slab and beam will need to be performed. If adjustments must be made, the most economical and least time consuming options will be selected in order to prevent an increase in time or budget.

Calculations

AHU – 8 is located in the attic and serves the art classrooms. This is the AHU that the enthalpy wheel will be installed in. The first step was to determine all the AHUs located in this attic. Once all the AHUs were located the AHU's weights and dimensions were found in the mechanical equipment schedules. The thickness of the slab and the amount of rebar in the slab were found in the structural drawings. These values can be seen in Figure 16 below.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AHUs Located in Attic (7" slab w/ #5 @ 14")

AHU - 6 → 4,200 lbs W = 5.125' H = 3.15' L = 12'

AHU - 7 → 7,600 lbs W = 8.3' H = 5.6' L = 15'

AHU - 8 → 7,600 lbs W = 8.3' H = 5.6' L = 15'

Figure 16 – AHU 6, 7, 8 Weights/Dimensions

Once these values were obtained the lb/ft^2 for each AHU was calculated. This calculation method can be seen below in Figure 17.

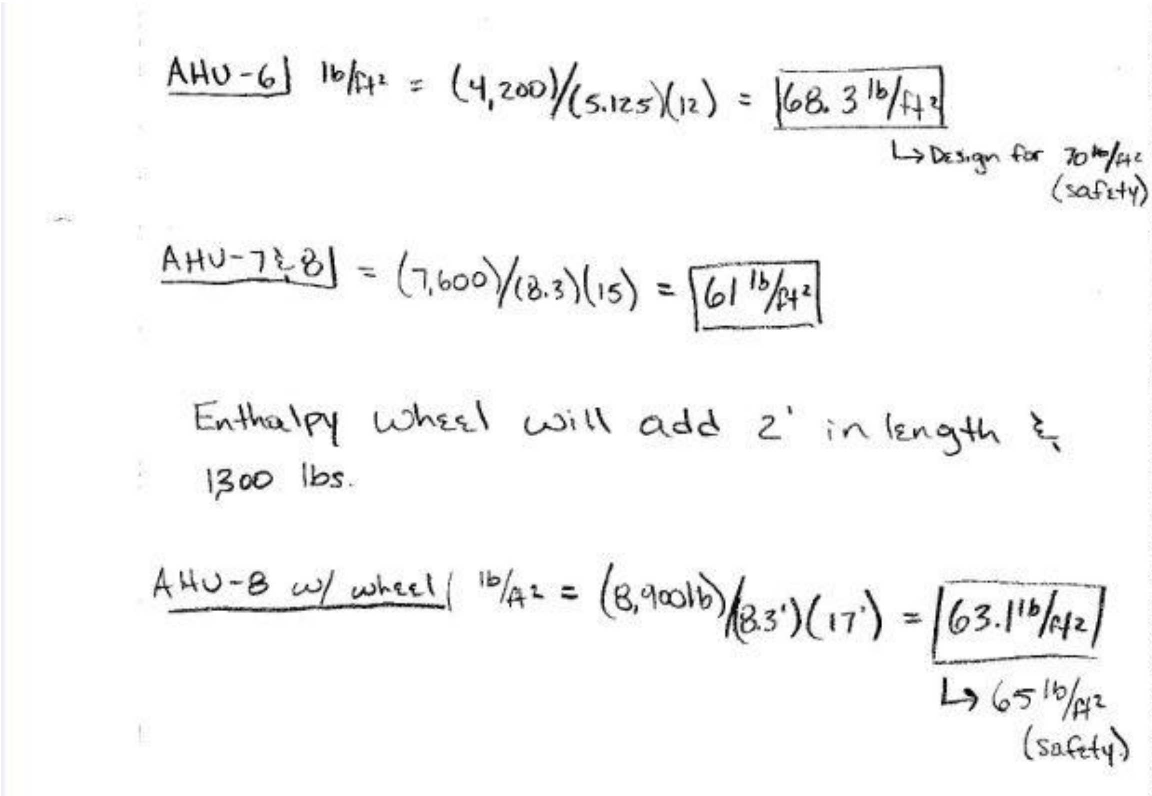
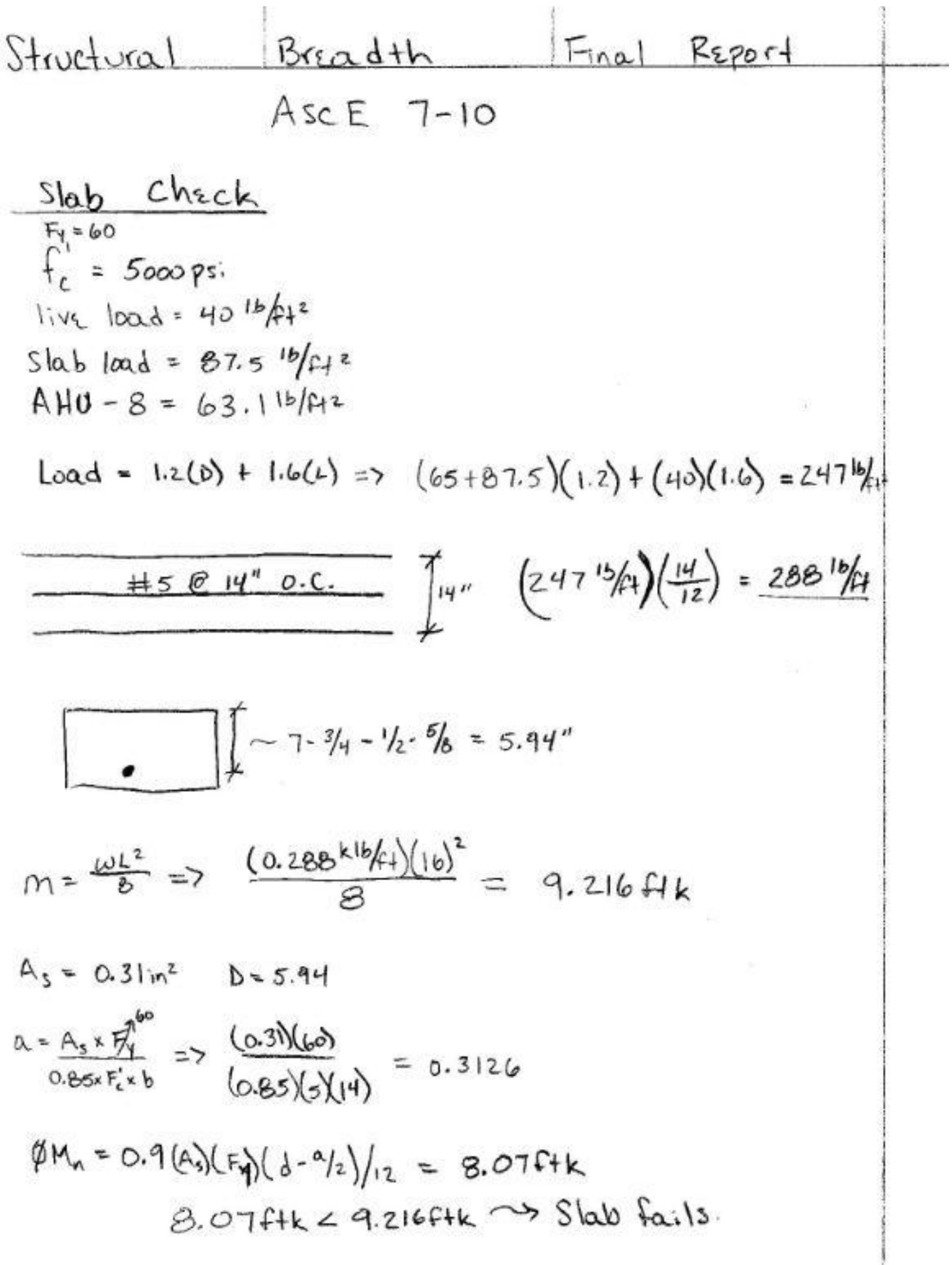


Figure 17 – AHU 6, 7, 8 lb/ft^2 Calculations

Once the lb/ft^2 was calculated a slab analysis was performed. During this analysis it was determined that the slab would fail with the added weight that is associated with the enthalpy wheel. These calculations can be seen in Figure 18 below. Looking at the structural plans AHU 6 does not fall in the tributary area of the slab and beam in question and therefore does not need to be accounted for in any of the calculations.



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ASCE 7-10

Slab Check

$F_y = 60$

$f'_c = 5000$ psi

live load = 40 lb/ft²

Slab load = 87.5 lb/ft²

AHU - 8 = 63.1 lb/ft²

Load = 1.2(D) + 1.6(L) => (65+87.5)(1.2) + (40)(1.6) = 247 lb/ft

#5 @ 14" O.C. — 14"

$(247 \text{ lb/ft})\left(\frac{14}{12}\right) = 288 \text{ lb/ft}$

~ 7-3/4 - 1/2 - 5/8 = 5.94"

$M = \frac{wL^2}{8} \Rightarrow \frac{(0.288 \text{ klb/ft})(16)^2}{8} = 9.216 \text{ ftk}$

$A_s = 0.31 \text{ in}^2$ D = 5.94

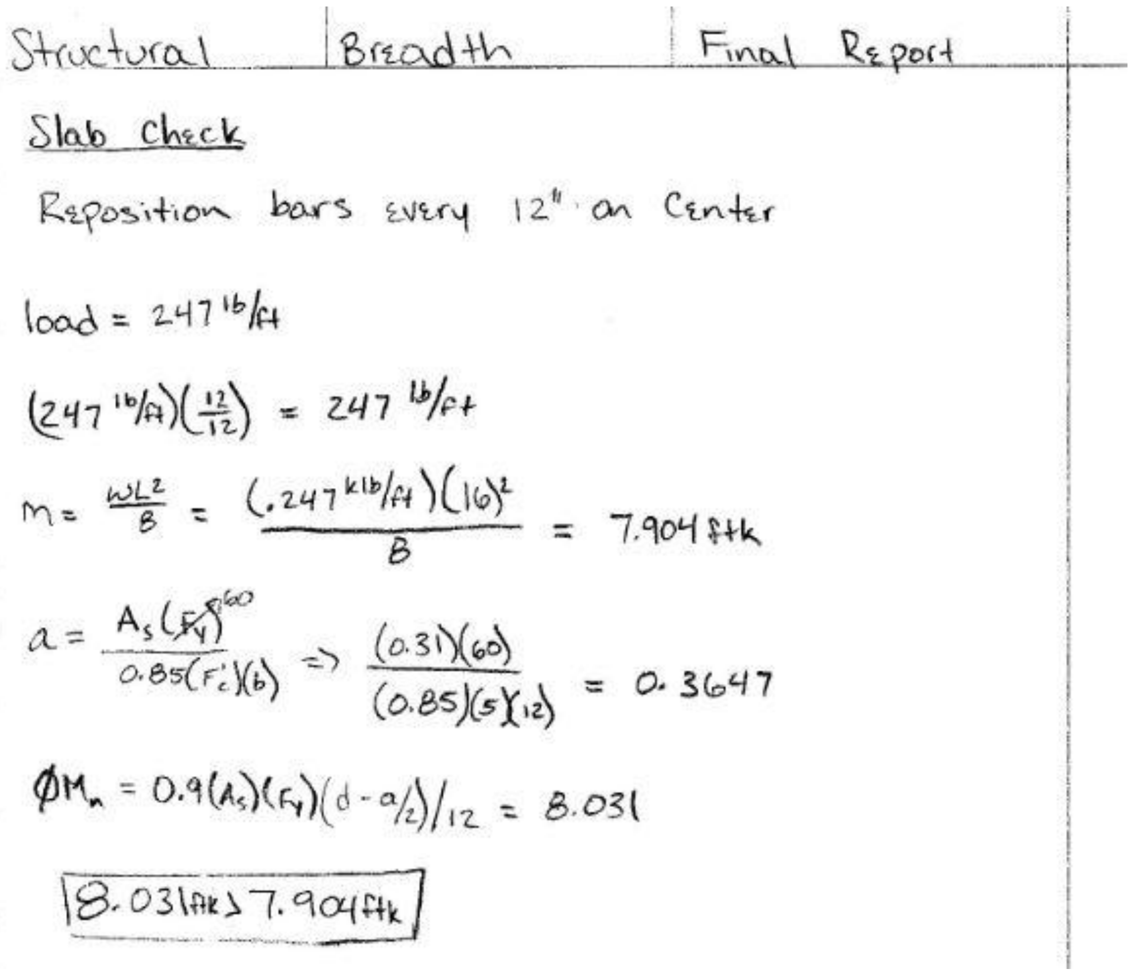
$a = \frac{A_s \times F_y}{0.85 \times F'_c \times b} \Rightarrow \frac{(0.31)(60)}{(0.85)(5)(14)} = 0.3126$

$\phi M_n = 0.9(A_s)(F_y)(d - a/2)/12 = 8.07 \text{ ftk}$

8.07ftk < 9.216ftk → Slab fails.

Figure 18 – Slab Analysis

It was recommended to space the rebar every 12" O.C. instead of every 14" O.C. from Ryan Dalrymple, a structural student and respected colleague of mine. To ensure that the slab would now be able to withstand the extra weight a second slab analysis was performed, this time with the rebar spaced closer together. These calculations can be found in Figure 19 below.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Slab Check

Reposition bars every 12" on Center

load = 247 lb/ft

$(247 \text{ lb/ft})(\frac{12}{12}) = 247 \text{ lb/ft}$

$M = \frac{wL^2}{8} = \frac{(.247 \text{ klb/ft})(16)^2}{8} = 7.904 \text{ ftk}$

$a = \frac{A_s(F_y)}{0.85(F'_c)(b)} \Rightarrow \frac{(0.31)(60)}{(0.85)(5)(12)} = 0.3647$

$\phi M_n = 0.9(A_s)(F_y)(d - a/2)/12 = 8.031$

$8.031 \text{ ftk} > 7.904 \text{ ftk}$

Figure 19 – Slab Re-Check Analysis

As you can see from Figure 19 the slab is able to withstand the extra weight and will not fail. Now that the slab is strong enough an analysis on the supporting beam was performed.

SpBeam was recommended for use in order to check that the beam would not fail. Figures 20 through 22 below are from spBeam showing the appropriate size of the beam that would need to be installed. This beam was cross checked with the scheduled beam and it was determined that the scheduled beam was well oversized and would not fail under the new conditions.

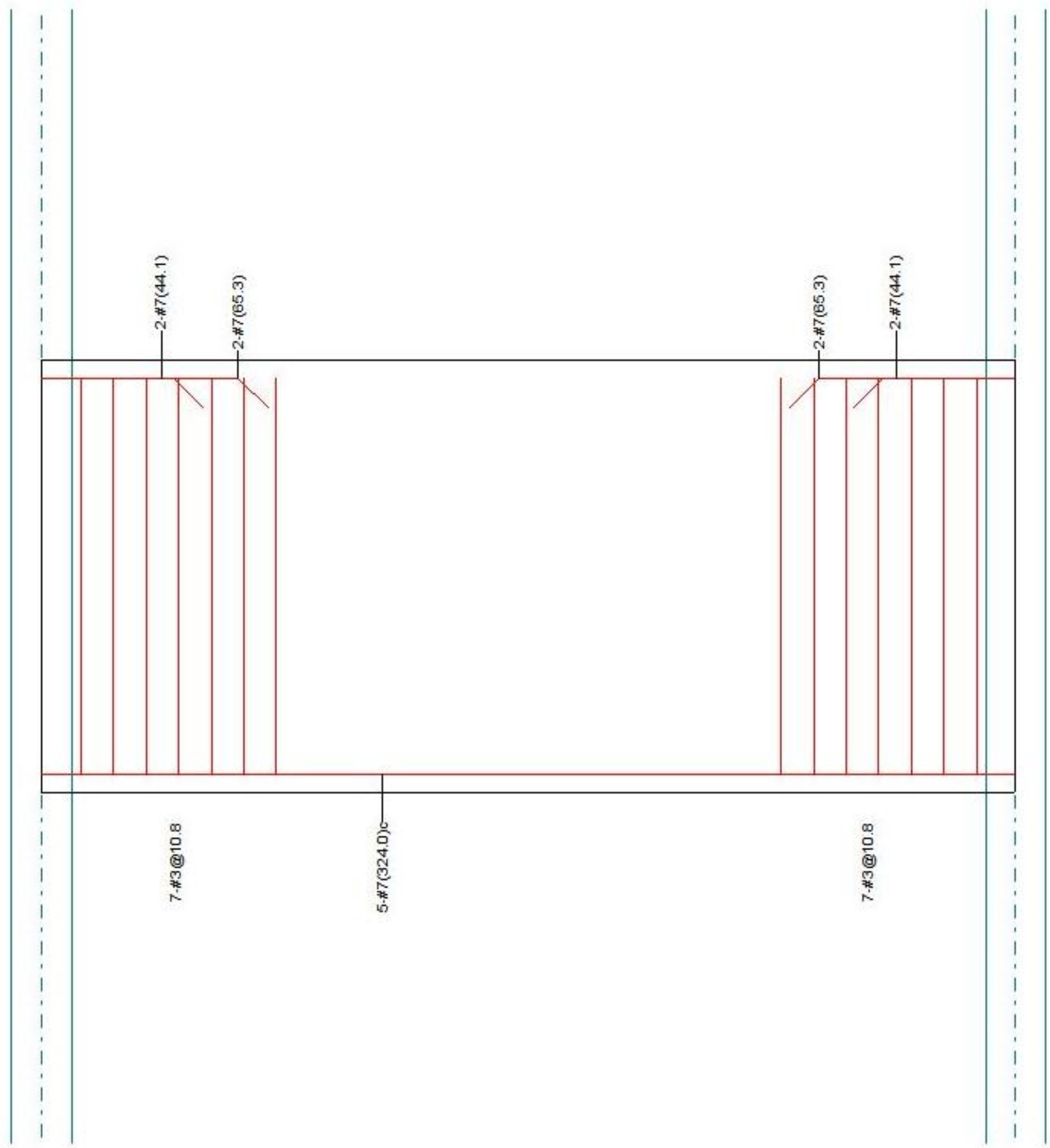

Figure 20 – spBeam Designed Reinforcing Diagram

```
[2] DESIGN RESULTS
==========================================================================================================

Top Reinforcement
=================
   Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)
   Span Zone      Width        Mmax      Xmax     AsMin     AsMax     SpReq     AsReq     Bars
   ---- ------ -------- ---------- -------- -------- -------- -------- -------- -------
      1 Left       2.70     105.26    0.833    0.954   14.477    8.933    0.692    4-#7  *3 *5
        Middle     2.70       0.00   13.500    0.000   14.477    0.000    0.000    ---
        Right      2.70     105.26   26.167    0.954   14.477    8.933    0.692    4-#7  *3 *5
   NOTES:
   *3 - Design governed by minimum reinforcement.
   *5 - Number of bars governed by maximum allowable spacing.

Top Bar Details
===============
   Units: Length (ft)
        _____________Left______________   ___Continuous__   _____________Right_____________
   Span    Bars  Length    Bars  Length     Bars  Length     Bars  Length    Bars  Length
   ---- ------- ------- ------- -------   ------- -------   ------- ------- ------- -------
      1    2-#7    5.45    2-#7    3.67     ---                2-#7    5.45    2-#7    3.67

Bottom Reinforcement
====================
   Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)
   Span    Width       Mmax      Xmax     AsMin     AsMax     SpReq     AsReq     Bars
   ---- -------- ---------- -------- -------- -------- -------- -------- -------
      1     1.67     309.57   13.500    2.409   44.722    3.600    2.030    5-#7  *3
   NOTES:
   *3 - Design governed by minimum reinforcement.

Bottom Bar Details
==================
   Units: Start (ft), Length (ft)
        _______Long Bars_______  _______Short Bars_______
   Span    Bars   Start  Length    Bars   Start  Length
   ---- ------- ------- ------- ------- ------- -------
      1    5-#7    0.00   27.00     ---

Flexural Capacity
=================
   Units: x (ft), As (in^2), PhiMn (k-ft)
   Span          x AsTop AsBot       PhiMn-       PhiMn+
   ---- --------- ----- ----- ------------ ------------
      1     0.000  2.40  3.00      -358.73       456.31
            0.833  2.40  3.00      -358.73       456.31
            2.672  2.40  3.00      -358.73       456.31
            3.672  1.20  3.00      -181.65       456.31
            4.445  1.20  3.00      -181.65       456.31
            5.445  0.00  3.00         0.00       456.31
            9.700  0.00  3.00         0.00       456.31
           13.500  0.00  3.00         0.00       456.31
           17.300  0.00  3.00         0.00       456.31
           21.555  0.00  3.00         0.00       456.31
           22.555  1.20  3.00      -181.65       456.31
           23.328  1.20  3.00      -181.65       456.31
           24.328  2.40  3.00      -358.73       456.31
           26.167  2.40  3.00      -358.73       456.31
           27.000  2.40  3.00      -358.73       456.31
```

Figure 21 – spBeam Design Results

Longitudinal Beam Shear Reinforcement Required

Units: d (in), Start, End, Xu (ft), PhiVc, Vu (kip), Av/s (in^2/in)

Span	d	PhiVc	Start	End	Vu	Xu	Av/s
1	34.06	72.26	3.672	6.948	50.82	3.672	0.0177
			6.948	10.224	33.88	6.948	0.0000
			10.224	13.500	16.94	10.224	0.0000
			13.500	16.776	16.94	16.776	0.0000
			16.776	20.052	33.88	20.052	0.0000
			20.052	23.328	50.82	23.328	0.0177

Longitudinal Beam Shear Reinforcement Details

Units: spacing & distance (in).

Span	Size	Stirrups (2 legs each unless otherwise noted)
1	#3	7 @ 10.8 + <-- 157.3 --> + 7 @ 10.8

Beam Shear Capacity

Units: d, Sp (in), Start, End, Xu (ft), PhiVc, PhiVn, Vu (kip), Av/s (in^2/in)

Span	d	PhiVc	Start	End	Av/s	Sp	PhiVn	Vu	Xu
1	34.06	72.26	0.000	1.083	-----	-----	103.40	69.81	0.000
			1.083	6.948	0.0203	10.8	103.40	50.82	3.672
			6.948	20.052	-----	-----	36.13	33.88	20.052
			20.052	25.917	0.0203	10.8	103.40	50.82	23.328
			25.917	27.000	-----	-----	103.40	69.81	27.000

Slab Shear Capacity

Units: b, d (in), Xu (ft), PhiVc, Vu(kip)

Span	b	d	Vratio	PhiVc	Vu	Xu
1 --- Not checked ---						

Deflections

Section properties

Units: Ig, Icr, Ie (in^4), Mcr, Mmax (k-ft)

	Ie,avg						Load Level: Dead		Load Level: Dead+Live	
Span	Dead	Dead+Live	Zone	Ig	Icr	Mcr	Mmax	Ie	Mmax	Ie
1	127144	127144	Middle	135859	20065	256.61	200.50	135859	243.61	135859
			Right	77760	14161	190.92	-104.69	77760	-127.20	77760

Maximum Instantaneous Deflections

Units: D (in)

Span	Ddead	Dlive	Dtotal
1	0.042	0.009	0.051

Maximum Long-term Deflections

Time dependant factor for sustained loads = 2.000
Units: D (in)

Span	Dsust	Lambda	Dcs	Dcs+lu	Dcs+l	Dtotal
1	0.042	2.000	0.084	0.093	0.093	0.136

Figure 22 – spBeam Design Results

Energy and Cost Evaluation of Redesign

Energy Savings

Currently the Student Center consumes 929,337 kBTUs annually for the heating coils, and 1,604,771 kBTUs annually for the cooling coils. When implementing the enthalpy wheel the center consumes 771,399 kBTUs annually for the heating coils, and 1,550,409 kBTUs annually for the cooling coils. This is a 17% reduction in the total heating coil loads annually and a 3.4% reduction in the total cooling coil loads annually. The total combined energy reductions results in a total savings of $3,553 annually. The graph below represents the energy reduction provided by the enthalpy wheel.

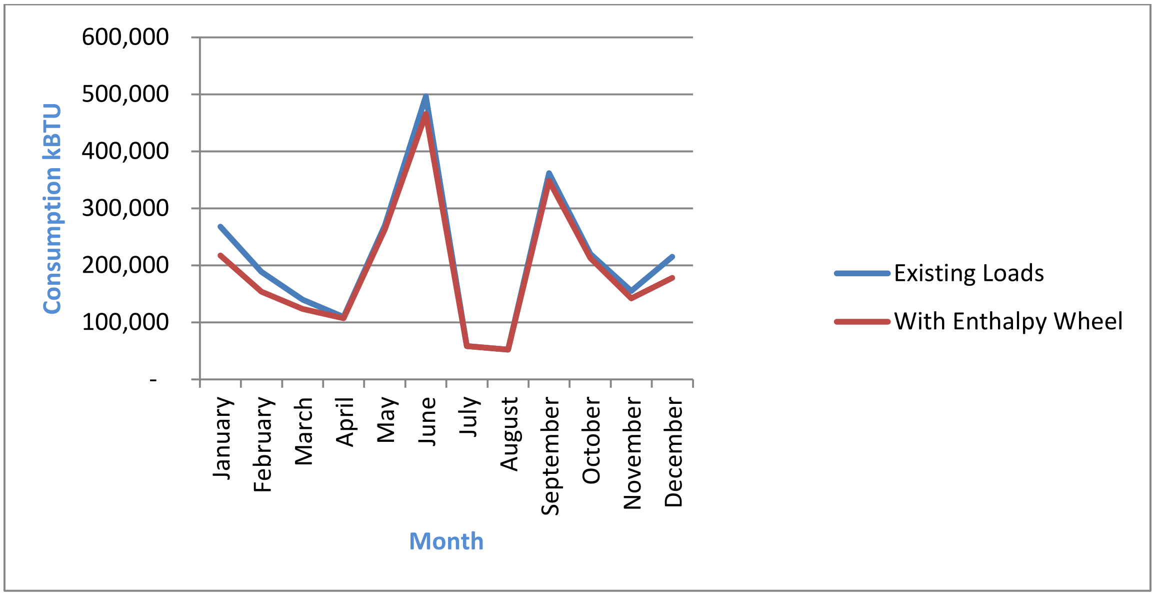

Figure 23 – Annual Energy Consumption (Existing vs. Enthalpy Wheel Redesign)

Upgrading the glass to Solarban 70XL saves just about the same amount of energy as the enthalpy wheel does. The enthalpy wheel saves more energy on the heating side, but the glass saves more energy on the cooling side. This in turn provides a larger annual savings in terms of dollars because cooling costs more than heating. When upgrading the glass the total combined energy reductions results in a total savings of $7,476 annually. Figure 24 below shows how much energy just the glass saves, and Figure 25 shows how much energy both the enthalpy wheel and glass saves annually. When both the enthalpy wheel and Solarban 70XL glass are implemented the total combined energy reductions results in a total savings of $9,622 annually.

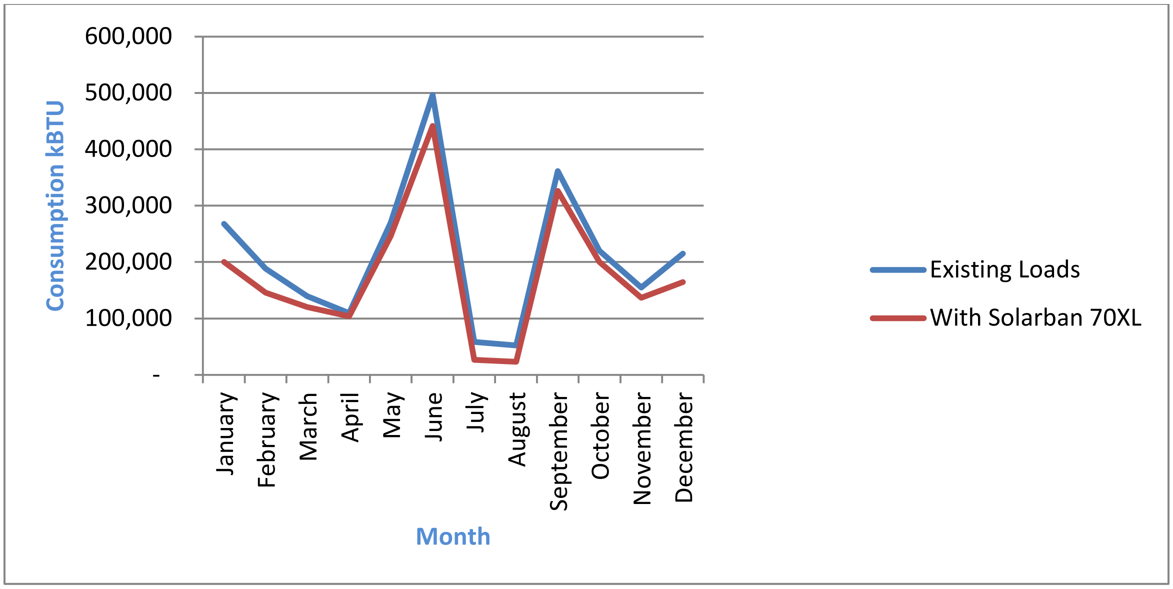

Figure 24 – Annual Energy Consumption (Existing vs. Solarban 70XL Upgrade)

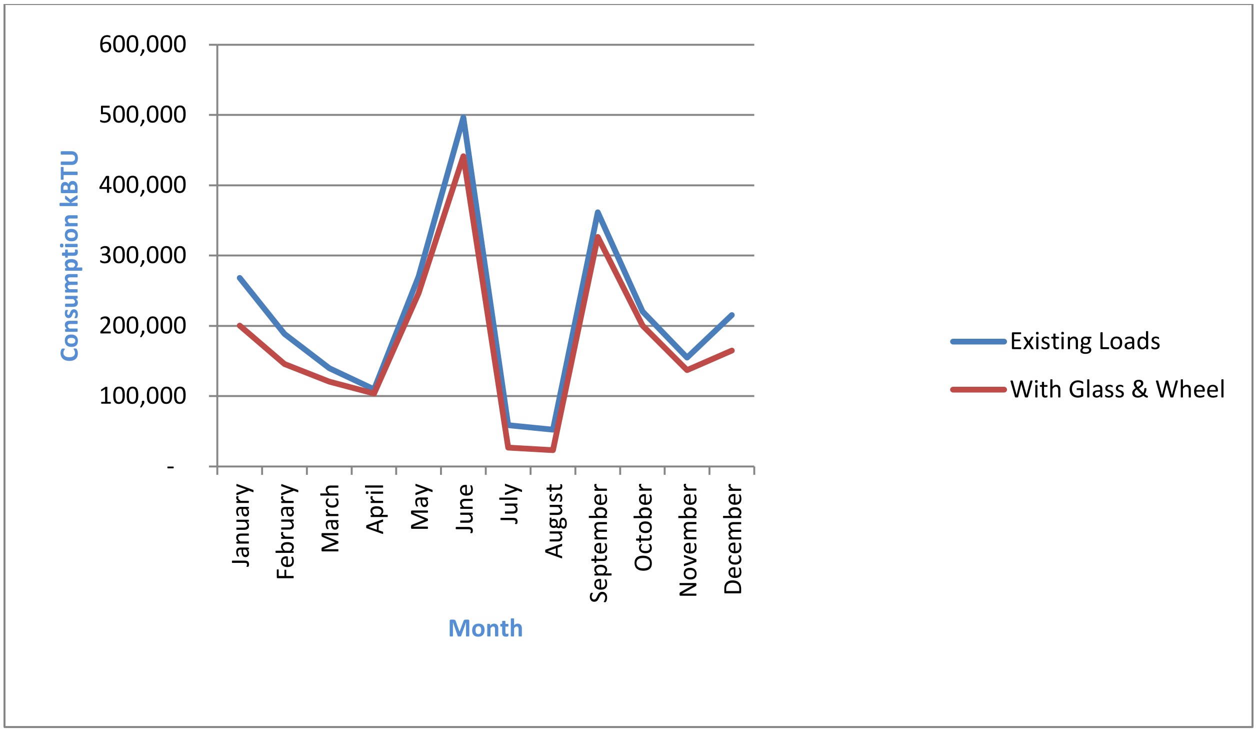

Figure 25 – Annual Energy Consumption (Existing vs. Wheel & Glass Redesign)

The energy reduction continues the same trend when the GSHP is implemented. When implementing the enthalpy wheel, Solarban 70XL glass, and the GSHP the center consumes 736,974 kBTUs annually for the heating coils, and 1,397,820 kBTUs annually for the cooling coils. This is a 20.7% reduction in the total heating coil loads annually and a 12.9% reduction in the total cooling coil loads annually. Figure 26 below represents the energy reduction provided by all three upgrades.

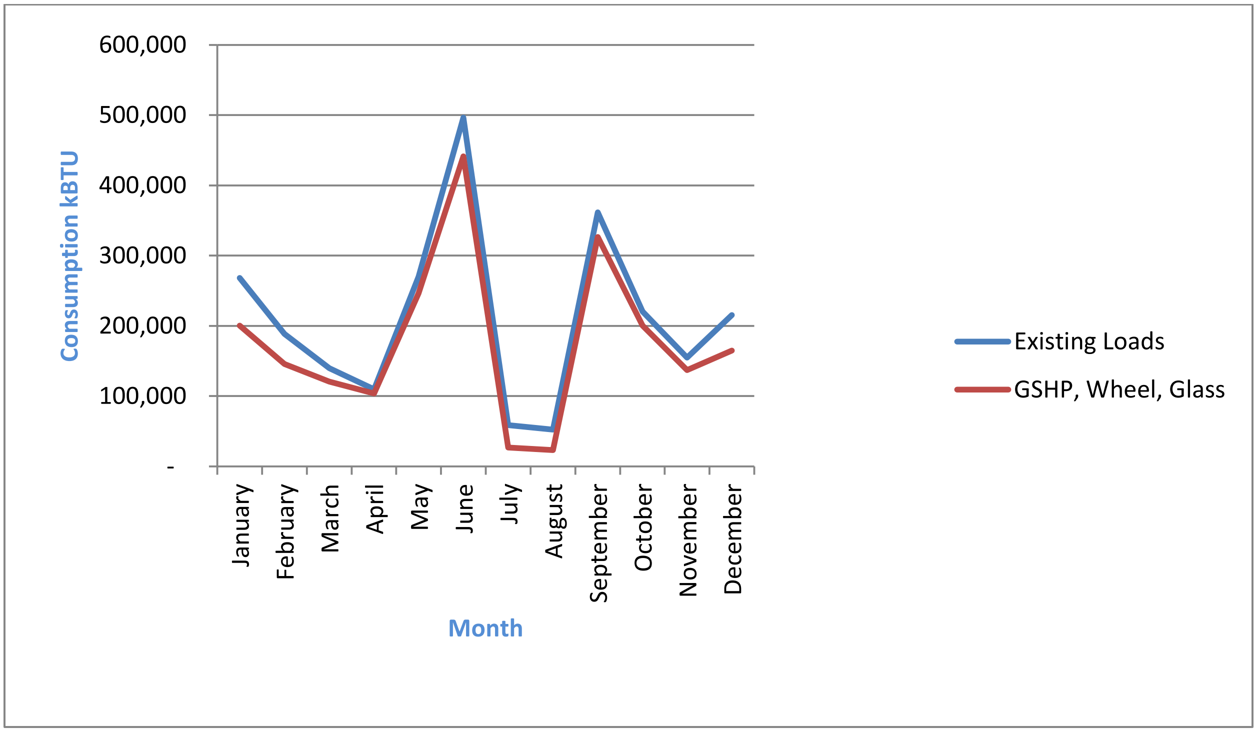

Figure 26 – Annual Energy Consumption (Existing vs. GSHP, Wheel & Glass Redesign)

Energy Savings

After a life cycle calculation was performed a recommendation to the building owner could be made. Figure 27 below shows each system cost and the associated payback period of that system. Maximizing the distance between the total cost and the payback period on the chart will maximize the life cycle cost. This ensures that the appropriate system will be selected to install.

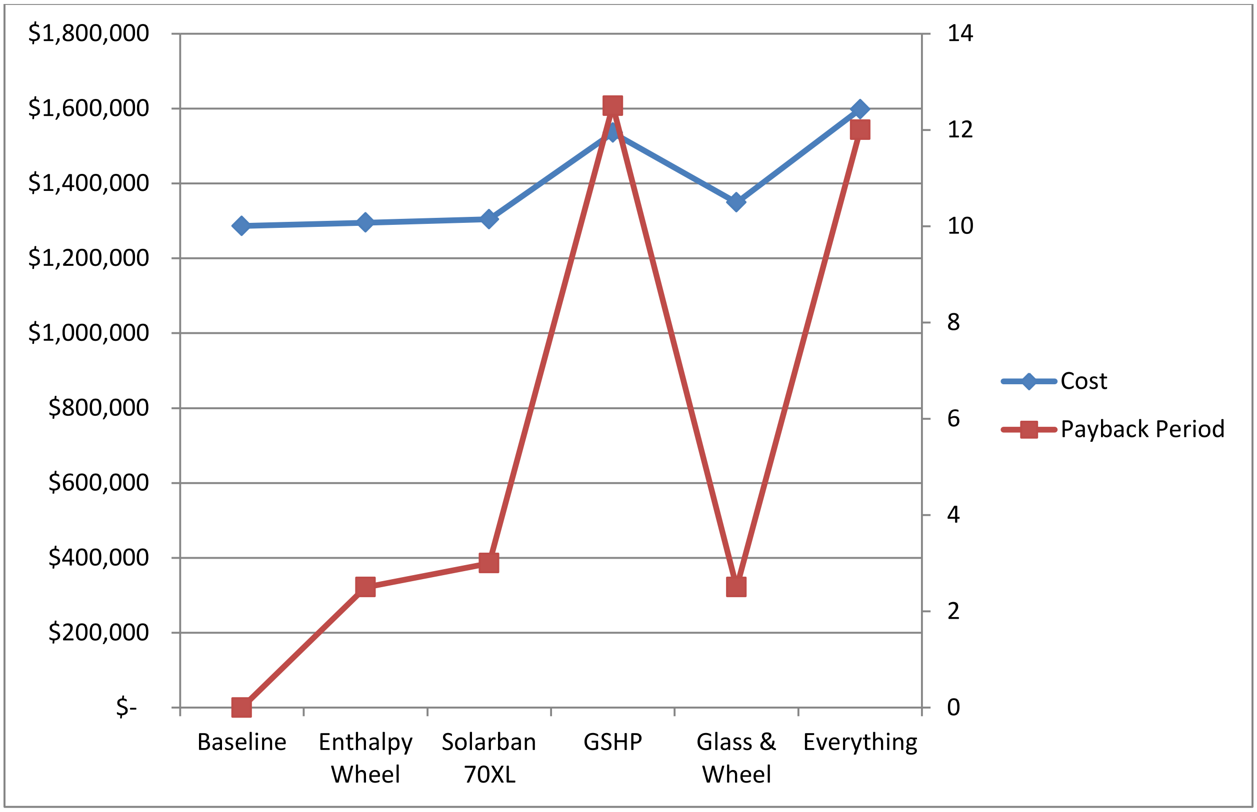

Figure 27 – Life Cycle Cost Analysis

System Recommendation

When reviewing the chart above the system that has the largest difference between total cost and payback period would be the combination of Solarban 70XL glass and the enthalpy wheel. This combination yields a payback period of 2.5 years. This is an extremely quick payback period and has a very low up front cost associated with it. Because the world is very delicate energy consumption should be a top priority. Unfortunately this is almost never true. In today's world building owners want buildings to cost far less and they typically will not care how much energy they are consuming. If this building owner plans on owning the building for 20^{+} years than implementing the GSHP, enthalpy wheel, and glass would be recommended. This combination yields a payback period of 12.5 years.

Arguments could be made that this is too high of a payback period. However if the owner truly cares about the environment and truly wants to save energy than this payback period is relatively low. McDonogh School was founded in 1873, so this new Student Center is expected to be in the owner's (McDonogh School) possession for a long time. If this was not a long term building owner (15 years or fewer) it would not be recommended to implement all three upgrades.

If the owner is unable to increase their budget to the levels required to install these upgrades then implementing the glass upgrade and installing an enthalpy wheel would be recommended. As stated above this yields a payback period of 2.5 years and is a very quick payback period.

Depending on the owner's building retention rate and ability to increase funding the two options stated above suit either case well. Both of these options will be able to provide lifecycle cost savings after the thirty year analysis period. This however can only be achieved if the required and recommended maintenance procedures are followed.

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Appendix A

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

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

$$F_{of} = \frac{4 \cdot \alpha \cdot \tau_f}{d_p^{\,2}} \qquad R_{ga} = \frac{G_f - G_1}{k_g}$$

$$F_{o1} = \frac{4 \cdot \alpha \cdot [\tau_f - \tau_1]}{d_p^{\,2}} \qquad R_{gm} = \frac{G_1 - G_2}{k_g}$$

$$F_{o2} = \frac{4 \cdot \alpha \cdot [\tau_f - \tau_2]}{d_p^{\,2}} \qquad R_{gd} = \frac{G_2}{k_g}$$

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