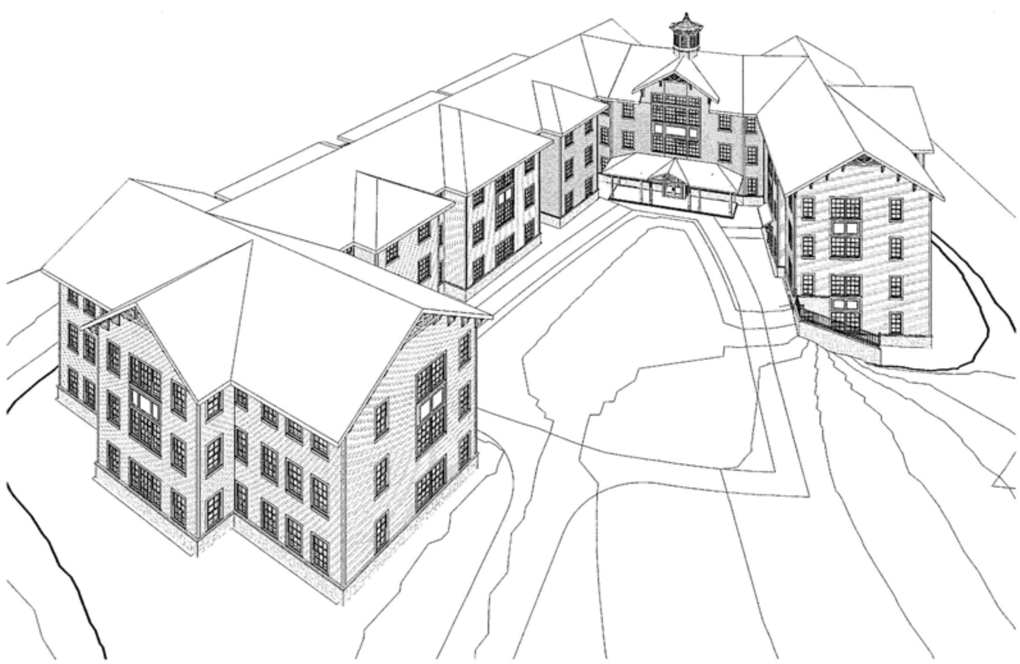
FINAL REPORT

AN ECONOMIC ANALYSIS OF GREEN DESIGN



NEW STUDENT HOUSING BUILDING
AT
THE MOUNT ST. MARY'S UNIVERSITY
EMMITSBURG, MD

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1. BUILDING ABSTRACT

MOUNT ST. MARY'S UNIVERSITY

STUDENT HOUSING PROJECT
16300 OLD EMITTSBURG ROAD
EMMITSBURG, MD 21747

Project Overview:

Function: Student housing / Dormatory
Size: 60,000 SF / 3 Stories / 180 Beds
Estimated Cost: $10,800,000 Total / $3,400,000 MEP
Dates of Construction: 2007 Completion Date
Delivery Method: GMP

Arcitecture:

Designed to create the appearance of a village
Comprised primarily of 4-bedroom suites, each with a shared bathroom and living area
Small lounge area provided on each floor
Designed to achieve LEED Certification

Project Team:

Owner: Mount St. Mary's University
Architect: Ayers / Saint / Gross Architects
Construnction Manager: Gilbane
Civil Engineer: Harris, Smariga, & Assoc., Inc.
Structural Engineer: Keast & Hood Co.
MEP Engineer: Burdette, Koehler, Murphy, & Assoc., Inc.

Electrical System:

Stepped down to 208Y/120V, 3 phase, 4 wire outside the building
(1) 1600v switchboard feeding the building
Various 120V fluorescent wall washers, ceiling-mounted pendants, and other conventional downlighting
Emergency lighting on battery backup

Mechanical System:

VAV system utilizing energy recovery and electric heat
12MBH to 30MBH geothermal heat pumps in each individual suite
(3) 1050CFM energy recovery units
(1) 750CFM, 600MBH domestic water heater

Structural System:

1′ spread footings and 5″ concrete slab on 6″ crushed stone
1 1/2″ fibermesh concrete over 3/4″ tounge and groove flooring
Floors supported by wooden bearing stud walls and wooden I-joists
Gabled roof made up of 2x6 wooden rafters

MOUNT ST. MARY'S UNIVERSITY

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3. ACKNOWLEDGEMENTS

I would like to take this opportunity to thank all the people who have supported me through my career at Penn State and this agonizing trial we like to call Senior Thesis.

Without the encouragement of my parents, I would never have been able to get through the past three years. They are the ones who instilled me with a drive to excel and succeed in such a punishing major. I only hope that some day I will be able to return the favor.

Right on the heels of my parents, I would like to thank my fiancée Jenny Gouldey for being there for me through everything for the past two and a half years. She makes all the hard work worth it, and all the other stuff worth even more.

I would like the thank all of the AE faculty for lending me their wisdom and expertise these past five years, and I would especially like to thank all the members of the mechanical department. Your classes, especially the ones at the graduate level, have left me far more prepared to enter the profession than I would have ever thought. Also, a special thanks to Dr. Srebric for getting me through Thesis.

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Finally, I would like to shout out to the entire AE Class of 2007. The friendships I made in this program are all that got me through sometimes. Rhodes, Potchak, Burgoyne, Ank, and Carr, thank you for not being afraid to work in groups whenever possible. Bem, Kaufman, and Conrad, thank you for being patient when the rest of us just could not figure something out. And Swartz, thanks for letting us help you get through all those pesky physics and mechanics classes so you could go on to graduate with the rest of. Haha, just kidding, buddy. Now that all this learning is almost over and done with and the real world is breathing down our necks, it will be the good times with all of you that I remember the most, even the late nights in the lab, the three day cram sessions, and all the things we did even though we knew weren't supposed to. Good luck everyone. It's been a good run.

4. EXECUTIVE SUMMARY

The Mount St. Mary's University began the design of this new student housing project with a fixed budget and certain goals. One of those goals was for the building to utilize sustainable systems in order to promote environmental consciousness while at the same time assuring a comfortable and functional building for the students who would reside there.

The following pages outline my analyses of this building with respect to marrying possible "green" design approaches to the realistic aspects of the university's budget. I will be attempting to determine what building systems have the potential to minimize life-cycle costs based on installation, maintenance, equipment, and yearly energy usage costs, and hopefully based on these analyses, I will be able to recommend the best possible sustainable building approach in terms of cost efficiency.

My depth work will entail a detailed analysis of the current geothermal system as well as a comparison to other conventional means of design for thermal comfort. Breadth work will encompass the implementation of photovoltaic panels for electrical energy generation, and an analysis will be performed as to how each system will affect constructional decisions and costs. Hopefully after completing all analyses, I will be able to specify with certainty the limits of the proposed systems and their actual impacts on environmentally conscious design.

Based on my previous studies of the new dormitory concluded last semester , I feel that the designed system for this new student housing project is probably one of the best possible based on the realistic budget of the project and the desires of the university. This investigation is to be preformed as an exercise in optimization, the goal of which being an attempt to determine a best possible sustainable systems based on initial, operational, and life-cycle costs.

5. PROJECT BACKGROUND

5.1. Design Objectives and Requirements

The Mount St. Mary's University began this new student housing project with a budget of approximately $10 Million, and their goal was to create a sustainable, environmentally friendly dormitory to house their growing population of students.

The vision for the project was to create an inviting dormitory consisting of 3- and 4-bedroom suites, each with their own living area and bathroom, as well as ample lounge space in which students could congregate and study. Each of these living units would have complete control over thermal comfort and lighting, and mechanical equipment would be as inconspicuous as possible. The building itself was to resemble a rural village, complementing the rest of the campus without being overly obtrusive, and at the same time, it had to be large enough to house approximately 200 students comfortably.

The university was also very interested in sustainable or "green" technologies. They wanted to project an image of environmental consciousness without taxing their budget too sorely or compromising the function of the building. A large number of windows were desired to take advantage of natural ventilation, and the university wanted to look into different options of sustainable design, such as energy recovery and geothermal heating and cooling, both of which were eventually adopted.

5.2. LEED Green Design Analysis

Created by the U.S. Green Building Council (USGBC), the Leadership in Energy and Environmental Design (LEED) rating system is considered to be the "nationally accepted benchmark for the design, construction, and operation of high performance green buildings." Utilization of the LEED system encourages an environmentally friendly approach to building design, while at the same time saving on building operating costs.

Four levels of LEED certification exist and are dependant upon the number of credits a building receives under six different categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Process. Receiving between 26 and 32 credits allows a building to become Certified, 33 to 38 receive a Silver rating, 39 to 51 will receive Gold, and 52 to 69 receive Platinum.

Those involved with the new student housing project at the Mount St. Mary's University were very interested in creating an efficient building that would also demonstrate the university's commitment to environmentally conscious design practices. Because this housing project was entirely new construction, a preliminary study of compliance to LEED-NC Version 2.2 was undertaken. Although the university has chosen not to pursue a LEED classification, the building would, in fact, have received a minimum of 26 credits and been a candidate for basic certification. It could possibly have been designed to receive a Silver rating if the university had pushed for certain credits, such as Innovative Wastewater Technologies, Measurement and Verification, Outdoor Air Delivery Monitoring, and Controllability of Systems.

Credits that would have been achieved due to mechanical systems are largely from three of the six categories: Water Efficiency, Energy and Atmosphere, and Indoor Environmental Quality. Requirements for Water Use Reduction, Enhanced Refrigerant Management, and Thermal Comfort credits were all designed into the building mechanical systems, and of the ten possible Optimize Energy Performance credits, it was assumed that a minimum of three could have been attained by the geothermal heat pump system. The entire LEED-NC checklist as it was compiled in the initial preliminary analysis is available in Appendix A of this report.

5.3. Site Factors Influencing Design

One of the objectives of the new student housing project was for the final design of the building to fit in with the style of the campus and project the image of a rural village. The desired gabled roof allowed little space for a cooling tower or the condensing units that are required in air source applications. The university also disliked the idea of a "farm" of condensing units clustered directly behind the building. The rural atmosphere of the campus forced the university to look into other, less obvious approaches, and when the geothermal system was suggested, they happily accepted this alternative. Geothermal wells are invisible to the general public, and the system's efficient ability to save on energy usage made it even more attractive.

Also, the extremes of the temperature ranges in the summer and winter months allowed energy recovery to be adopted by the university for the project. Prior to the addition of the energy recovery units, the building design had been relying entirely on natural ventilation to meet the building's outdoor air requirements. As another form of sustainable design, these units could replace the exhaust fans with only a short period of payback while allowing a more generous amount of ventilation air to be introduced into the building.

5.4. Indoor and Outdoor Design Conditions

The indoor design conditions on this project were based on standard summer and winter comfort levels for residential buildings. While each suite will have its own thermostat, allowing students to regulate the temperature to their own levels of comfort, the building was designed to maintain the setpoints that are listed in Table 5.4.1 below:

Table 5.4.1: Indoor Design Conditions

DESIGN CONDITIONS SCHEDULE										
Room Description	Occupied Hours						Unoccupied Hours			
	Summer		Winter		Ventilation		Summer		Winter	
	DB (°F)	% RH	DB (°F)	% RH	OA CFM	AC/hr	DB (°F)	% RH	DB (°F)	% RH
Residential Suite	75	50	70	30	50	1.0	85	50	65	30
Lobby	75	50	70	30	50	0.8	85	50	65	30
Lounge	75	50	70	30	50	0.8	85	50	65	30
Small Lounge	75	50	70	30	50	1.0	85	50	65	30
Electrical Room / Hallway	75	50	70	30	50	1.8	85	50	65	30

Outdoor design conditions were taken from Carrier's HAP for the city of Hagerstown, Maryland. They are shown in Table 5.4.2 below:

Table 5.4.2: Outdoor Design Conditions

OUTDOOR DESIGN CONDITIONS		
Design:		
	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)
Summer	94.0	75.0
Winter	8.0	5.8

Monthly:				
	Max. DBT	Min. DBT	Max. WBT	Min. WBT
January	50.8	28.8	47.0	28.3
February	54.0	32.0	52.0	31.5
March	65.0	43.0	61.0	42.5
April	75.0	53.0	65.0	52.5
May	84.8	62.8	70.0	62.3
June	91.0	69.0	73.0	66.5
July	94.0	72.0	75.0	68.8
August	94.0	72.0	75.0	68.8
September	88.8	66.8	72.0	65.4
October	78.0	56.0	67.0	55.5
November	68.8	46.8	61.0	46.3
December	56.0	34.0	52.0	33.5

5.5. Energy Sources and Rates

The new student housing project at the Mount St. Mary's University uses electricity for most of its systems, making use of natural gas only for the domestic hot water heater. Because the new student housing project is not yet built, electric and natural gas rates were assumed comparable to those provided by Baltimore Gas and Electric.

Electric rates were taken from the Large General Service schedule for Type II-A Market priced service. The electric service rates were separated into delivery service customer charge, demand charges, energy charges, and a delivery service charge. The energy charges were divided into peak, intermediate, and off-peak periods. Information pertaining to rating periods and electrical utility rates may be found in respective Tables B.1 and B.2 of Appendix B of this report.

Natural gas rates were taken from the General Service-C schedule, and rates were separated into customer and delivery charges. The distribution charge was broken down based on the amount of gas (therms) used in one month. Information pertaining to natural gas rates may be found in Table B.3 of Appendix B of this report.

There are no known incentives being offered that would influence energy consumption or operational costs.

5.6. Design Ventilation Requirements

The new student housing project at the Mount St. Mary's University utilizes a dedicated outdoor air system with energy recovery coupled with natural ventilation. Three energy recovery units provide a constant flow of 50 CFM of outdoor air to each of the building's heat pumps. It was determined by previous analysis that natural ventilation from the windows alone would have been sufficient to adequately ventilate the building to the approval of Standard 62.1-2004.

It was determined by the mechanical consultant on the project that should natural ventilation alone be used, the building would be very negatively pressurized as well as possibly being underventilated in the winter months when windows would most often be closed. The energy recovery units were, therefore, proposed as an alternative to simple exhaust fans. Due to the University's dedication to environmentally friendly design, they adopted the plan, which would have initially supplied 100 CFM of ventilation air to each of the heat pumps. The flow was cut back to 50 CFM due to cost restraints.

A building ventilation analysis was performed on the building's mechanical ventilation systems based on ASHRAE Standard 62.1-2004. The results of that study may be seen in Table 5.6.1 below:

Table 5.6.1: Calculated vs. Design Ventilation Flow Rates

	Max Z_p	System Ventilation Efficiency (E_v)	Population Density (P_s)	Occupant Diversity (D)	Uncorrected Outdoor Intake (V_{ou}) [CFM]	Nominal Outside Air (ΣV_{oz}) [CFM]	Required Outside Air (V_{ot}) [CFM]	Actual Supplied Ventilation Air [CFM]
ERU-1	0.11	1	60	0.87	1102	1161	1102	1050
ERU-2	0.10	1	66	0.79	1325	1431	1325	1050
ERU-3	0.09	1	57	1.00	990	1001	990	750
Total Building						3593	3417	2850

At first glance, it would appear that all three ERU's are undersized and do not meet the building's ventilation requirements. However, one must keep in mind the fact that natural ventilation alone would be sufficient under the circumstances; the mechanical ventilation is only for supplemental and pressurization purposes. Had cost not constrained the units from delivering 100 CFM to each of the pumps, the mechanical system alone would have far exceeded the requirements listed in the Standard.

5.7. Design Heating and Cooling Loads

In order to create a comparison of estimated heating and cooling loads to those scheduled by the mechanical engineer, Carrier HAP was utilized to simulate the new student housing project at the Mount St. Mary's University. A brief summary of calculated load results as compared to actual design data is provided in Table 5.7.1 below. Some inconsistencies between the numbers can be contributed to incorrect estimates of schedules, lighting and electrical equipment power densities, and other general conditions. The large difference in the cooling and heating loads may also be contributed to the fact that the design data is based on the total rated capacity of the building's various geothermal heat pumps; the actual loads being seen by these units are not described on the design documents and are probably less than their rated capacities.

Table 5.7.1: Calculated vs. Design Cooling and Heating Loads

Energy Usage Comparisons						
System	Output	Cooling Total (Tons)	Cooling Sensible (Tons)	Heating (Tons)	Cooling (ft^2/Ton)	Heating (ft^2/Ton)
ERU-1	HAP	23.0	20.2	22.0	634	664
	Design	36.9	30.8	33.9	395	430
ERU-2	HAP	28.5	24.5	27.1	619	649
	Design	41.4	33.1	36.3	426	484
ERU-3	HAP	19.6	17.0	19.8	662	655
	Design	31.3	23.6	25.6	414	505

6. EXISTING MECHANICAL SYSTEMS DESCRIPTION

The following are descriptions of the three main mechanical systems at the new student housing project, as well as their respective components. The three major systems analyzed are the geothermal heat pump system, the ventilation system with energy recovery, and the domestic service water system. A brief listing of abbreviations and symbols referenced in the following schematics is provided in Figure 6.1 below:

Figure 6.1: Abbreviations and Symbols Used in Following Schematics

	ABBREVIATIONS AND SYMBOLS
CS	CONDENSER WATER SUPPLY
CR	CONDENSER WATER RETURN
OA	OUTDOOR AIR
EA	EXHAUST AIR
FD	FIRE DAMPER
CW	DOMESTIC COLD WATER
HW	DOMESTIC HOT WATER
HWR	DOMESTIC RECIRCULATED HOT WATER
RPBFP	REDUCED PRESSURE BACK FLOW PREVENTER
	BALL VALVE
	BUTTERFLY VALVE

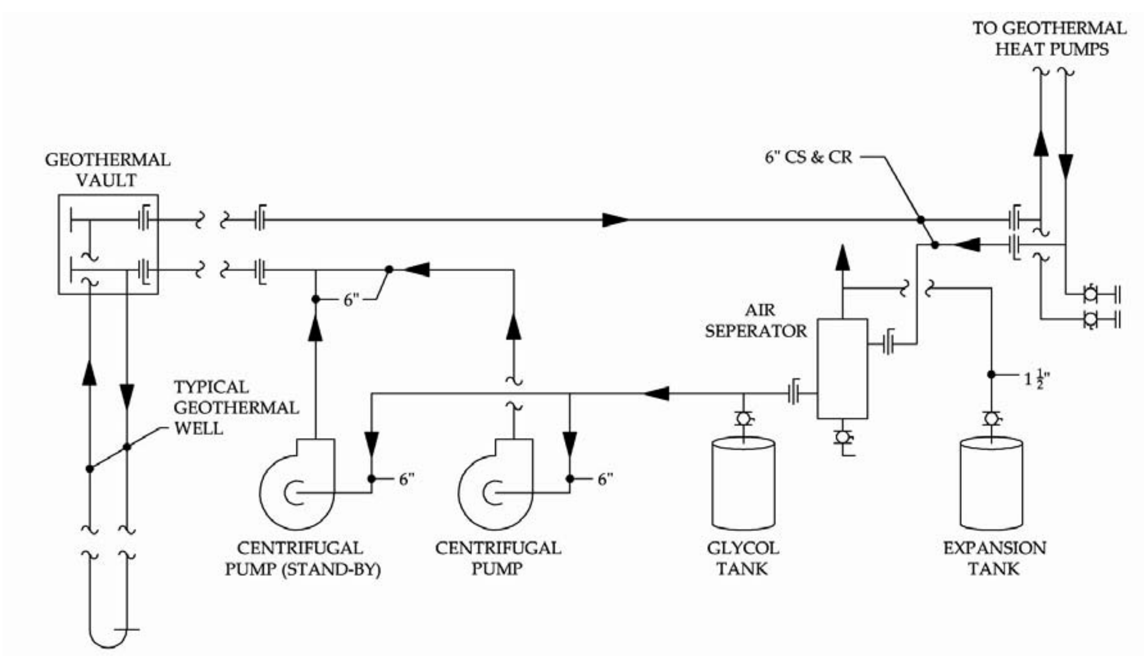
6.1. Geothermal Heat Pump System

The new student housing project at the Mount St. Mary's University utilizes a geothermal heat pump system to both heat and cool the building. Originally designed with 125 vertical wells, each 4 inches in diameter and 200 feet deep, the system has recently been redesigned with 64 vertical wells, each 4 inches in diameter and 400 feet deep. They are located around the front of the site and stem from a geothermal pipe distribution vault located beneath the main courtyard of the building. From this vault, the condenser water is distributed directly to the heat pumps located throughout the building for either heating or cooling.

The condenser water returns to the building's mechanical room, where it is sent through an air separator, and it is approximately here that both the 160 gallon expansion tank and the glycol tank are linked to the system. The water is then run through one of two centrifugal pumps capable of moving 375 GPM and back out to the geothermal vault for redistribution to the vertical wells.

Some of the benefits of this geothermal system, impacting first cost, maintenance costs, and energy costs, are that it eliminates the need for chillers, boilers, and cooling towers. Partially because of this, the heat pumps themselves are capable of achieving higher coefficients of performance and energy efficiency ratings than conventional heat pumps.

Figure 6.1.1: Geothermal Heat Pump System Schematic



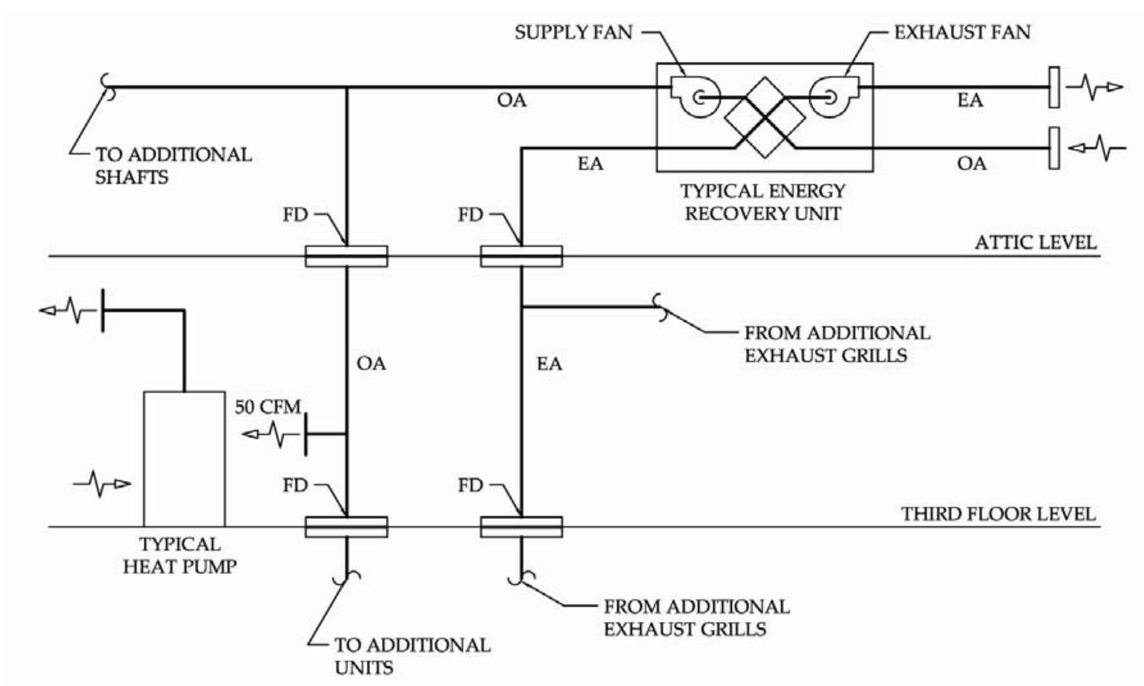
6.2. Ventilation System

The building's ventilation system serves a supplemental function and is coupled with natural ventilation. It consists of three energy recovery units located in the attic of the building, which were incorporated into the system in place of exhaust fans in an attempt to keep the building pressurized and to increase the amount of outdoor air reaching the occupied spaces.

Exhaust air is pulled from bathrooms and mechanical rooms throughout the building at a rate comparable to that of the ventilation air being brought in. These energy recovery units utilize the wasted energy in the exhaust streams to pretreat the ventilation air being brought into the building. Electric duct heaters may also be utilized during winter months to raise the temperature of the air further. This air is then supplied directly to the closets housing the individual heat pumps at a constant rate of 50 CFM, where it is mixed with recirculated air and conditioned further before being supplied to the space.

Using energy recovery to pretreat the ventilation air saves a great deal of energy later in the process of heating and cooling. During the extremes of the summer and winter, pretreating the ventilation air can reduce the overall outdoor air load to as low as 20% of what it would be without energy recovery.

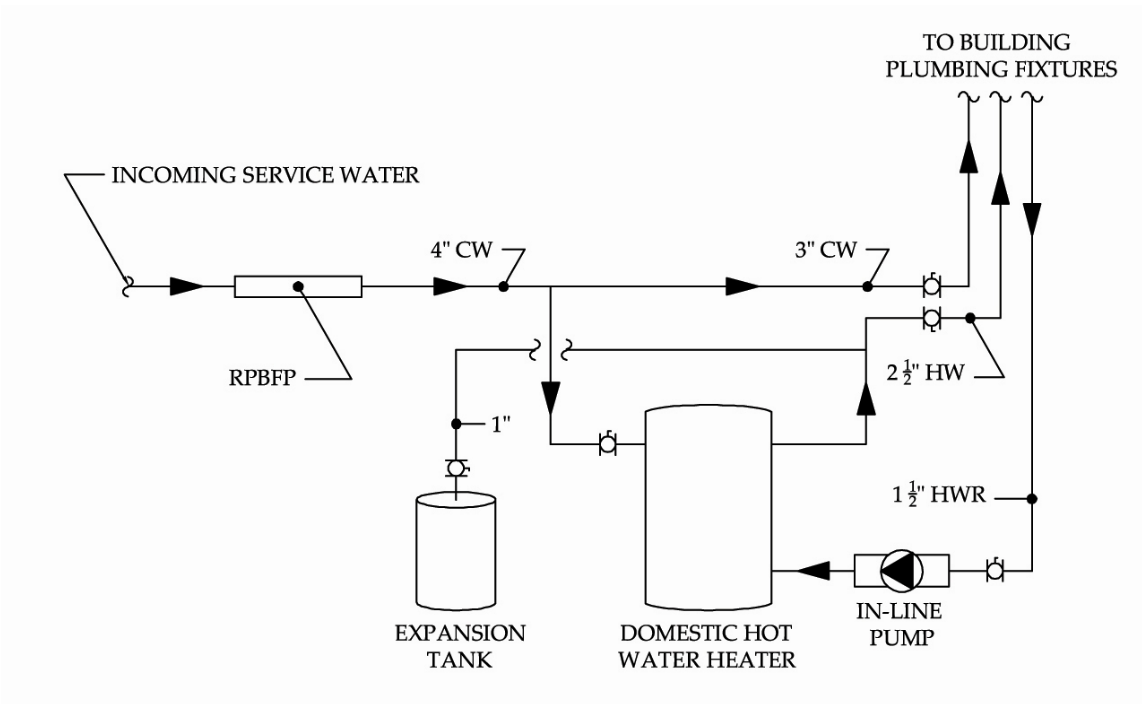
Figure 6.2.1: Ventilation System with Energy Recovery Schematic



6.3. Domestic Service Water System

The building's incoming domestic service water is brought in through a reduced pressure back flow preventer into the mechanical room in the basement. From there, the water is split from a 4 inch pipe into 3 and 2 ½ inch pipes, the latter of which then feeds into a 750 GPH domestic hot water heater connected to a 35 gallon expansion tank. Bother the cold and hot water are then fed to all the various bathrooms, janitor's closets, and water fountains located throughout the building. The hot water is recirculated through a 15 GPM in-line pump located in the mechanical room.

Figure 6.3.1: Domestic Water Service System Schematic



7. MECHANICAL DEPTH WORK

7.1 Goals and Justification

I have decided to take the geothermal heat pump system under consideration as the main depth topic of this investigation. While I would defend this system as being the best form of heating and cooling under the circumstances, the fact remains that such a system is very expensive, and as the focus of this thesis is to be the sustainability of the building as a whole based on overall first cost and life-cycle savings, a system with such a great first cost must be analyzed to see if its benefits and life-cycle savings warrant its adoption.

There are three other potential types of systems which I would like to compare against the geothermal system in terms of both system costs and total building costs: conventional air-source split systems rejecting heat to condensing heat pump units, water-source heat pumps rejecting heat to a cooling tower, and a relatively new form of heating and cooling, variable refrigerant volume (VRV) fancoil units, which also reject heat to condensing units.

The existing geothermal heat pump system consists of 58 water-source heat pumps connected to a series of 64 closed vertical ground loops. The system is unlike traditional water-source systems. The vertical loops reject heat to the ground during the summer months, eliminating the need for a cooling tower or other heat sink, and they extract warmth from the ground during the winter months, eliminating the need for a boiler. Air-source applications also require outdoor condensing units, which are unnecessary in this system.

While the system can be expensive to install, the vertical wells generally costing anywhere from three to twelve dollars per installed lineal foot of piping, they have the potential to have great savings over the lifetime of the system. In most applications, water-source heat pumps perform more efficiently when connected to a ground loop than to a building loop with a boiler and cooling tower. Both geothermal and boiler/cooling tower systems utilize essentially the same heat pumps, and at rated conditions, they will also have similar coefficients of performance. However, boiler/cooling tower systems are generally designed for temperatures between 60°F and 70°F, while geothermal systems are generally able to operate at lower temperatures, which translates into greater heat pump performance when operating in cooling mode. Because of this, great savings can be achieved in commercial applications where the heat pumps are operating in cooling most of the time regardless of climate, resulting in significant hours of part-load operation and much greater savings over boiler/cooling tower systems (McQuay, 2006).

Coupled with the fact that energy consumed by the boiler and cooling tower is not a factor in geothermal systems, this additional savings due to part load cooling can allow a geothermal system to use up to 50% less energy than a conventional boiler/cooling tower system (McQuay, 2006). The only piece of mechanical equipment drawing power in a geothermal system is the pump, which only uses slightly more energy than in a conventional system. Maintenance costs are also greatly reduced due to the absence of the boiler and cooling tower, and geothermal systems alleviate the need for additional items like sump water heaters, cooling tower chemicals, and make-up water (McQuay, 2006).

Even very high efficiency direct expansion (DX) split systems cannot usually match the performance of water-source heat pumps at cold temperatures. Most units are rated between 40 and 50 degrees Fahrenheit, and their level or performance in heating mode drops of significantly as the temperature decreases (EERE, 2005). The first cost on a job like Mount St. Mary's may be very high also as each system requires separate machinery: an indoor evaporator and an outdoor condensing heat pump unit. However, the air-source system does not require the large pumps, cooling towers, or boilers that may be necessary in water-source applications, which may bring its yearly energy usage and first costs closer to that of the water-source systems.

VRV was introduced to me during my internship this summer, and it was the opinion of several of the engineers there that such a system could have definite benefits once it is better understood. It implements variable flow of refrigerant to provide simultaneous heating and cooling and can also achieve far greater lift than conventional systems (Daikin, 2006). During my investigation, I will be looking at Daikin VRV units, as they appear to be the forerunners of this particular form of technology.

The four systems listed above are all realistic alternatives that merit an investigation into the cost benefits of their application on the Mount St. Mary's project. Careful determination of the locations of the heat rejection apparatus would be necessary due to the aforementioned aesthetic requirements of the building, but I feel that a detailed comparison of these systems will prove to be a large deciding factor when the building is finally analyzed with regard to all proposed systems. The poorer efficiencies of several of these systems might be offset by their overall savings in the long run, and I feel that in the interest of implementing other sustainable forms of design, the prohibitive first cost of the geothermal system might cause another choice to prove more favorable in this new light. Carrier's HAP will be used to perform the necessary calculations and energy and cost analyses.

7.2. Case 1: Existing Geothermal System

The geothermal water-source heat pump system was opted for over a more conventional boiler/cooling tower system by the Mount St. Mary's University chiefly due to its energy saving potential and value as a green system. At the time still working towards a possible LEED rating, the university was also opposed to the idea of a "farm" of condensing units or cooling towers taking up space on the property, and the environmentally friendly geothermal design seemed the best choice at the time.

I have since utilized Carrier's HAP to model the building in its entirety as accurately as possible, complete with the energy recovery and geothermal HVAC systems. McQuay's Enfinity Model FCW vertical heat pump units were specified by the design documents, ranging between 1 and 2.5 tons. Design conditions were input into the program as shown in Section 5.2 of this report, and energy data was input as described in Section 5.3. All information pertaining to the units as required input by HAP was taken from the design documents or Table 7.2.1 below, which details the heating and cooling capabilities of the heat pump units. Additional information can be found in the cut sheets in Appendix D.

Table 7.2.1: Ground-Source Performance Data

McQuay Enfinity Model FCW - Ground-Source Heat Pump						
Unit Size (Tons)	Airflow (CFM)	Water Flow (GPM)	Cooling @ 77 °F		Heating @ 32 °F	
			BTU/h	EER	BTU/h	COP
1.0	400	3.1	12,000	14.2	9,400	3.2
1.5	630	5.2	21,400	16.2	14,800	3.5
2.0	800	5.9	24,500	15.1	18,400	3.6
2.5	1000	7.2	31,400	16.9	24,500	3.5

Notice the high energy efficiency ratios when in cooling mode. This is because of the fact that the system is capable of operating at a lower rated temperature than conventional water-source applications due to the stable temperature conditions of the earth. At part load, the values above will increase further.

After running the program, it was determined that the total annual operating cost of the new dormitory is $115,002. Of that amount, $46,604 is mechanical system costs, meaning that the building's HVAC system totals roughly 40% of the yearly operational costs. Figures 7.2.1 and 7.2.2 below describe the percentage of annual component costs and the monthly component cost totals, respectively.

Figure 7.2.1: Percentage of Annual Ground-Source Component Costs

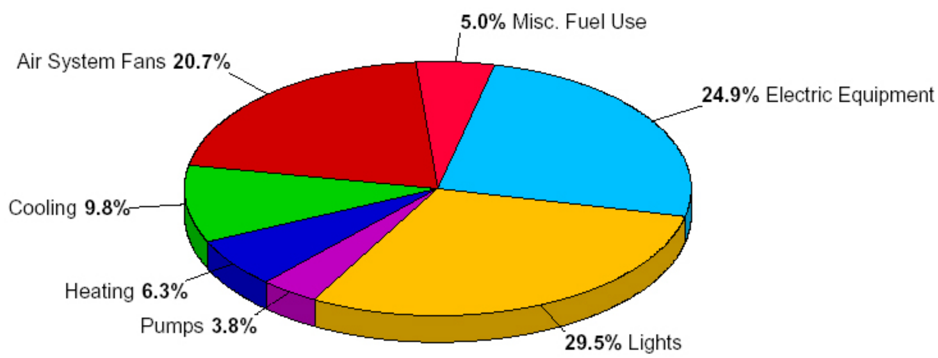
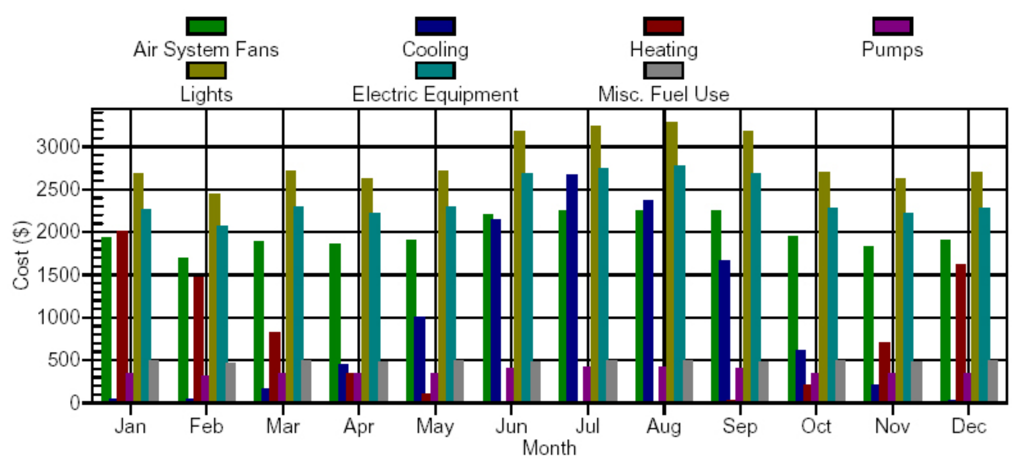


Figure 7.2.2: Monthly Ground-Source Component Cost Totals



These results were very much in line with what I had been expecting. Lighting and electrical equipment constituted 54.4% of the yearly costs, while cooling and heating loads were kept to lower percentages of 9.8% and 6.3%, respectively. From the graph of the monthly loads, it can be seen that basic electrical costs proved more expensive than cooling costs even in the hottest months and more expensive than heating costs during the winter months.

7.3. Case 2: Water-Source Heat Pump System

The new dormitory was originally designed with a 1000 MBH boiler and a cooling tower capable of handling 100 tons of cooling. This more traditional approach to water-source heat pump systems would have been a good fit for the building, saving on first costs and shortening the schedule of the project.

Working with the same HAP model used for the geothermal simulation, I was able to alter the systems to conform to a boiler/cooling tower arrangement. Information pertaining to the original boiler and cooling tower selections was retrieved from the mechanical designer and input into the program. Since McQuay's Enfinity water-source heat pumps were specified for the geothermal system, I modeled this new system using the Enfinity Model FCV, which is basically the same heat pump used in the geothermal application but rated for different operating conditions. Information required by HAP pertaining to these units was input as shown in Table 7.3.1 below. Additional information can be found in the cut sheets in Appendix D.

Table 7.3.1: Water-Source Performance Data

McQuay Enfinity Model FCV - Water-Source Heat Pump						
Unit Size	Airflow	Water Flow	Cooling @ 86 °F		Heating @ 68 °F	
(Tons)	(CFM)	(GPM)	BTU/h	EER	BTU/h	COP
1.0	400	3.1	11,200	12.1	15,200	4.3
1.5	630	5.2	19,800	13.9	24,900	4.7
2.0	800	5.9	22,800	13.0	30,200	4.7
2.5	1000	7.2	30,400	14.6	37,200	4.8

It can be seen in the performance data above that the coefficients of performance of the water-source heat pumps are slightly higher than those of the geothermal heat pumps, due to the higher rated temperatures achieved through the use of a boiler. However, the building in question has higher yearly cooling loads than heating loads, and it can be seen above that, when compared to the energy efficiency ratios of the geothermal heat pumps, those of the water-source heat pumps are somewhat less efficient. Coupled with the additional costs of running a boiler and cooling tower, I am expecting the yearly expenses of this system to be a bit higher than the geothermal system.

After rerunning the program, it was found that now the total annual operating cost of the dormitory would be $123,709. Of that amount, $55,340 would be mechanical system costs, and the building's HVAC systems would total roughly 45% of the yearly operational costs. Figures 7.3.1 and 7.3.2 below describe the percentage of annual component costs and the monthly component cost totals, respectively.

Figure 7.3.1: Percentage of Annual Water-Source Component Costs

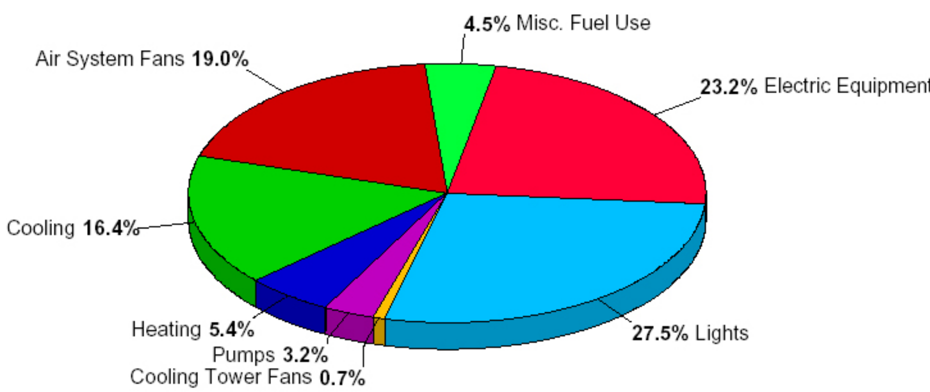


Figure 7.3.2: Monthly Water-Source Component Cost Totals

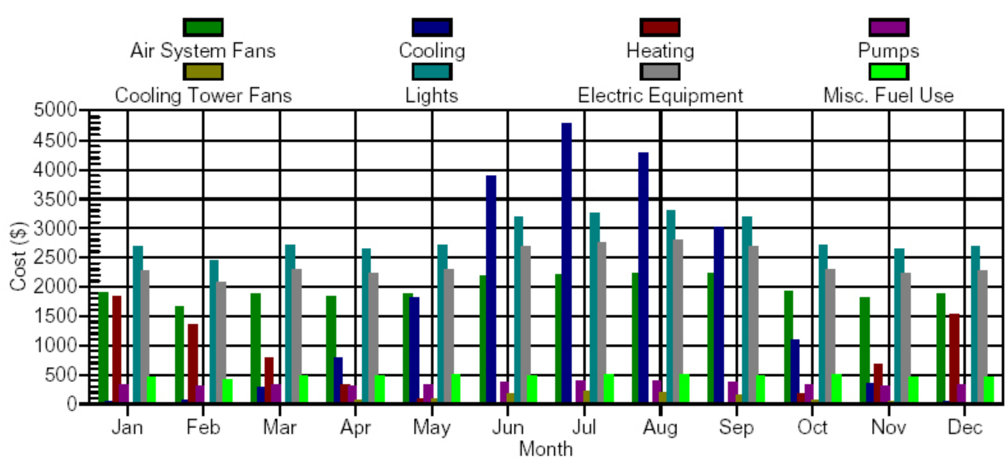


Table 7.3.2 below shows a detailed breakdown of the annual costs of the HVAC components and the savings possible by the geothermal system.

Table 7.3.2: Potential Savings of Geothermal over Water-Source

	Air System Fans	Cooling	Heating	Pumps	Boiler	Cooling Tower Fans	Total
Water-Source	$23,479	$18,580	$6,717	$3,934	$1,726	$904	$55,340
Ground-Source	$23,764	$11,302	$7,225	$4,313	$0	$0	$46,604
Savings	-$285	$7,278	-$508	-$379	$1,726	$904	$8,736

From this table, it quickly becomes apparent that there is very little difference between the systems with regards to system fans. As expected, the water-source pumps appear to be approximately 8% more efficient when heating, and there is a slightly greater expense with the pumps for the geothermal system, which can be explained do to the additional friction head incurred by the ground loops. However, in cooling mode, the geothermal system is almost 40% more efficient, and the costs of the boiler and cooling tower amount to an additional $2,630 annually. Overall, the geothermal system is predicted to save almost $9,000 annually, which translates to 16% of the total yearly mechanical system costs.

7.4. Case 3: Air-Source DX Split Heat Pump System

A slightly less efficient alternative with a possibly high first cost would be DX split systems utilizing air-source heat pump technology. As stated above, even the most efficient of these systems cannot match the performance of a water-source heat pump system under most circumstances; however, they have no associated boiler, cooling tower, or pump costs. Because of this, they merit further investigation.

Again altering my original HAP model, I this time selected air-source split DX terminal units. I wanted to stay with McQuay as the previous two simulations had used this manufacturer as the basis of design. For the evaporators, I chose Model SAH air handlers ranging from 1.5 to 3.5 tons, and for the condensing units, I selected Model HCC air-source heat pumps ranging from 1.5 to 2.5 tons. These units are considered high efficiency models by the manufacturer, having SEER ratings of 12. Information required by HAP pertaining to the evaporators and condensers are shown in Table 7.4.1 below. Additional information can be found in the cut sheets in Appendix D.

Table 7.4.1: Air-Source Performance Data

McQuay Air-Source DX Split Heat Pump System (12 SEER)					
Condenser Size (Tons)	Evaporator Size (Tons)	Cooling @ 95 °F		Heating @ 47 °F	
		BTU/h	EER	BTU/h	COP
1.5	1.5	16,000	11.0	17,000	3.0
	2.5	17,000	12.0	18,000	3.5
2.0	2.0	21,100	11.5	22,000	3.0
2.5	2.5	24,800	11.3	27,000	3.0
	3.5	27,400	12.0	29,400	3.3

This system is considered by McQuay to be a high efficiency system for its type, and yet the efficiency ratings in both heating and cooling are less than those of either of the water-source or ground-source systems. However, this system will have no yearly costs associated with pumps, boilers, or cooling towers, so it may prove competitive with one or both of the previous systems analyzed.

After rerunning the program, it was found that the total annual operating cost of the dormitory using air-source units instead of water-source ones would be $125,971. Of that amount, $57,299 would be mechanical system costs, and the building's HVAC systems would total roughly 46% of the yearly operational costs. Figures 7.4.1 and 7.4.2 below describe the percentage of annual component costs and the monthly component cost totals, respectively.

Figure 7.4.1: Percentage of Annual Air-Source Component Costs

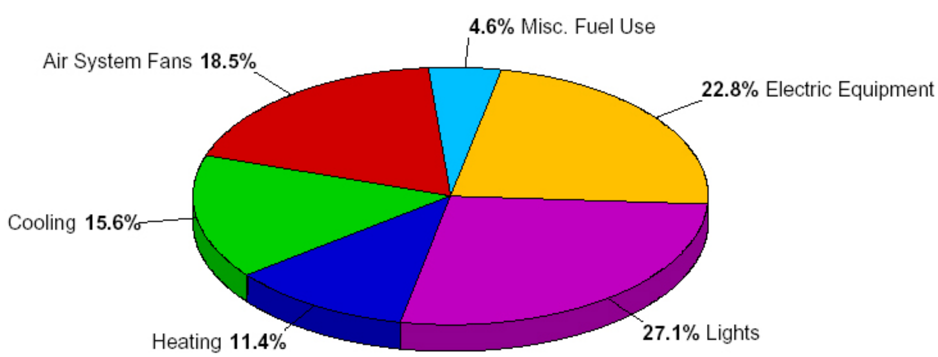


Figure 7.4.2: Monthly Air-Source Component Cost Totals

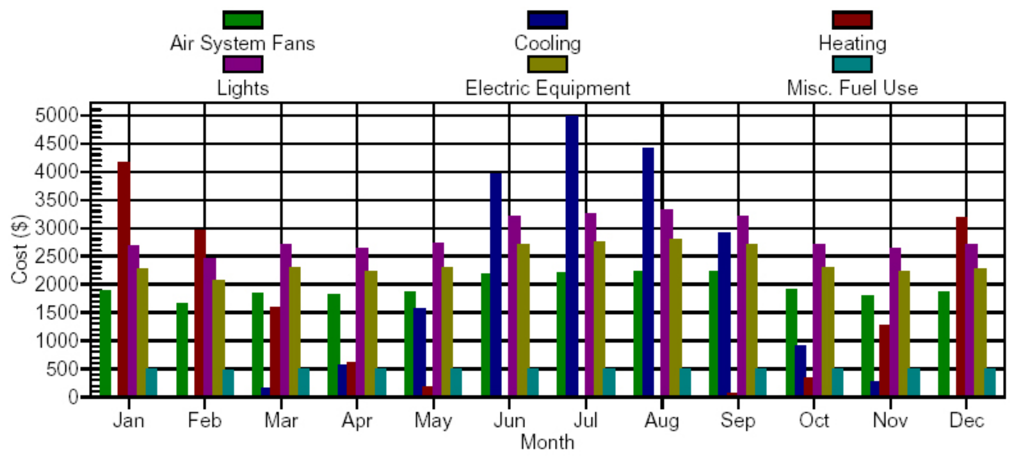


Table 7.4.2 below shows a detailed breakdown of the annual costs of the HVAC components and the savings possible by the geothermal system.

Table 7.4.2: Potential Savings of Geothermal over Air-Source

	Air System Fans	Cooling	Heating	Pumps	Boiler	Cooling Tower Fans	Total
Air-Source	$23,311	$19,686	$14,302	$0	$0	$0	$57,299
Ground-Source	$23,764	$11,302	$7,225	$4,313	$0	$0	$46,604
Savings	-$453	$8,384	$7,077	-$4,313	$0	$0	$10,695

Again, the system fans are approximately equivalent in terms of yearly cost, and both systems have no boiler or cooling tower costs. The pumps in the geothermal system add an additional $4,300 annually; however, the savings in both heating and cooling costs greatly outweigh this cost. The geothermal system is roughly 43% more efficient when cooling and 50% more efficient when heating, allowing for an annual savings of almost $11,000.

What proves interesting are the yearly cost comparisons between the air-source system and the conventional water-source system, which can be seen in Table 7.4.3 below.

Table 7.4.3: Potential Savings Comparisons of Water-Source and Air-Source

	Air System Fans	Cooling	Heating	Pumps	Boiler	Cooling Tower Fans	Total
Air-Source	$23,311	$19,686	$14,302	$0	$0	$0	$57,299
Water-Source	$23,479	$18,580	$6,717	$3,934	$1,726	$904	$55,340
Savings	-$168	$1,106	$7,585	-$3,934	-$1,726	-$904	$1,959

Here the total annual costs are very close, and although a more efficient system, the water-source system will potentially only save some $2,000 per year over the air-source system. The greater efficiencies of the water-source system showed that if no additional machinery were analyzed, it would save approximately $9,000 yearly in combined heating and cooling costs; however, between the pumps, the boiler, and the cooling tower, the air-source system would gain back approximately $7,000 of that initial savings. The give and take between the systems initially makes them both look equally viable, and if a designer were attempting to choose between these two systems, the first costs of the systems would play a major role, which is something that will be analyzed later in this report.

7.5. Case 4: Variable Refrigerant Volume System

During the course of these system analyses, it was eventually determined that an energy analysis of Daikin's VRV system was beyond the abilities of the modeling software available. As Carrier does not yet carry variable refrigerant volume systems, HAP has not yet been implemented with the capability to model VRV systems. According to a Daikin representative I spoke with, the present method of effectively sizing such units for a particular building involves using Daikin's own patented software. The software is not available for private use, and having the representative perform such an analysis on my building as a purely hypothetical exercise was more than I was willing to ask. Therefore, I will outline the merits of the system without the benefit of an energy analysis.

While gaining widespread notoriety overseas, VRV systems are still very new and unknown to American engineers. Driven by a highly intelligent inverter that controls the compressor, the condensing units are capable of being modulated by the cooling or heating requirements of the zone. Working in heat pump mode, a sing condensing unit can control up to 20 indoor terminal units at loads of 16 combined cooling tons and 18 combined heating tons. The system is able to then simultaneously heat and cool within the same circuit by diverting exhaust heat from indoor units in cooling mode to other areas which require heating (Daikin, 2006).

According to the manufacturer the condensing units are much more compact than conventional units and require minimal clearance space, approximately 2 feet between units, allowing them to be clustered far more tightly together. They are also require no structural reinforcement once installed due to their lightweight and vibration-free construction, and they are capable of achieving far greater lift than conventional systems: 165 feet of height difference, 490 feet of piping to the most distant indoor unit, and up to 1000 feet of total piping length. The indoor terminal units come in a wide selection of styles for different applications, ranging in capacities from 1 to 4 tons (Daikin, 2006).

At the new dormitory at the Mount St. Mary's, an estimated five of the 16-ton condensing units would be required to deal with the building's 71 peak tons of cooling and 69 peak tons of heating. Each condensing unit would be responsible for approximately 12 of the building's 58 terminal units, and could be located in a cluster behind the building or hidden in the attic level, their exhaust being vented outside alongside the exhaust from the energy recovery units. The ideal terminal units to be used on this project would be concealed vertical units, much the same size as the water-source heat pumps specified by the design documents. While this type of terminal unit is not yet available in America, the Daikin representative assured me that they are already in use in Europe and should become available in the next few years.

Lacking the access to necessary programs, further analysis of a potential VRV system at this site cannot be attempted. In present practice, if Daikin's VRV units were desired on a job, the mechanical engineer would work closely with a Daikin representative to size the building systems as a whole, which is beyond the scope of this thesis. Still, I feel that in a few years such technology could work its way into common usage. VRV could have been very applicable on this project, and it should seriously be considered by mechanical design consultants on similar future jobs as feasible alternatives to conventional systems.

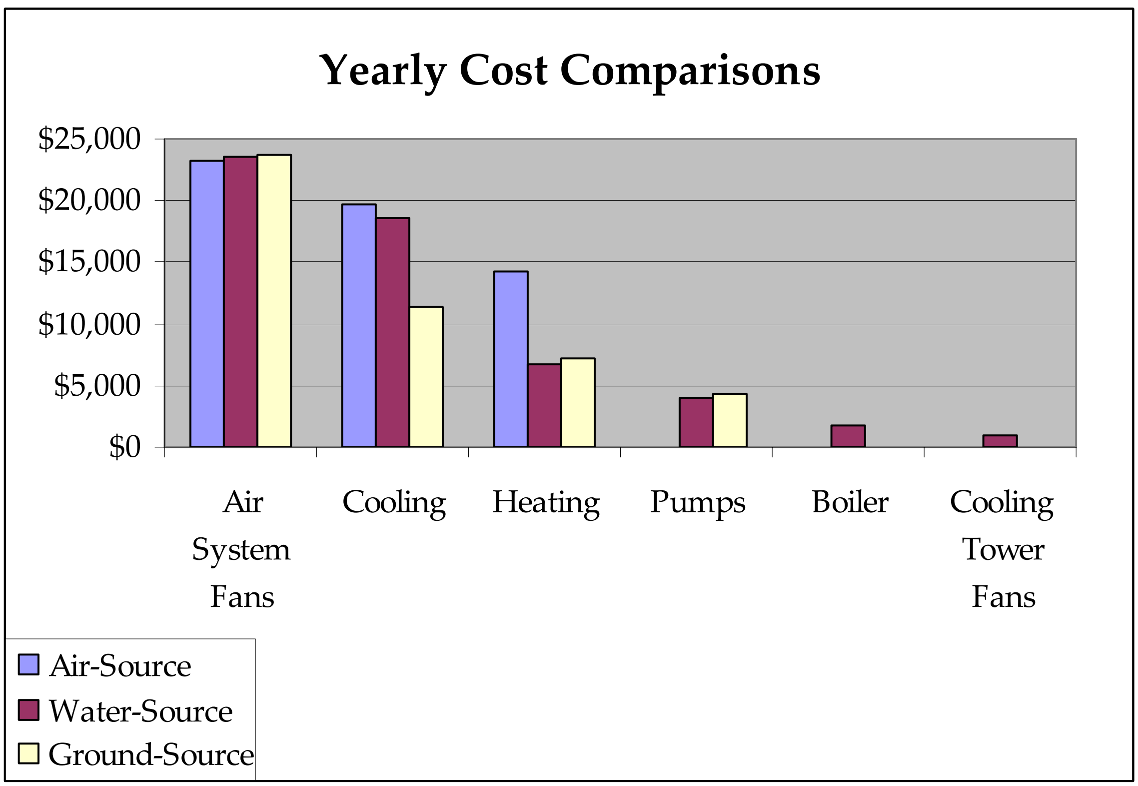
7.6. Conclusions

Of the three systems modeled, the geothermal system proved to be the most efficient and economic. A breakdown of the yearly savings possible by each system as well as a comparison of yearly HVAC component costs can be seen in Table 7.6.1 and Figure 7.6.1 below, respectively.

Table 7.6.1: Potential Yearly Savings of Compared Systems

HVAC System Components							
	Air System Fans	Cooling	Heating	Pumps	Boiler	Cooling Tower Fans	Total
Air-Source	$23,311	$19,686	$14,302	$0	$0	$0	$57,299
Water-Source	$23,479	$18,580	$6,717	$3,934	$1,726	$904	$55,340
Ground-Source	$23,764	$11,302	$7,225	$4,313	$0	$0	$46,604
						Ground-Source savings over Air-Source:	$10,695
						Ground-Source savings over Water-Source:	$8,736
						Water-Source savings over Air-Source:	$1,959

Figure 7.6.1: Yearly HVAC Component Cost Comparisons



On a basis of annual cost savings, the geothermal system would appear to be the correct choice for this project. The graph in Figure 7.6.1 illustrates this quite clearly, showing vast disparities between some of the component costs. While VRV units could possibly prove even more efficient still, they must be left in question as no available tool could be located to effectively model such a system.

For a university concerned with green design, the high first cost of the geothermal system could very well be shown as justified following the life-cycle cost analysis which will be preformed later in this report. The annual savings over time are very appealing, and should the geothermal system prove to be the most overall cost-effective alternative, the Mount St. Mary's University will end up with not only an environmentally friendly heating and cooling system, but also one that saves them money over the long term.

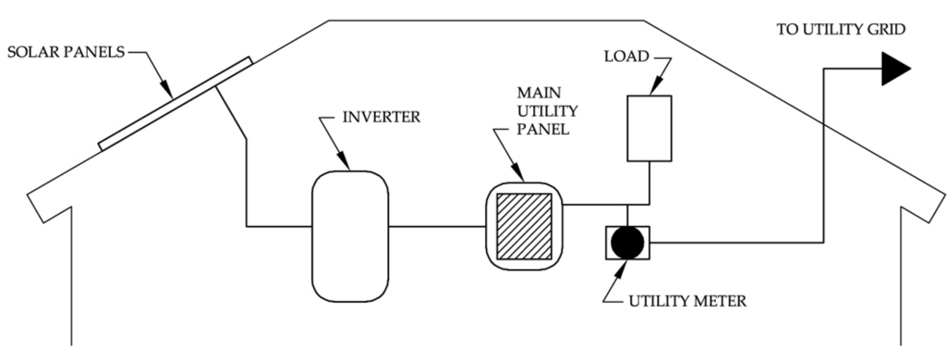
8. ELECTRICAL BREADTH WORK

8.1. Goals and Justification

Because the Mount St. Mary's University has shown such an interest in environmentally friendly design, a photovoltaic system for energy generation could also prove beneficial on this project. Photovoltaic (PV) modules would be located at certain locations along the south-sloping roofs and could be used to create electric energy, which could offset some of the building's costs associated with energy usage. Along with this as-yet undetermined amount of PV cells, inverters would be required convert the solar generated DC power into utility grade AC power, and from there, the AC power would be connected to the building's primary panelboard.

This arrangement would constitute a basic grid-tie system, in which the building is still connected to the electrical utility company and will use electricity from the grid as needed to compensate for the shortcomings of the photovoltaic system. Should the photovoltaic system be designed to be capable of exceeding the electrical demands of the building, the additional energy produced could then be sold back to the electrical utility company. A schematic of a basic grid-tie system can be seen in Figure 8.1.1 below.

Figure 8.1.1: Basic On-Grid Photovoltaic System



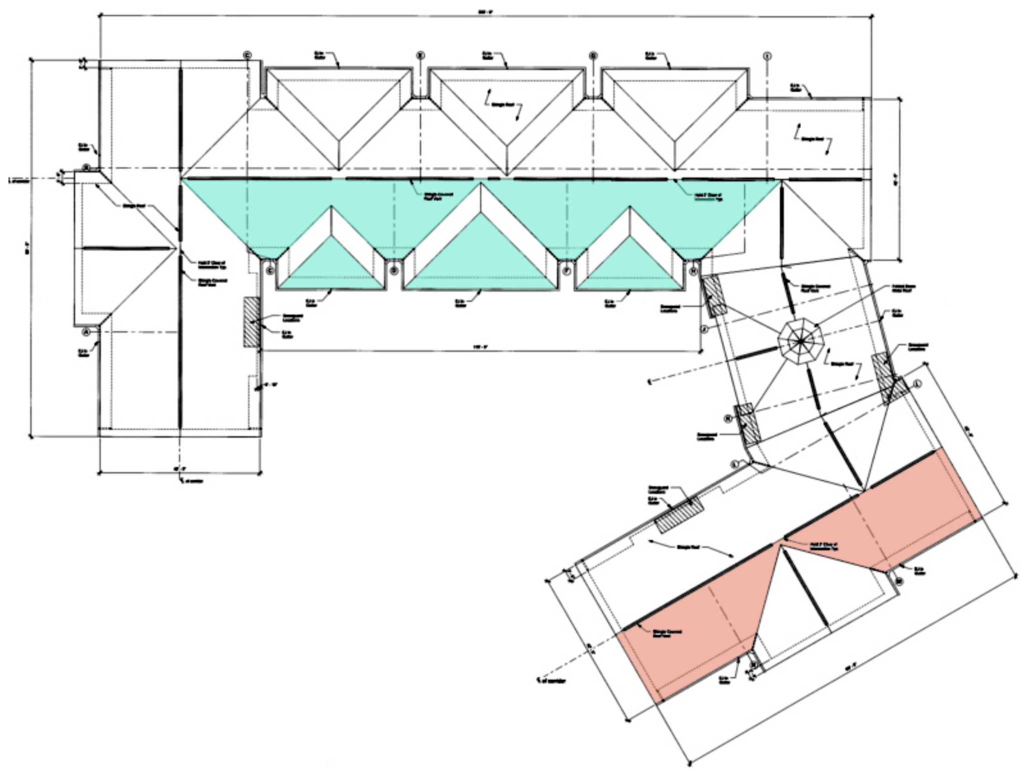
It is more likely that a photovoltaic system designed for the new dormitory at the Mount St. Mary's will only be capable of offsetting energy costs; however, most of the energy produced at this site would be during peak usage hours. This means that some portion of the building's energy costs would be mitigated during the most expensive portion of the day.

This system is one with a very high first cost. The technologies involved have not yet reached a point where there are as economically viable as other more traditional methods. Photovoltaic systems are, however, very innovative and sustainable, and many states will give incentives for their implementation. All these factors must be taken into account, as well as the potential yearly energy savings from the solar energy generation, in order to discover the feasibility of implementing a photovoltaic system into the scope of this project. In order to model this system, I will be utilizing RETScreen International's energy modeling software for photovoltaic systems.

8.2. Photovoltaic System Analysis

The new dormitory at the Mount St. Mary's University has roofs sloped at 30°, several of which are directly south facing or approximately so. In order to achieve the greatest amount of energy generation from the proposed PV panels, this south-facing orientation is greatly desired. A preliminary assessment of usable roof area is shown in Figure 8.2.1 below. The areas in blue have an azimuth of 0°, meaning they are directly south-facing, while the areas in red face slightly to the southeast and have an azimuth of 30°.

Figure 8.2.1: Available Roof Area for Photovoltaic Panels

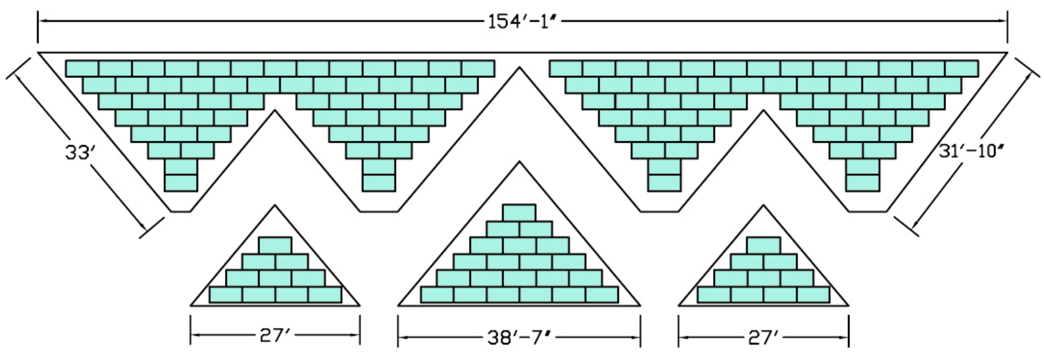


It was determined that there is 3255 ft^2 of available south-facing roof, while the additional roof area facing southeast totals 1942 ft^2. However, due to the geometric shape of the PV panels and the triangular areas of the available roof spaces, it must be determined exactly how many PV panels will most effectively occupy the usable space.

Because this company is a principal supplier of solar technologies in the Maryland area, I have chosen BP Solar's high efficiency PV modules for the project. These model BP3160 panels consist of silicon nitride multicrystalline silicone cells and are each capable of producing 160 watts of power for a warranted life of 25 years. The dimensions of a single module are 62.8 inches by 31.1 inches, and based on this size, I was able to determine the maximum number of PV panels that could realistically be used on the building's roof.

The base case I will be looking at will be covering only the south facing roof with panels, which can be seen in Figure 8.2.2 below.

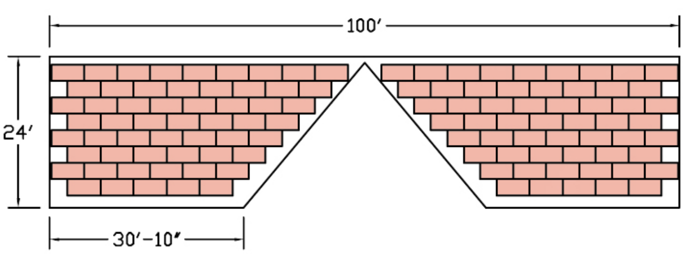
Figure 8.2.2: Base Case PV Panel Roof Coverage



It was determined here that 155 panels could be placed on the south facing roof in an aesthetically pleasing manner, which would account for 65% of the available roof area.

The alternate case I will be examining will incorporate additional panels to the southeast facing roof, which can be seen in figure 8.2.3 below.

Figure 8.2.3: Alternate Case PV Panel Roof Coverage



This roof proved capable of holding an additional 112 panels and using almost 80% of the available roof space. Even though these panels would not face directly south, they would still receive a good deal of morning sunlight and are a justifiable addition to this analysis.

RETScreen required many conditions to be set in order to analyze the photovoltaic systems. Solar data was estimated for Baltimore, Maryland as it was the closest location with yearly solar data, the slope of the panels was set to 30°, an on-grid system was specified, and manufacturer's data for BP 3160 solar panels was selected. As stated above, 155 panels were specified at a solar azimuth of 0° for the base case, and 267 panels at a modified azimuth of 12.5°, based on the ratio of south-facing panels to southeast-facing panels, were specified for the alternate case.

Cost inputs were determined by shopping around online for prevailing prices of the equipment I selected to design my system around. Based on a price of $800 dollars per panel as quoted from AdvancedEnergyOnline.com and an initial assumption of a 25% reduction in the price of the panels due to buying in large quantities, a cost of $3750/kW produced by the system was input into the program. Similarly, an inverter cost of $764/kW was input based on a price of $3820 per 5000 watt inverter from Xantrex.com. System installation was assumed to be $1500 per installed kW, inverter repair or replacement was set at 25 years, and the module support structure was estimated to be $50/m^2. All transportation costs were considered included in equipment costs, and engineering, feasibility, and developmental expenses were ignored.

For financial inputs, the debt interest rate was estimated to be 6.5% over a 15 year payback period, the avoided cost of energy was estimated to be $0.135/kWh based on the average yearly peak charges required by BG&E to purchase electrical grid energy, and the discount rate was set at 5%. There were also several state and federal grants and incentives that I found applied to my building during the course of my research. Maryland has both a Solar Energy Grant Program and a Clean Energy Incentives Act. The Solar Energy Grant Program offers reimbursement of 20% of the installed cost of commercial photovoltaic systems up to $5000. The Clean Energy Incentives Act offers state income tax credits of 15% of the installed cost up to $2000 for all photovoltaic systems. At present, the federal government is also offering solar energy tax credits of 30% of the installed cost of a photovoltaic system (after other state grants and incentives) through the end of the year 2008, by which time the new dormitory at the Mount St. Mary's University will be complete. These grants and incentives have also been incorporated into the RETScreen program.

See Appendix F for a complete set of input for both the base and alternate cases analyzed. The results of the simulation are displayed in Table 8.2.1 below.

Table 8.2.1: Base and Alternate PV System Results

Case	Nominal kW Produced	Yearly MWh	Installed Cost	Grants & Incentives	First Cost (Adjusted)	Annual Energy Savings	Payback Period (Years)
Base	24.80	33.79	$168,728	$55,519	$113,209	$4,562	28.2
Alternate	42.72	57.98	$287,894	$91,268	$196,626	$7,827	27.0

The grants and incentives offered by the state and federal governments reduce the first costs of both systems by a sizable amount, approximately 32% in each case. Still, the energy outputs of these systems are simply not good enough to justify the implementation of a photovoltaic system.

In the base case, using all available south-facing roof space, the yearly useful energy generated is 33.79 MWh. For comparison purposes, the yearly energy required to operate the building with the geothermal system was computed by HAP to be roughly 860 MWh. This base case photovoltaic system would only produce about 4% of the building's required energy requirement yearly, allowing for $4,562 in annual energy savings and 28.2 years just for a simple payback.

Similarly, in the alternate case with the addition of 112 southeast-facing panels, the yearly useful energy generated rose to 57.98 MWh. This value would account for almost 7% of the building's yearly energy requirement, save $7,827 yearly, and would still have a simple payback as high as 27 years.

With payback periods of more than 25 years for each of the proposed systems, a photovoltaic system is simply not worth incorporating into the scope of this project. Acceptable length of time for a payback on an energy saving system such as this is generally 7 years, and these systems far exceed that number. Even with government incentives, photovoltaic technology is presently just too expensive to manufacture and purchase. While the Mount St. Mary's University is very concerned about green design, they do not have the resources to add such an expensive system to the building. With a tight budget to begin with, they could never have been able to justify utilizing photovoltaic technology simple to earn a few additional LEED credits.

9. CONSTRUCTION MANAGEMENT BREADTH WORK

9.1. Goals and Justification

In the Mechanical Depth section of this report, the annual costs associated with energy consumption were determined, and the potential savings of the geothermal system over conventional water-source and split air-source systems was estimated. However, in order to truly ascertain which system is the most cost effective, a life-cycle cost analysis must be performed.

This analysis is being included as breadth work due to the unique aspects of the geothermal system that directly impact on the construction of the building. The vertical wells incorporate an unusual phase to the excavation of the site and the construction of the building, one that impacts on the construction schedule as well. In order to perform an accurate life-cycle cost analysis, therefore, these additional issues dealing with the excavation and installation of the geothermal wells must be addressed along with equipment first costs and annual energy consumption costs.

This breadth will also attempt to bring to light some of the other factors that could require addressing when constructing a geothermal system. I spoke with the project manager from Gilbane who is in charge of the construction of the new dormitory at the Mount St. Mary's University, and he was able to inform me of some of the other issues he has already encountered at the site due to this system. These issues will also be addressed below.

9.2. Cost Analyses and Comparisons

In order to get an accurate estimate of equipment, installation, and overhead and profit costs, I consulted RS Means Mechanical Cost Data from 2007 for the majority of the components of each system. A comprehensive website dedicated to geothermal heat pump systems was referenced to accurately estimate vertical well excavation and installation costs at $5 per lineal foot and materials costs at $1 per lineal foot. These values put the estimated cost of each 400 foot deep well at $2400, a cost which will have a great impact on the overall life-cycle cost.

A complete listing of system components and costs can be seen in Appendix G, but Table 9.2.1 below shows an abbreviated listing of the first costs associated with each of the systems.

Table 9.2.1: System First Costs

System Type	Equipment Costs	Installation Costs	Overhead and Profit	Total Installed First Cost
Ground-Source Heat Pumps	$121,575	$152,560	$22,540	$296,675
Water-Source Heat Pumps	$130,050	$31,490	$28,985	$190,525
Air-Source Heat Pumps	$104,675	$39,065	$30,160	$173,900

Based on the information listed above, it is immediately recognizable that the geothermal system has a far greater installed first cost than the other two systems. This can be attributed directly to the installation costs associated with the vertical wells, causing the installation costs of the geothermal system to be almost four times those of the air-source system and five times those of the water-source system. Equipment costs of the ground-source system are actually less than those of the water-source system because of the lack of a boiler and cooling tower, and the air-source system proves to have the least equipment costs because it does not need condenser water pumps either.

Coupling the above first costs with the annual energy consumption costs earlier computed using HAP, the life-cycle costs of each system can be seen in Table 9.2.2 below. A 25 year system life was used, and the discount rate was estimated at 5%.

Table 9.2.2: System Life-cycle Costs

	Ground-Source	Water-Source	Air-Source
Equipment First Costs	$121,575	$130,050	$104,675
Installation Costs	$152,560	$31,490	$39,065
Overhead and Profit	$22,540	$28,985	$30,160
Annual Energy Consumption Costs	$46,604	$55,340	$57,299
Discount Rate	0.05	0.05	0.05
System Life (Years)	25	25	25
Life Cycle Cost	$953,509	$970,484	$981,469

Based on this analysis, the geothermal heat pump system does prove that it has the potential to be the most cost effective solution on this project over time.

The system here is projected to save almost $17,000 over conventional water-source and almost $28,000 over air-source in a time period of 25 years. However, the initial first costs of the system proved to be a large hurdle to overcome. It took roughly 17.5 years for the savings of the system to initially overtake air-source and another 1.7 years to surpass water-source. Should the building in question have been something other than a dormitory with a much shorter life span, the savings possible with geothermal would never been seen.

Also, there are other considerations that must be addressed with a geothermal system that could have been taken into account in an even more in-depth analysis. The project manager in charge of seeing this dormitory built told me that the scheduling and coordination on this project has been somewhat more difficult than on more conventional systems. At present, at least one water line, and perhaps additional underground utility lines, needs to be rerouted in order to install the geothermal system.

An additional issue involves the installation of the wells themselves. Because there was a concern that driving heavy machinery over the finished wells might damage their integrity, the excavation for the 64 vertical loops can not even commence until the framing for the building has been entirely completed. Once begun, he estimated that his team should be able to complete the exterior installation of the geothermal system in four to five weeks, averaging a mere two wells per day. Then he would need an additional three weeks for piping and connecting the system to the heat pumps. A complete schedule for HVAC equipment is provided in Appendix H of this report. Because this installation has been pushed back so far, the project may take longer to complete than a more conventional system would, and temporary heating or cooling equipment may need to be brought in and set up at an additional cost in order to allow the laborers to work during certain periods of the year.

These additional matters would have needed to at least be considered when selecting the correct system for this building. Still, since the geothermal system requires far less maintenance than the other two systems and should be operational much longer than the 25 years used in this study, the system will continue to provide great savings year after year.

10. CONCLUSIONS AND RECOMMENDATIONS

As I had initially surmised, the geothermal system currently being installed at the new dormitory at the Mount St. Mary's University proved to be worth the additional mechanical design and upfront costs. Not only does the system save thousands of dollars in energy usage costs annually, but in an application such as this one where the building could potentially be in operation for 50 years or longer, the life cycle savings are going to be substantial. Also, should electricity rates increase dramatically in the coming years, the annual savings over comparable systems will also increase in turn.

The analyses of the mechanical systems also offer a realistic comparison of how air-source split DX heat pump systems, conventional boiler/cooling tower water-source heat pump systems, and geothermal heat pump systems actually perform from an energy usage perspective. The HAP model is able to show which pieces of equipment actually draw the most power, and the effects of the differing efficiencies between the heat pumps can clearly be distinguished from the results. Because of this, the geothermal is seen to back up the claims of energy savings made by proponents of the technology.

A photovoltaic system, on the other hand, would not be worth the cost of its installation. With a payback period of roughly 27 years as a best case scenario, the system is just too inefficient and costly upfront to warrant its inclusion in such a project. The Mount St. Mary's University may have been willing to spend a little extra money initially on the geothermal system in order to reap its potential benefits and promote environmentally friendly design, but unless the technology becomes drastically less expensive in the future, photovoltaic systems will continue to be difficult to justify on installations such as this one.

Therefore, it is the recommendation of the author of this report that the Mount St. Mary's University would have the most success building this dormitory if it merely keeps to its original plans and designs. The geothermal system really is the best choice of those mechanical alternatives analyzed, and the university has willingly accepted the inflated first costs in order to reap the benefits later on. The finished system will save money over time, continue to remain efficient where comparable systems would require maintenance or overhauls, and allow the university to further its goal of fostering environmental awareness through the application of green design.

11. REFERENCES

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APPENDIX A – LEED CHECKLIST

LEED-NC Version 2.2 Registered Project Checklist

Mount St. Mary's University Student Housing Project

Yes	?	No		Sustainable Sites	14 Points
6		8			
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
1			Credit 1	**Site Selection**	1
		1	Credit 2	**Development Density & Community Connectivity**	1
		1	Credit 3	**Brownfield Redevelopment**	1
		1	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
		1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
		1	Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	1
		1	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
		1	Credit 5.1	**Site Development**, Protect or Restore Habitat	1
1			Credit 5.2	**Site Development**, Maximize Open Space	1
1			Credit 6.1	**Stormwater Management**, Quantity Control	1
1			Credit 6.2	**Stormwater Management**, Quality Control	1
1			Credit 7.1	**Heat Island Effect**, Non-Roof	1
		1	Credit 7.2	**Heat Island Effect**, Roof	1
1			Credit 8	**Light Pollution Reduction**	1

Yes	?	No		Water Efficiency	5 Points
3		2			
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
		1	Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
		1	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No		Energy & Atmosphere	17 Points
4	1	12			
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**Fundimental Refrigerant Management**	Required
3	1	6	Credit 1	**Optimize Energy Performance**	1 to 10
		3	Credit 2	**On-Site Renewable Energy**	1 to 3
		1	Credit 3	**Enhanced Commissioning**	1
1			Credit 4	**Enhanced Refrigerant Management**	1
		1	Credit 5	**Measurement & Verification**	1
		1	Credit 6	**Green Power**	1

continued...

Yes	?	No			
	3	10	**Materials & Resources**		13 Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
		1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1
		1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1
		1	Credit 1.3	**Building Reuse**, Maintain 50% of Interiorr Non-Structural Elements	1
	1		Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
		1	Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
		1	Credit 3.1	**Materials Reuse**, 5%	1
		1	Credit 3.2	**Materials Reuse**, 10%	1
	1		Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ post-industrial)	1
		1	Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ post-industrial)	1
	1		Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally	1
		1	Credit 5.2	**Regional Materials,** 20% Extracted, Processed & Manufactured Regionally	1
		1	Credit 6	**Rapidly Renewable Materials**	1
		1	Credit 7	**Certified Wood**	1

Yes	?	No			
10	4	1	**Indoor Environmental Quality**		15 Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
	1		Credit 1	**Outdoor Air Delivery Monitoring**	1
		1	Credit 2	**Increased Ventilation**	1
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
1			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
1			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
	1		Credit 5	**Indoor Chemical & Pollutant Source Control**	1
	1		Credit 6.1	**Controllability of Systems**, Lighting	1
	1		Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
1			Credit 7.1	**Thermal Comfort**, Design	1
1			Credit 7.2	**Thermal Comfort**, Verication	1
1			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
1			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Yes	?	No			
3	1	1	**Innovation & Design Process**		5 Points
1			Credit 1.1	**Innovation in Design**: Education Program	1
1			Credit 1.2	**Innovation in Design**: O&M Materials	1
	1		Credit 1.3	**Innovation in Design**: None	1
		1	Credit 1.4	**Innovation in Design**: None	1
1			Credit 2	**LEED™ Accredited Professional**	1

Yes	?	No		
26	9	34	**Project Totals** (pre-certification estimates)	69 Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

APPENDIX B - UTILITY INFORMATION

Table B.1: BG&E Rating Periods

Rating Periods	
Summer:	
Peak	10 AM to 8 PM on Weekdays
Intermediate	7 AM to 10 AM and 8 PM to 11 PM on Weekdays
Off-Peak	All Weekends and Holidays
Non-Summer:	
Peak	7 AM to 11 AM and 5PM to 9 PM on Weekdays
Intermediate	11 AM to 5 PM on Weekdays
Off-Peak	All Weekends and Holidays

Table B.2: BG&E Electrical Utility Rates

Delivery Service Customer Charge:	$100.00/Month	
Delivery Charges	Summer ($/kW)	Non-Summer
Transmition Charge for Market-Priced Service:	0.98	0.98
Delivery Service:	2.67	2.67
Energy Charges	Summer (¢/kWh)	Non-Summer
Generation Charge for Market-Priced Service:		
Peak	15.138	12.236
Intermediate	11.835	10.662
Off-Peak	10.340	8.646
Delivery Service Charge:	1.239 ¢/kWh	

Table B.3: BG&E Natural Gas Utility Rates

Natural Gas Utility Rates	
Customer Charge	
	$100.00/Month
Delivery Price	
First 10,000 Therms:	19.75 ¢/Therm
All Over:	9.48 ¢/Therm

APPENDIX C - ADDITIONAL HAP OUTPUT

Table C.1: Annual Ground-Source Component Costs

Component	Ground ($)
Air System Fans	23,764
Cooling	11,302
Heating	7,225
Pumps	4,313
Cooling Tower Fans	0
HVAC Sub-Total	**46,604**
Lights	33,943
Electric Equipment	28,653
Misc. Electric	0
Misc. Fuel Use	5,802
Non-HVAC Sub-Total	**68,398**
Grand Total	**115,002**

Table C.2: Monthly Ground-Source HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Cooling Towers ($)	HVAC Total ($)
January	1,923	28	1,993	340	0	4,284
February	1,678	41	1,453	309	0	3,481
March	1,884	163	820	343	0	3,210
April	1,848	437	335	332	0	2,952
May	1,890	996	94	343	0	3,323
June	2,194	2,138	5	402	0	4,739
July	2,235	2,653	1	411	0	5,300
August	2,236	2,359	3	416	0	5,014
September	2,238	1,654	24	402	0	4,318
October	1,932	602	195	341	0	3,070
November	1,818	203	700	332	0	3,053
December	1,887	27	1,603	341	0	3,858
Total	**23,764**	**11,302**	**7,225**	**4,313**	**0**	**46,604**

Table C.3: Annual Water-Source Component Costs

Component	Water ($)
Air System Fans	23,479
Cooling	20,306
Heating	6,717
Pumps	3,934
Cooling Tower Fans	904
HVAC Sub-Total	**55,340**
Lights	34,057
Electric Equipment	28,750
Misc. Electric	0
Misc. Fuel Use	5,562
Non-HVAC Sub-Total	**68,370**
Grand Total	**123,709**

Table C.4: Monthly Water-Source HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Cooling Towers ($)	HVAC Total ($)
January	1,894	30	1,823	309	1	4,057
February	1,652	51	1,342	281	3	3,329
March	1,862	271	774	313	18	3,238
April	1,830	776	307	303	42	3,258
May	1,867	1,804	81	313	80	4,145
June	2,170	3,869	3	367	162	6,571
July	2,206	4,780	0	374	204	7,564
August	2,212	4,268	2	380	183	7,045
September	2,216	3,002	16	368	132	5,734
October	1,912	1,080	173	312	57	3,534
November	1,799	345	674	303	20	3,141
December	1,859	29	1,521	310	1	3,720
Total	**23,479**	**20,306**	**6,717**	**3,934**	**904**	**55,340**

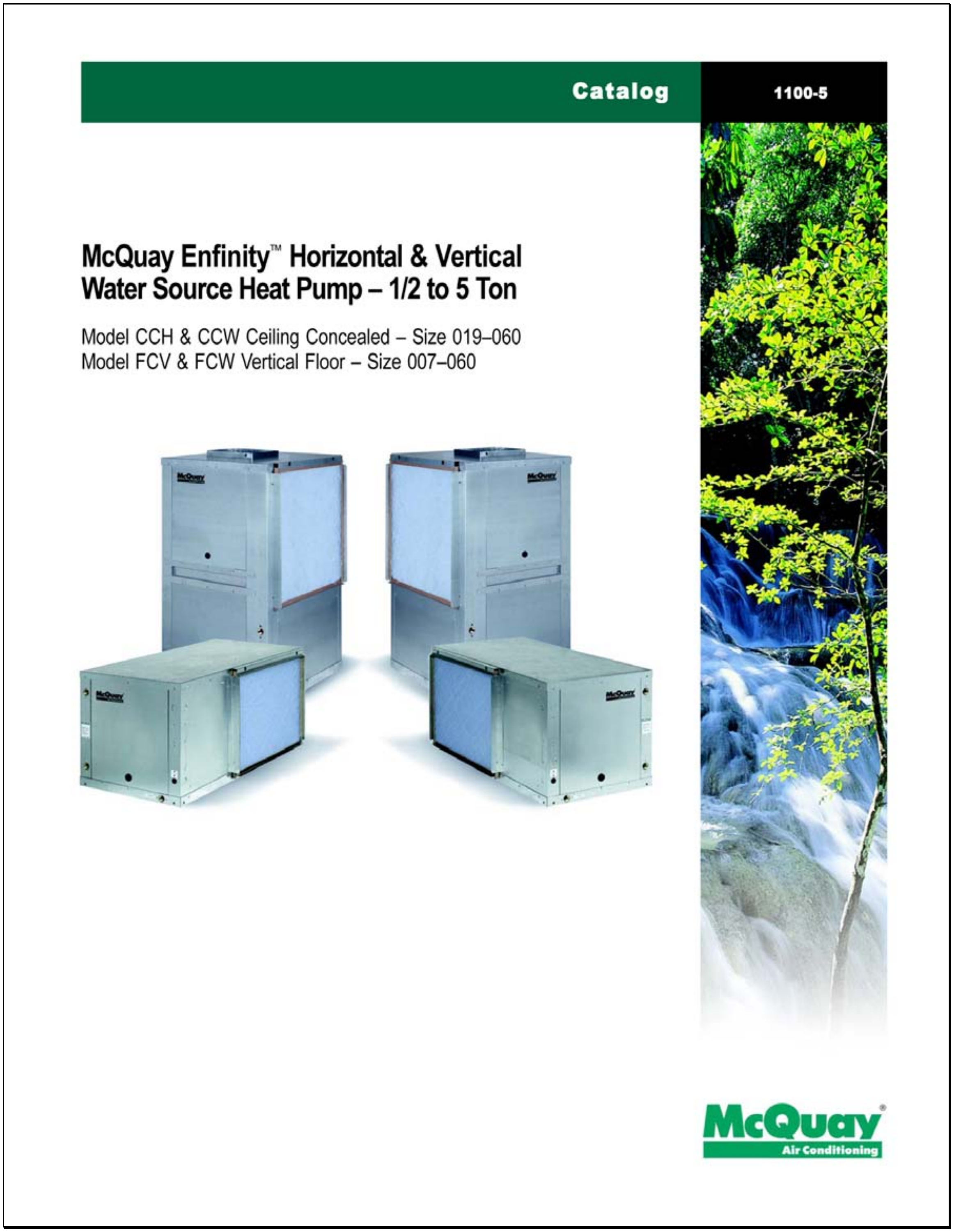
Table C.5: Annual Air-Source Component Costs

Component	Air ($)
Air System Fans	23,311
Cooling	19,686
Heating	14,302
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	**57,299**
Lights	34,092
Electric Equipment	28,779
Misc. Electric	0
Misc. Fuel Use	5,802
Non-HVAC Sub-Total	**68,672**
Grand Total	**125,971**

Table C.6: Monthly Air-Source HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Cooling Towers ($)	HVAC Total ($)
January	1,880	8	4,140	0	0	6,028
February	1,639	17	2,951	0	0	4,607
March	1,838	152	1,586	0	0	3,576
April	1,812	550	608	0	0	2,970
May	1,855	1,564	170	0	0	3,589
June	2,162	3,948	11	0	0	6,121
July	2,196	4,974	1	0	0	7,171
August	2,206	4,407	6	0	0	6,619
September	2,206	2,897	45	0	0	5,148
October	1,897	900	336	0	0	3,133
November	1,778	261	1,266	0	0	3,305
December	1,842	7	3,181	0	0	5,030
Total	**23,311**	**19,686**	**14,302**	**0**	**0**	**57,299**

APPENDIX D - MECHANICAL CUT SHEETS


Catalog 1100-5

McQuay Enfinity™ Horizontal & Vertical Water Source Heat Pump – 1/2 to 5 Ton

Model CCH & CCW Ceiling Concealed – Size 019–060
Model FCV & FCW Vertical Floor – Size 007–060

McQuay®
Air Conditioning

Enfinity Vertical ISO Performance Data – Water Loop

Water Loop Performance Data per ISO Standard 13256-1.

UNIT SIZE	AIRFLOW		WATERFLOW		VOLTAGE	COOLING				HEATING		
	CFM	L/S	GPM	L/S		BTU/HR	WATTS	EER	COP	BTU/HR	WATTS	COP
007	230	109	1.4	0.09	115-1-60 208/230-1-60 265-1-60	6200	1815	12.2	3.6	8000	2342	4.3
009	300	142	2.2	0.14	115-1-60 208/230-1-60 265-1-60	8500	2489	11.8	3.5	11600	3397	4.3
012	400	189	3.1	0.20	115-1-60 208/230-1-60 265-1-60	11200	3279	12.1	3.6	15200	4451	4.3
019	630	297	5.2	0.33	208/230-1-60 265-1-60	19800	5798	13.9	4.1	24900	7291	4.7
024	800	378	5.9	0.37	208/230-1-60 265-1-60 208/230-3-60 460-3-60	22800	6676	13.0	3.8	30200	8843	4.7
030	1000	472	7.2	0.45	208/230-1-60 265-1-60 208/230-3-60 460-3-60	30400	8901	14.6	4.3	37200	10893	4.8
036	1200	566	8.8	0.56	208/230-1-60 208/230-3-60 460-3-60	35700	10453	15.1	4.4	43800	12825	4.9
042	1400	661	10.7	0.68	208/230-1-60 208/230-3-60 460-3-60 575-3-60	41000	12005	15.1	4.4	51900	15197	4.9
048	1600	755	11.6	0.73	208/230-1-60 208/230-3-60 460-3-60 575-3-60	45700	13381	13.8	4.0	56900	16661	4.5
060	2000	944	14.8	0.93	208/230-1-60 208/230-3-60 460-3-60 575-3-60	60100	17598	13.9	4.1	74300	21756	4.7

Notes:
EER = Energy Efficiency Ratio COP = Coefficient of Performance L/s = Liters per second

Cooling capacity is based on 80.6°F db, 66.2°F wb (27/19°C) entering air temperature and 86°F (30°C) entering water temperature.
Heating capacity is based on 68°F (20°C) entering air temperature and 68°F (20°C) entering water temperature.

Catalog 1100 McQuay Enfinity Water Source Heat Pumps 53

Enfinity Vertical ISO Performance Data – Ground Loop

Ground Loop Performance Data per ISO Standard 13256-1.

UNIT SIZE	AIRFLOW		WATERFLOW		VOLTAGE	COOLING				HEATING		
	CFM	L/S	GPM	L/S		BTU/HR	WATTS	EER	COP	BTU/HR	WATTS	COP
007	230	109	1.4	0.09	115-1-60 208/230-1-60 265-1-60	6600	1933	14.2	4.2	5000	1464	3.1
009	300	142	2.2	0.14	115-1-60 208/230-1-60 265-1-60	9100	2665	13.8	4.0	7400	2167	3.3
012	400	189	3.1	0.20	115-1-60 208/230-1-60 265-1-60	12000	3514	14.2	4.1	9400	2752	3.2
019	630	297	5.2	0.33	208/230-1-60 265-1-60	21400	6266	16.2	4.7	14800	4334	3.5
024	800	378	5.9	0.37	208/230-1-60 265-1-60 208/230-3-60 460-3-60	24500	7174	15.1	4.4	18400	5388	3.6
030	1000	472	7.2	0.45	208/230-1-60 265-1-60 208/230-3-60 460-3-60	31400	9194	16.9	5.0	24500	7174	3.5
036	1200	566	8.8	0.56	208/230-1-60 208/230-3-60 460-3-60	36900	10805	17.4	5.1	29200	8550	3.7
042	1400	661	10.7	0.68	208/230-1-60 208/230-3-60 460-3-60 575-3-60	42700	12503	17.6	5.2	33900	9926	3.7
048	1600	755	11.6	0.73	208/230-1-60 208/230-3-60 460-3-60 575-3-60	47900	14026	16.1	4.7	36700	10746	3.3
060	2000	944	14.8	0.93	208/230-1-60 208/230-3-60 460-3-60 575-3-60	61300	17949	16.0	4.7	48200	14113	3.5

Notes:
EER = Energy Efficiency Ratio COP = Coefficient of Performance L/S = Liters per second

Cooling capacity is based on 80.6°F db, 66.2°F wb (27/19°C) entering air temperature and 77°F (25°C) entering water temperature.
Heating capacity is based on 68°F (20°C) entering air temperature and 32°F (0°C) entering water temperature.

54 McQuay Enfinity Water Source Heat Pumps Catalog 1100

Fan Performance

Enfinity Vertical Units (007 - 060)

(includes allowance for dry coil and filter)

Size	Speed	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
007	*High	310	300	300	290	280	270	250	240	230	210	190	170	140	–
009	*High	460	450	440	430	420	410	400	380	360	340	320	310	280	250
012	Low	370	360	350	340	330	320	310	290	270	250	220	–	–	–
012	*High	480	470	450	440	420	410	390	380	360	330	310	290	240	–
019	*Low	1020	1000	990	980	960	940	920	900	870	840	800	750	670	600
019	High	1220	1200	1180	1160	1130	1110	1070	1040	1010	970	930	880	810	730
024	Low	1030	1020	1000	980	950	930	900	880	850	810	770	720	670	620
024	*High	1180	1160	1130	1100	1060	1030	1000	970	940	900	860	820	760	700
030	Low	–	–	–	980	970	970	950	940	920	900	880	850	810	750
030	*High	1230	1220	1220	1210	1200	1190	1170	1140	1120	1100	1060	1020	980	930
036	Low	–	–	1230	1210	1200	1180	1160	1140	1110	1080	1050	1010	950	–
036	*High	1510	1500	1490	1480	1470	1440	1400	1360	1320	1270	1220	1170	1110	1050
042	Low	–	–	–	–	–	–	–	–	–	–	–	–	–	–
042	*High	2150	2140	2120	2090	2060	2010	1950	1890	1830	1700	1440	1220	1100	–
048	*Low	–	–	–	–	1990	1970	1930	1880	1830	1770	1700	1550	1280	–
048	High	2390	2350	2300	2260	2220	2190	2160	2110	2040	1970	1880	1790	1700	1560
060	Low	–	–	–	–	2000	1990	1990	1970	1930	1890	1830	1730	1490	–
060	*High	2530	2520	2510	2490	2460	2430	2400	2360	2310	2250	2170	2090	1960	1840

Low Static Motor - Sizes 019 - 024

Size	Speed	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
19	*Low	690	670	650	620	600	570	550	510	-	-	-	-	-	-
19	High	910	890	860	840	810	780	740	710	670	610	550	-	-	-
24	Low	690	670	650	620	600	570	550	510	-	-	-	-	-	-
24	*High	910	890	860	840	810	780	740	710	670	610	550	-	-	-

*Above fan selections are as wired from the factory.

For wet coil, calculate face velocity (cfm/ coil face area, sq. ft.). Add the following static to the external static pressure for the corresponding face velocity: 300 fpm = 0.05", 400 fpm = 0.10", 500 fpm = 0.14". Re-enter table at the increased external static pressure to determine final cfm.

Physical Data

Unit Size	007	009	012	019	024
Fan Wheel - D x W (In.)	6.3 x 6.0	6.3 x 6.0	6.2 x 7.4	9.5 x 7.1	9.5 x 7.1
Fan Motor Horsepower	1/20	1/8	1/8	1/3	1/3
Coil Face Area (Sq. Ft.)	.97	1.17	1.17	2.75	2.75
Coil Rows	3	3	3	3	3
Refrigerant Charge (Oz.)	14.3	17	18	33	37
Filter, (Qty.) Size (In.)		(1) 12 x 20		(1) 22 x 22	
Water Connections, Female NPT (In.)	1/2	1/2	1/2	1/2	1/2
Condensate Connections, Female NPT (In.)	3/4	3/4	3/4	3/4	3/4
Weight, Operate (Lbs.)	113	113	113	213	213
Weight, Shipping (Lbs.)	135	135	135	232	232

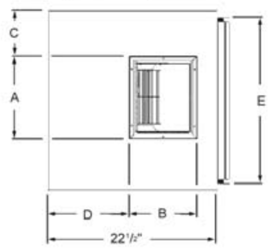
Unit Size	030	036	042	048	060
Fan Wheel - D x W (In.)	9.5 x 7.1	9.5 x 7.1	12.9 x 11.1	12.9 x 11.1	12.9 x 11.1
Fan Motor Horsepower	1/3	1/2	1/2	3/4	3/4
Coil Face Area (Sq. Ft.)	3.5	3.5	4.42	4.42	6.63
Coil Rows	3	3	3	3	3
Refrigerant Charge (Oz.)	43	45	57	51	78
Filter, (Qty.) Size (In.)	(1) 24 x 24		(1) 24 x 30		(2)17.5 x 30.25
Water Connections, Female NPT (In.)	3/4	3/4	3/4	3/4	3/4
Condensate Connections, Female NPT (In.)	3/4	3/4	3/4	3/4	3/4
Weight, Operate (Lbs.)	224	224	310	310	384
Weight, Shipping (Lbs.)	243	243	331	331	403

Dimensional Data – Vertical Size 019 & 024

Right Hand and Left Hand Return

Right and Left Hand Return determined by facing the water connection side of the unit.

Top View – Right Hand

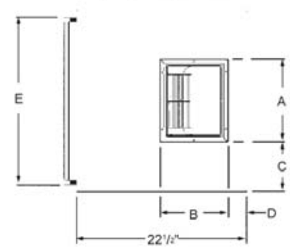


NOTE: Dimensions are approximate

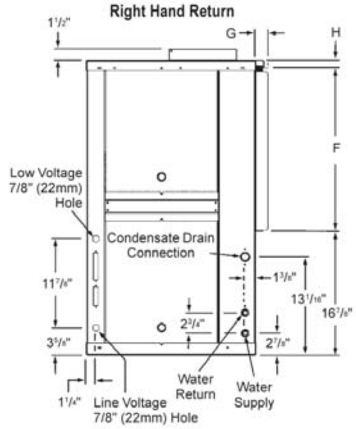
Discharge Duct Dimensions	A	B	C	D
Right Hand	11"	9"	6 1/2"	11"
Left Hand	11"	9"	6 1/2"	2 1/2"

Overall Unit Dimensions = 22 1/2"W x 24"L x 39 3/16"H

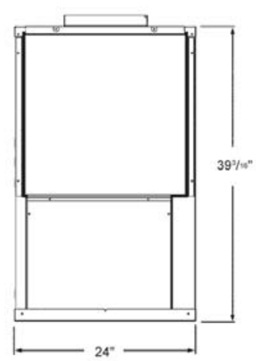
Top View – Left Hand



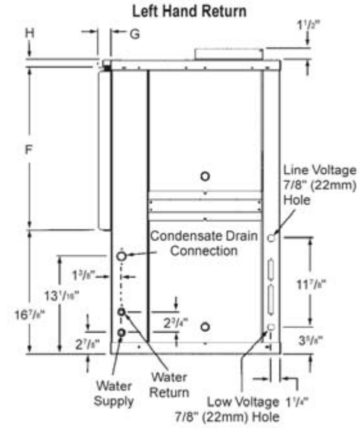
Right Hand Return



Filter (Side) View



Left Hand Return



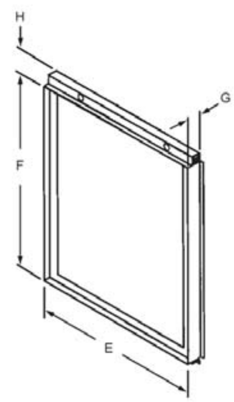
Return Air Duct Collar / Filter Rack

Standard 1"

UNIT SIZE	E	F	G	H
019 & 024	22" (559mm)	21 1/4" (540mm)	1 11/16" (43mm)	1 1/16" (27mm)

Optional 2"

UNIT SIZE	E	F	G	H
019 & 024	22" (559mm)	21 1/4" (540mm)	1 11/16" (43mm)	1" (25mm)



Catalog 1100 McQuay Enfinity Water Source Heat Pumps 81

AHP 12 SEER High Efficiency Split System Heat Pump

1-1/2 to 5 Ton
[5.28 kW to 17.56 kW]

Outdoor split system heat pump section is designed for ground-level or rooftop mounting application.

Standard Features

- High-efficiency compressor with internal high-pressure relief
- Louvered guard protects coil from damage and adds strength to unit
- Copper tube, aluminum fin coil
- Brass suction and liquid service valves with sweat connections
- Quiet operating top discharge
- Totally enclosed, permanently lubricated condenser motor
- Fully charged for 15' [4.57m] of tubing length
- Discharge line muffler
- Low-pressure control for loss of charge protection
- Factory-installed bi-flow liquid line filter drier
- Suction line accumulator
- Check-flowrater expansion device
- Time-initiated, temperature-terminate defrost
- Bottom pan rails elevate unit above slab
- Crankcase heater (where indicated)

Air Handler Compatibilities

- SAH multi-position electric heat air handlers

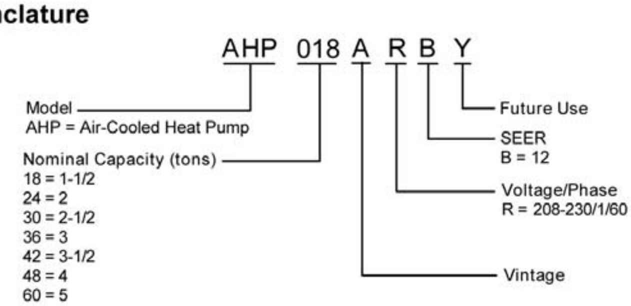
Cabinet Construction

- Polyester powder paint provides superior durability and improved UV protection
- Heavy gauge, zinc-clad, G90 galvanized steel
- When properly anchored, meets the 2001 Florida Building Code unit integrity requirements for hurricane-type winds

Accessories

- Standard room thermostat with 1-stage cool/2-stage heat (Model HPT18-60)
- Digital room thermostat with 1-stage cool/2-stage heat (CHTP18-60H)
- Outdoor lock-out thermostats (OTEHR18-6)
- Outdoor thermostat (OT18-60). Required for all heat pumps if outdoor ambient temperature is 0° F with 50% or higher RH

Model Nomenclature



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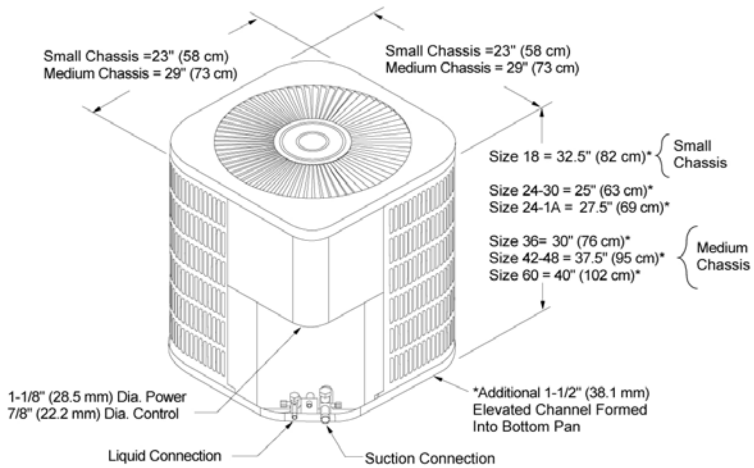
Physical Data

Model	Liquid Connection	Suction Connection	Type	Approx. Shipping Wt. (Lbs.)
AHP018ARBY	3/8" [9.5 mm]	3/4" [19 mm]	Sweat	127 [57.6 kg]
AHP024ARBY	3/8" [9.5 mm]	3/4" [19 mm]	Sweat	147 [66.7 kg]
AHP030ARBY	3/8" [9.5 mm]	3/4" [19 mm]	Sweat	142 [64.4 kg]
AHP036ARBY	3/8" [9.5 mm]	3/4" [19 mm]	Sweat	152 [68.9 kg]
AHP042ARBY	3/8" [9.5 mm]	7/8" [22.2 mm]	Sweat	162 [73.5 kg]
AHP048ARBY	3/8" [9.5 mm]	7/8" [22.2 mm]	Sweat	178 [80.7 kg]
AHP060ARBY	3/8" [9.5 mm]	7/8" [22.2 mm]	Sweat	182 [82.6 kg]

Dimensions



Electrical Data

Model	Volts	PH	HZ	+ Minimum Circuit Ampacity	* Maximum Overcurrent Protection	Minimum Volts	Maximum Volts	Compressor		Condenser Fan	
								RLA	LRA	FLA	HP
† AHP018ARBY	208/230	1	60	11.7	20	197	253	8.6	49.0	0.9	1/6
† AHP024ARBY	208/230	1	60	13.2	20	197	253	9.8	56.0	0.9	1/6
** AHP030ARBY	208/230	1	60	18.0	30	197	253	13.5	72.5	1.1	1/6
** AHP036ARBY	208/230	1	60	19.3	30	197	253	14.7	83.0	0.9	1/6
** AHP042ARBY	208/230	1	60	24.8	40	197	253	18.4	95.0	1.8	1/4
** AHP048ARBY	208/230	1	60	24.7	40	197	253	18.3	109.0	1.8	1/4
** AHP060ARBY	208/230	1	60	33.8	50	197	253	25.0	148.0	2.5	1/3

† With Crankcase Heat
* May use fuses or HACR type Circuit Breakers of the same size as noted
+ Wire size should be determined in accordance with National Electrical Codes; extensive wire runs will require larger wire sizes
**With Scroll Compressor

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Performance Ratings

Outdoor Section Model	Indoor Section Model	Cooling					Heating						Decibels
		Total BTUH (1)	Sensible BTUH	BTUH @ 75° F/ 63° F -95° F (2) Total	BTUH @ 75° F/ 63° F -95° F (2) Sensible	SEER	EER (3)	BTUH 47° F	COP 47° F	BTUH 17° F	COP 17° F	HSPF	
AHP018ARBY	SAH018ARFY	17000	12700	16000	12200	11.00	10.00	17000	3.00	9400	2.00	7.00	72
	SAH032ARFY	18000	14200	17000	13700	12.00	11.00	18000	3.50	10000	2.20	7.50	
	SAH032ARTY												
AHP024ARBY	SAH024ARFY	22400	16800	21100	16400	11.50	10.50	22000	3.00	12100	2.20	7.00	73
	SAH024ARTY												
	SAH032ARFY	23000	18000	21700	17400	12.00	11.00	23000	3.30	13600	2.60	7.80	
	SAH032ARTY												
	SAH042ARFY	23000	18000	21700	17400	12.00	11.00	23000	3.30	13600	2.60	7.80	
	SAH042ARTY												
AHP030ARBY	SAH030ARFY	27200	20400	24800	19100	11.30	10.50	27000	3.00	14600	2.20	7.00	80
	SAH032ARFY	29000	21600	27400	20700	12.00	11.00	29400	3.30	17000	2.40	7.50	
	SAH032ARTY												
	SAH042ARFY	29000	21600	27400	20700	12.00	11.00	29400	3.30	17000	2.40	7.50	
	SAH042ARTY												
AHP036ARBY	SAH036ARFY	33000	23800	31150	24900	11.30	10.30	33000	3.20	19000	2.10	7.50	80
	SAH036ARTY												
	SAH042ARFY	34000	24500	32100	23300	12.00	11.00	35000	3.50	20000	2.30	7.80	
	SAH042ARTY												
AHP042ARBY	SAH042ARFY	38500	27600	36200	29300	11.30	10.30	38500	3.30	21000	2.10	7.50	80
	SAH042ARTY												
	SAH049ARFY	40000	30400	37800	29300	12.00	11.00	40000	3.50	22400	2.30	8.00	
	SAH049ARTY												
AHP048ARBY	SAH048ARFY	44000	32500	41500	31000	11.50	10.50	44000	3.30	24000	2.20	7.50	80
	SAH049ARFY	44000	32500	41500	31000	12.00	11.00	45000	3.50	25000	2.30	8.00	
	SAH049ARTY												
	SAH061ARFY	46000	35000	43400	33600	12.00	11.00	46000	3.60	27000	2.40	8.00	
	SAH061ARTY												
AHP060ARBY	SAH060ARFY	55000	39600	51900	37000	11.30	10.30	55000	3.20	30000	2.10	7.50	80
	SAH061ARFY	56000	40300	52600	37700	12.00	11.00	56000	3.30	31000	2.30	8.00	
	SAH061ARTY												

HSPF = heating seasonal performance factor.
When mix matching outdoor and indoor units, the indoor unit check-flowrator must match the outdoor unit size.
See "SAH" unit for coil instructions.
1) Certified per ARI 240 @ 80ºF/67ºF inside - 95ºF
2) TVA Rating
3) Energy Efficiency Ratio @ 80ºF/67ºF inside - 95ºF

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SAH Multi-Position Air Handler with Flowrater

1-1/2 to 5 Ton

Multi-position air handler may be installed in any room with sufficient ventilation and room for service, such as in a utility room, closet, alcove, or basement.

Standard Features

- Multi-position (upflow/horizontal or downflow) air handler
- Built-in filter rack for 1" filter (filter not included)
- Direct-drive, multi-speed motor allows air volume variation for heating/cooling requirements
- Equipped with a check flowrater for cooling only and heat pump applications
- Built-in coil with horizontal and vertical thermoplastic drain pans and secondary drains
- Copper tube/aluminum fin coil
- Power supply entry on top and from both sides
- Low-voltage entry on top and from both sides
- Transformer and blower time delay on all units

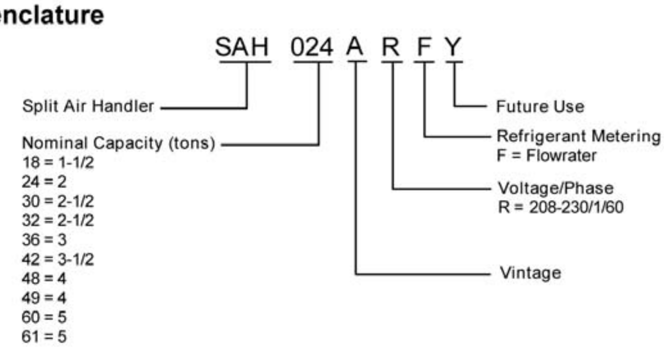
Cabinet Construction

- Fully insulated steel cabinet
- Rust-resistant, galvanized cabinet sides and back

Accessories

- Pre-tested, pre-wired, field-installed electric heat kits in 5 kW to 20 kW are available (single-phase models); 15 kW and 20kW (3-phase models); featuring electric heat limit control, rust-resistant nickel chromium heating elements and circuit breakers (select models)
- Permanent washable plastic air filters (FIL18-32, FIL36-42 and FIL48-61)
- Thermal Expansion Valve Kits for air conditioning-only applications
- Coil Insulation Kit for downflow applications (DPI 18-30, DPI 36-42, DPI 48-61)
- Horizontal drain pan insulation kits (DPIH 18-32, DPIH-36-42, DPIH 48-61)

Model Nomenclature



2

Electrical Data

Model	Single Supply Circuit: Minimum Circuit Ampacity @ 208/240V	Single Supply Circuit: Maximum Overcurrent Protection @ 208/240V (amps)	Minimum VAC	Maximum VAC	Blower Motor: FLA	Blower Motor: HP
SAH018ARFY	1.2/1.2	15/15	197	253	0.96	1/5
SAH024ARFY	1.9/1.9	15/15	197	253	1.5	1/5
SAH030ARFY	2.4/2.4	15/15	197	253	1.95	1/3
SAH032ARFY	2.4/2.4	15/15	197	253	1.95	1/3
SAH036ARFY	2.7/2.7	15/15	197	253	2.15	1/3
SAH042ARFY	2.8/2.8	15/15	197	253	2.2	1/2
SAH048ARFY	3.3/3.3	15/15	197	253	2.6	1/2
SAH049ARFY	3.3/3.3	15/15	197	253	2.6	1/2
SAH060ARFY	4.9/4.9	15/15	197	253	3.9	3/4
SAH061ARFY	4.9/4.9	15/15	197	253	3.9	3/4

Physical Data

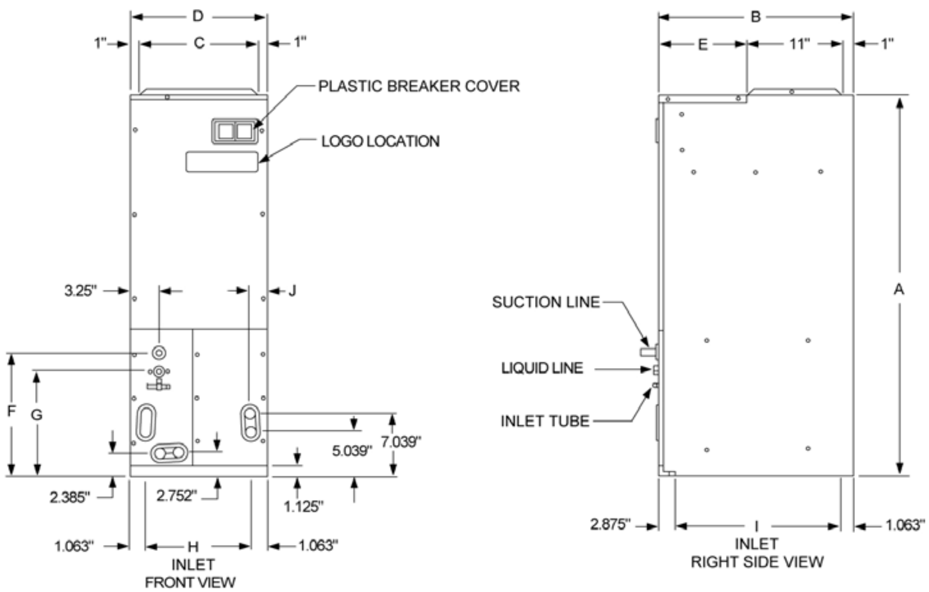
Model	Blower: Diameter	Blower: Width	Coil Drain Connection: FPT	Refrigerant Connection: Liquid	Refrigerant Connection: Suction	Approximate Shipping Weight (pounds)
SAH018ARFY	8"	6"	3/4"	3/8"	5/8"	105
SAH024ARFY	9-1/2"	6"	3/4"	3/8"	3/4"	106
SAH030ARFY	9-1/2"	6"	3/4"	3/8"	3/4"	113
SAH032ARFY	9-1/2"	6"	3/4"	3/8"	3/4"	120
SAH036ARFY	9-1/2"	8"	3/4"	3/8"	3/4"	141
SAH042ARFY	9-1/2"	8"	3/4"	3/8"	3/4"	144
SAH048ARFY	9-1/2"	8"	3/4"	3/8"	7/8"	173
SAH049ARFY	9-1/2"	8"	3/4"	3/8"	7/8"	178
SAH060ARFY	10-5/8"	10-5/8"	3/4"	3/8"	7/8"	192
SAH061ARFY	10-5/8"	10-5/8"	3/4"	3/8"	7/8"	201

Blower Performance

Model	Speed	CFM Delivered Against External Static Pressure: 0.1"	0.2"	0.3"	0.4"	0.5"
SAH018ARFY	HIGH	700	630	580	530	490
	LOW	674	600	545	490	380
SAH024ARFY	HIGH	1056	1020	980	920	870
	LOW	935	910	880	850	790
SAH030ARFY	HIGH	1150	1110	1040	980	920
	LOW	1060	1040	980	910	860
SAH032ARFY	HIGH	1150	1090	1020	950	900
	MEDIUM	870	830	790	750	710
	LOW	640	610	570	530	490
SAH036ARFY	HIGH	1549	1470	1420	1360	1290
	LOW	1322	1310	1280	1320	1150
SAH042ARFY	HIGH	1586	1530	1470	1410	1350
	LOW	1524	1490	1420	1367	1175
SAH048ARFY	HIGH	1670	1610	1530	1470	1390
	LOW	1580	1520	1470	1410	1340
SAH049ARFY	HIGH	1670	1610	1530	1470	1390
	LOW	1580	1520	1470	1410	1340
SAH060ARFY	HIGH	2170	2080	2000	1920	1850
	LOW	1900	1810	1780	1710	1630
SAH061ARFY	HIGH	2170	2080	2000	1920	1850
	LOW	1900	1810	1780	1710	1630

Dry coil with Filter in Place
SCFM Correction for Wet Coil - 4%

Dimensions



Base Model Number	A	B	C	D	E	F	G	H	I	J
SAH018ARFY	41.125"	22"	13.5"	15.5"	10"	13.375"	10.811"	13.125"	17.938"	2.024"
SAH024ARFY	41.125"	22"	13.5"	15.5"	10"	13.375"	10.811"	13.125"	17.938"	2.024"
SAH030ARFY	41.125"	22"	13.5"	15.5"	10"	13.375"	10.811"	13.125"	17.938"	2.024"
SAH032ARFY	41.125"	22"	13.5"	15.5"	10"	13.375"	10.811"	13.125"	17.938"	2.024"
SAH036ARFY	46.75"	22"	17.5"	19.5"	10"	13.375"	10.811"	17.125"	17.938"	2.024"
SAH042ARFY	46.75"	22"	17.5"	19.5"	10"	13.375"	10.811"	17.125"	17.938"	2.024"
SAH048ARFY	53.25"	24"	20"	22"	12"	14.5"	11.935"	19.625"	19.938"	1.837"
SAH049ARFY	53.25"	24"	20"	22"	12"	14.5"	11.935"	19.625"	19.938"	1.837"
SAH060ARFY	53.25"	24"	20"	22"	12"	14.5"	11.935"	19.625"	19.938"	1.837"
SAH061ARFY	53.25"	24"	20"	22"	12"	14.5"	11.935"	19.625"	19.938"	1.837"

Expansion Valve Kits For Air Conditioning-only Applications

Kit Number	Used With	Description
XVB18-36C	SAH018ARFY to SAH036ARFY	20% bleed valve
XVB42-60C	SAH042ARFY to SAH060ARFY	20% bleed valve
XV18-36C	SAH018ARFY to SAH036ARFY	Non-bleed valve
XV42-60C	SAH042ARFY to SAH060ARFY	Non-bleed valve

Coil Insulation Kit For Downflow Applications

Chassis Size	Insulation Kit
Small	DPI18-302
Medium	DPI36-422
Large	DPI48-612

Note: Each kit contains enough material to modify 20 coils

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APPENDIX E - ELECTRICAL CUT SHEETS

bp solar

BP 3160

160 Watt Photovoltaic Module

High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells.

Performance

Rated power (P_{max})	160W
Power tolerance	± 5%
Nominal voltage	24V
Limited Warranty[1]	25 years

Configuration

B BP 3160B	Bronze frame with output cables and polarized Multicontact (MC) connectors
S BP 3160S	Clear universal frame with output cables and polarized Multicontact (MC) connectors
L BP 3160L	Unframed laminate version of BP 3160S
U BP 3160U	Clear universal frame with standard junction box

Electrical Characteristics[2]

Electrical Characteristics[2]	BP 3160
Maximum power (P_{max})[3]	160W
Voltage at Pmax (V_{mp})	35.1V
Current at Pmax (I_{mp})	4.55A
Warranted minimum P_{max}	152W
Short-circuit current (I_{sc})	4.8A
Open-circuit voltage (V_{oc})	44.2V
Temperature coefficient of I_{sc}	(0.065±0.015)%/ °C
Temperature coefficient of V_{oc}	-(160±20)mV/°C
Temperature coefficient of power	-(0.5±0.05)%/ °C
NOCT (Air 20°C; Sun 0.8kW/m^2; wind 1m/s)	47±2°C
Maximum series fuse rating	15A (S, L); 20A (U)
Maximum system voltage	600V (U.S. NEC & IEC 61215 rating) 1000V (TÜV Rheinland rating)

Mechanical Characteristics

Dimensions	**B,S,U** **L**	Length: 1593mm (62.8") Width: 790mm (31.1") Depth: 50mm (1.97") Length: 1580mm (62.2") Width: 783mm (30.8") Depth: 19mm (0.75")
Weight	**B,S,U** **L**	15.0 kg (33.1 pounds) 12.4 kg (27.3 pounds)
Solar Cells	**B,S,L,U**	72 cells (125mm x 125mm) in a 6x12 matrix connected in series
Output Cables	**B,S,L**	RHW AWG# 12 (4mm^2) cable with polarized weatherproof DC rated Multicontact connectors; asymmetrical lengths - 1250mm (-) and 800mm (+)
Junction Box	**U**	Standard junction box with 6-terminal connection block; IP 54, accepts PG 13.5, M20, ½ inch conduit, or cable fittings accepting 6-12mm diameter cable. Terminals accept 2.5 to 10mm^2 (8 to 14 AWG) wire.
Diodes	**B,S,L,U**	Three 9A, 45V Schottky by-pass diodes included
Construction	**B,S,L,U**	Front: High-transmission 3mm (1/8th inch) tempered glass; Back: Tedlar; Encapsulant: EVA
Frame	**B,S,U**	Anodized aluminum alloy type 6063T6 Universal frame; Color: bronze (B); silver (S,U)

1. Warranty: Power output for 25 years. Freedom from defects in materials and workmanship for 5 years. See our website or your local representative for full terms of these warranties.
2. These data represent the performance of typical BP 3160 products, and are based on measurements made in accordance with ASTM E1036 corrected to SRC (STC.)
3. During the stabilization process that occurs during the first few months of deployment, module power may decrease by up to 3% from typical P_{max}.

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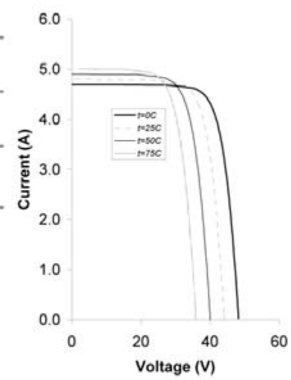
Quality and Safety

ESTI	Module power measurements calibrated to World Radiometric Reference through ESTI (European Solar Test Installation at Ispra, Italy)
CE	Manufactured in ISO 9001-certified factories; conforms to European Community Directives 89/33/EEC, 73/23/EEC, 93/68/EEC; certified to IEC 61215
TÜV	Framed modules certified by TÜV Rheinland as Safety Class II (IEC 60364) equipment for use in systems up to 1000 VDC
UL	Listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating)
FM	Approved by Factory Mutual Research in NEC Class 1, Division 2, Groups C & D hazardous locations (U)

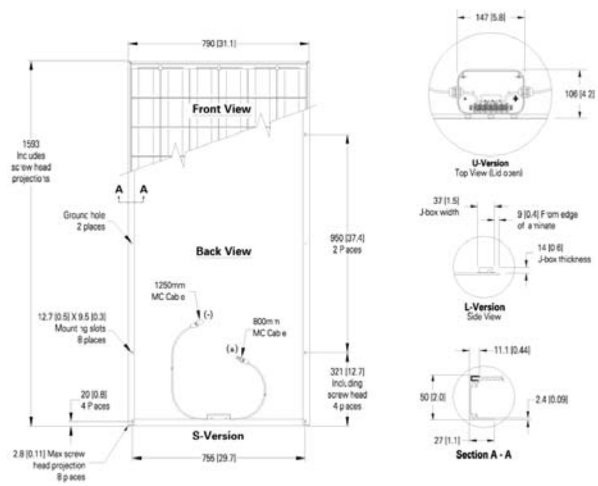
BP 3160 I-V Curves



Qualification Test Parameters

Temperature cycling range	-40°C to +85°C (-40°F to 185°F)
Humidity freeze, damp heat	85% RH
Static load front and back (e.g. wind)	50psf (2400 pascals)
Front loading (e.g. snow)	113psf (5400 pascals)
Hailstone impact	25mm (1 inch) at 23 m/s (52mph)

Dimensions in brackets are in inches. Unbracketed dimensions are in millimeters. Overall tolerances ±3mm (1/8")



Included with each module: self-tapping grounding screws, instruction sheet, and warranty document.

Note: This publication summarizes product warranty and specifications, which are subject to change without notice.

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bp solar

Smart choice for power

xantrex

GT Series Grid Tie Solar Inverters

Performance, Value and Peace of Mind

Xantrex GT Series Grid Tie Solar Inverters

Xantrex photovoltaic string inverters offer high efficiency, clean aesthetics, high reliability, as well as lower installed cost, through time-saving installation and included features. The result is a high-performance inverter that makes utility-interactive installations easier and more cost effective.

Technology

- Proven high-frequency design in a compact enclosure
- Integrated DC/AC disconnect that is NEC compliant to eliminate the need for external DC (PV), and in some jurisdictions, AC disconnects
- Large heat sink offers extraordinary heat dispersion without the need for a cooling fan
- Backlit, two-line, 16-character liquid crystal display (LCD) provides instantaneous power, daily and lifetime energy production, photovoltaic array voltage and current, utility voltage and frequency, time online "selling" today, fault messages, and installer customized screens
- Bright LED indicators provide system status at-a-glance
- LCD vibration sensor allows the tap of a finger to turn backlight on and to cycle through display screens
- Integrated RS232 and Xanbus™ RJ45 communication ports
- Free PC software for remote monitoring and system troubleshooting available online

Installation

- Flexible module selection and sizing due to wide PV input MPPT tracking voltage range
- Lightweight and versatile mounting bracket simplifies installation
- Modular design allows inverters to be mounted side-by-side, using each wiring box as a wiring raceway
- Easy access DC (photovoltaic) and AC (utility) terminal block simplifies wiring
- Integrated, lockable AC/DC disconnect saves installation time and balance of system component cost
- Rugged NEMA 3R inverter enclosure allows reliable outdoor and indoor installations

Performance

- Best-in-class efficiency to maximize investment of solar system
- Accurate MPPT tracking ensures maximum energy harvest under any condition
- Excellent thermal performance
- FCC Part B compliance means less potential interference with communication, radio, and consumer electronics

Serviceability

- 10-year standard warranty
- Sealed inverter enclosure can be separated from the wiring box allowing DC/AC connections to remain intact in the unlikely event the inverter needs to be serviced

xantrex GT SERIES WARRANTY 10 YEARS

Standard 10-year warranty

Xantrex Technology Inc.
Customer Service/Technical Support
customerservice@xantrex.com
Toll free: 1-800-670-0707

UL 1741 CSA 107.1-01 PHOTOVOLTAIC POWER INVERTER

www.xantrex.com

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Smart choice for power

xantrex

Xantrex GT Series Grid Tie Solar Inverters

Electrical Specifications

Models	GT2.5-NA-DS-240	GT3.0-NA-DS-240	GT3.3-NA-DS-240 GT3.3-NA-DS 208	GT3.8-NA-DS-240	GT5.0-NA-DS-240
Maximum AC power output	2500 W	3000 W	3300 W	3800 W	5000 W
AC output voltage (nominal)	240 Vac	240 Vac	240 Vac 208 Vac	240 Vac	240 Vac
AC output voltage range	211 - 264 Vac	211 - 264 Vac	211 - 264 Vac 183 - 228 Vac	211 - 264 Vac	211 - 264 Vac
AC frequency (nominal)	60 Hz	60 Hz	60 Hz	60 Hz	60 Hz
AC frequency range	59.3 - 60.5 Hz	59.3 - 60.5 Hz	59.3 - 60.5 Hz	59.3 - 60.5 Hz	59.3 - 60.5 Hz
Maximum continuous output current	11.8 A	14.2 A	15.6 A 18 A	16 A	23 A
Current THD	< 3%	< 5%	< 3%	< 3%	< 2%
Power factor	> 0.9	> 0.9	> 0.9	> 0.9	> 0.9
DC input voltage range	195 - 600 Vdc	195 - 600 Vdc	195 - 600 Vdc	195 - 600 Vdc	235 - 600 Vdc
Peak power tracking voltage range	195 - 550 Vdc	195 - 550 Vdc	195 - 550 Vdc	195 - 550 Vdc	235 - 550 Vdc
Peak inverter efficiency	94.8%	94.6%	95.3% 94.7%	95.7%	96.5%
CEC efficiency	94.0%	94.5%	94.5% 94.0%	95.0%	95.5%
Night-time power consumption	1 W	1 W	1 W	1 W	1 W
Output over-current protection	15 A	20 A	20 A 25 A	20 A	30A

Mechanical Specifications

Operating temperature range	-13°F to +149°F (-25°C to +65°C)
Enclosure type	NEMA 3R (outdoor rated)
Unit weight	49.0 lbs (22.2 kg) to 58.0lb (25.8 kg)
Shipping weight	57.0 lbs (25.9 kg) to 65.0lb (27.2 kg)
Shipping dimensions (H x W x D)	34.1 x 20.4 x 10.3" (866 x 518 x 262 mm)
Inverter dimensions (H x W x D)	28.5 x 15.9 x 5.7" (755 x 403 x 146 mm)
Mounting	Wall mount (mounting bracket included)

Features

PV / Utility disconnect	Eliminates need for external PV (DC) disconnect. Complies with NEC requirements.				
Cooling	Convection cooled, fan not required.				
Display	Backlit, two-line, 16-character liquid crystal display provides instantaneous power, daily and lifetime energy production, PV array voltage and current, utility voltage and frequency, time online "selling" today, fault messages, and installer customizable screens.				
Communications	One RS 232 and two Xanbus™ RJ45 ports.				
Wiring box	PV, utility, ground, and communications connections. The inverter can be separated from the wiring box				
Warranty	10-year standard				
Part number (negative ground)	864-0108	864-0002	864-0107 864-0111	864-0119	864-0118
Part number (positive ground)	864-0112	N/A	864-0114	N/A	N/A

Options

Positive grounding	Positive grounding configurations available for the GT2.5-A-DS-240, GT3.3-NA-DS-240, GT3.3-NA-DS-208, & GT3.8-NA-DS-240 inverters as required.

Specifications subject to change without notice.

DS20070116JS_GT2.5-5.0-inverters.indd

APPENDIX F - RETSCREEN INPUTS

Figure F.1: Base Case Energy Model Input

RETScreen® Energy Model - Photovoltaic Project — Training & Support

Site Conditions		Estimate	Notes/Range
Project name		Mt. St. Mary's	See Online Manual
Project location		Maryland	
Nearest location for weather data	-	Baltimore, MD	Complete SR&SL sheet
Latitude of project location	°N	39.2	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	1.65	
Annual average temperature	°C	12.8	-20.0 to 30.0

System Characteristics		Estimate	Notes/Range
Application type	-	On-grid	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	poly-Si	
PV module manufacturer / model #		BP Solar/ BP 3160 S	See Product Database
Nominal PV module efficiency	%	12.7%	4.0% to 15.0%
NOCT	°C	45	40 to 55
PV temperature coefficient	% / °C	0.40%	0.10% to 0.50%
Miscellaneous PV array losses	%	5.0%	0.0% to 20.0%
Nominal PV array power	kWp	24.80	
PV array area	m²	195.3	
Power Conditioning			
Average inverter efficiency	%	95%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	23.6	
Inverter capacity	kW (AC)	25.0	
Miscellaneous power conditioning losses	%	5%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	173.0	
Overall PV system efficiency	%	10.5%	
PV system capacity factor	%	15.6%	
Renewable energy collected	MWh	35.571	
Renewable energy delivered	MWh	33.792	
	kWh	33,792	
Excess RE available	MWh	0.000	
			Complete Cost Analysis sheet

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Figure F.2: Base Case Solar Data Input

RETScreen® Solar Resource and System Load Calculation - Photovoltaic Project

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Baltimore, MD	See Weather Database
Latitude of project location	°N	39.2	-90.0 to 90.0
PV array tracking mode	-	Fixed	
Slope of PV array	°	30.0	0.0 to 90.0
Azimuth of PV array	°	0.0	0.0 to 180.0

Monthly Inputs

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/d)	Monthly solar fraction (%)
January	1.00	2.07	0.0	3.17	-
February	1.00	2.86	1.6	3.84	-
March	1.00	3.88	6.7	4.54	-
April	1.00	4.90	12.0	5.13	-
May	1.00	5.61	17.5	5.42	-
June	1.00	6.17	22.4	5.76	-
July	1.00	6.02	24.8	5.70	-
August	1.00	5.32	23.9	5.38	-
September	1.00	4.38	20.2	4.91	-
October	1.00	3.31	13.6	4.22	-
November	1.00	2.23	8.3	3.28	-
December	1.00	1.78	2.7	2.80	-

		Annual	Season of use
Solar radiation (horizontal)	MWh/m²	1.48	1.48
Solar radiation (tilted surface)	MWh/m²	1.65	1.65
Average temperature	°C	12.8	12.8

Load Characteristics		Estimate
Application type	-	On-grid

Return to Energy Model sheet

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Figure F.3: Base Case Cost Information Input

RETScreen® Cost Analysis - Photovoltaic Project

Type of analysis: Pre-feasibility | Currency: $ | Cost references: None

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study							
Other - Feasibility study	Cost	0	$ 10,000	$ -		-	-
Sub-total :				$ -	0.0%		
Development							
Other - Development	Cost	0	$ 15,000	$ -		-	-
Sub-total :				$ -	0.0%		
Engineering							
Other - Engineering	Cost	0	$ 10,000	$ -		-	-
Sub-total :				$ -	0.0%		
Energy Equipment							
PV module(s)	kWp	24.80	$ 3,750	$ 93,000		-	-
Transportation	project	0	$ -	$ -		-	-
Other - Energy equipment	Cost	0	$ -	$ -		-	-
Credit - Energy equipment	Credit	0	$ -	$ -		-	-
Sub-total :				**$ 93,000**	55.1%		
Balance of Equipment							
Module support structure	m^2	195.3	$ 50	$ 9,764		-	-
Inverter	kW AC	25.0	$ 764	$ 19,100		-	-
Other electrical equipment	kWp	24.80	$ 50	$ 1,240		-	-
System installation	kWp	24.80	$ 1,500	$ 37,200		-	-
Transportation	project	0	$ -	$ -		-	-
Other - Balance of equipment	Cost	0	$ -	$ -		-	-
Credit - Balance of equipment	Credit	0	$ -	$ -		-	-
Sub-total :				**$ 67,304**	39.9%		
Miscellaneous							
Training	p-h	6	$ 65	$ 390		-	-
Contingencies	%	5%	$ 160,694	$ 8,035		-	-
Sub-total :				**$ 8,425**	5.0%		
Initial Costs - Total				**$ 168,728**	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M							
Property taxes/Insurance	project	0	$ -	$ -		-	-
O&M labour	p-h	10	$ 55	$ 550		-	-
Other - O&M	Cost	0	$ -	$ -		-	-
Credit - O&M	Credit	0	$ -	$ -		-	-
Contingencies	%	0%	$ 550	$ -		-	-
Sub-total :				**$ 550**	100.0%		
Annual Costs - Total				$ 550	100.0%		

Periodic Costs (Credits)		Period	Unit Cost	Amount		Interval Range	Unit Cost Range
Inverter Repair/Replacement	Cost	25 yr	$ 19,100	**$ 19,100**		-	-
			$ -	$ -		-	-
			$ -	$ -		-	-
End of project life		-	$ -	$ -			Go to GHG Analysis sheet

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Figure F.4: Base Case Economic Input and Financial Results

RETScreen® Financial Summary - Photovoltaic Project

Annual Energy Balance

Project name		Mt. St. Mary's			
Project location		Maryland	Nominal PV array power	kWp	24.80
Renewable energy delivered	MWh	33.792	Net GHG reduction	t_{CO2}/yr	15.93
Firm RE capacity	kW	-	Net GHG emission reduction - 50 yrs	t_{CO2}	796.52
Application type		On-grid			

Financial Parameters

Avoided cost of energy	$/kWh	0.135	Debt ratio	%	50.0%
RE production credit	$/kWh	-	Debt interest rate	%	6.5%
			Debt term	yr	15
GHG emission reduction credit	$/$t_{CO2}$	-	Income tax analysis?	yes/no	No
Energy cost escalation rate	%	5.0%			
Inflation	%	0.0%			
Discount rate	%	5.0%			
Project life	yr	50			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	$	-	O&M	$	550
Development	0.0%	$	-	Fuel	$	-
Engineering	0.0%	$	-	Debt payments - 15 yrs	$	8,972
Energy equipment	55.1%	$	93,000	**Annual Costs and Debt - Total**	**$**	**9,522**
Balance of equipment	39.9%	$	67,304			
Miscellaneous	5.0%	$	8,425	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**168,728**	Energy savings/income	$	4,562
Incentives/Grants		$	55,519			
				Annual Savings - Total	**$**	**4,562**
Periodic Costs (Credits)						
Inverter Repair/Replacement		$	19,100	Schedule yr # 25,50		
		$	-			
		$	-			
End of project life -		$	-			

Financial Feasibility

			Calculate energy production cost?	yes/no	No
Pre-tax IRR and ROI	%	8.3%			
After-tax IRR and ROI	%	8.3%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	28.2			
Year-to-positive cash flow	yr	21.3	Project equity	$	84,364
Net Present Value - NPV	$	88,774	Project debt	$	84,364
Annual Life Cycle Savings	$	4,863	Debt payments	$/yr	8,972
Benefit-Cost (B-C) ratio	-	2.05	Debt service coverage	-	0.47

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Figure F.5: Alternate Case Energy Model Input

RETScreen® Energy Model - Photovoltaic Project — *Training & Support*

Site Conditions		Estimate	Notes/Range
Project name		**Mt. St. Mary's**	See Online Manual
Project location		**Maryland**	
Nearest location for weather data	-	Baltimore, MD	Complete SR&SL sheet
Latitude of project location	°N	39.2	-90.0 to 90.0
Annual solar radiation (tilted surface)	MWh/m²	1.64	
Annual average temperature	°C	12.8	-20.0 to 30.0

System Characteristics		Estimate	Notes/Range
Application type	-	**On-grid**	
Grid type	-	Central-grid	
PV energy absorption rate	%	100.0%	
PV Array			
PV module type	-	poly-Si	
PV module manufacturer / model #		BP Solar/ BP 3160 S	See Product Database
Nominal PV module efficiency	%	12.7%	4.0% to 15.0%
NOCT	°C	45	40 to 55
PV temperature coefficient	% / °C	0.40%	0.10% to 0.50%
Miscellaneous PV array losses	%	5.0%	0.0% to 20.0%
Nominal PV array power	kWp	**42.72**	
PV array area	m²	336.4	
Power Conditioning			
Average inverter efficiency	%	95%	80% to 95%
Suggested inverter (DC to AC) capacity	kW (AC)	40.6	
Inverter capacity	kW (AC)	40.0	
Miscellaneous power conditioning losses	%	5%	0% to 10%

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Specific yield	kWh/m²	172.4	
Overall PV system efficiency	%	10.5%	
PV system capacity factor	%	15.5%	
Renewable energy collected	MWh	61.029	
Renewable energy delivered	MWh	**57.977**	
	kWh	57,977	
Excess RE available	MWh	**0.000**	
			Complete Cost Analysis sheet

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Figure F.6: Alternate Case Solar Data Input

RETScreen® Solar Resource and System Load Calculation - Photovoltaic Project

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Baltimore, MD	See Weather Database
Latitude of project location	°N	39.2	-90.0 to 90.0
PV array tracking mode	-	Fixed	
Slope of PV array	°	30.0	0.0 to 90.0
Azimuth of PV array	°	12.5	0.0 to 180.0

Monthly Inputs

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/d)	Monthly solar fraction (%)
January	1.00	2.07	0.0	3.14	-
February	1.00	2.86	1.6	3.81	-
March	1.00	3.88	6.7	4.52	-
April	1.00	4.90	12.0	5.12	-
May	1.00	5.61	17.5	5.42	-
June	1.00	6.17	22.4	5.76	-
July	1.00	6.02	24.8	5.71	-
August	1.00	5.32	23.9	5.37	-
September	1.00	4.38	20.2	4.89	-
October	1.00	3.31	13.6	4.19	-
November	1.00	2.23	8.3	3.25	-
December	1.00	1.78	2.7	2.77	-

		Annual	Season of use
Solar radiation (horizontal)	MWh/m²	1.48	1.48
Solar radiation (tilted surface)	MWh/m²	1.64	1.64
Average temperature	°C	12.8	12.8

Load Characteristics		Estimate
Application type	-	On-grid

Return to Energy Model sheet

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Figure F.7: Alternate Case Cost Information Input

RETScreen® Cost Analysis - Photovoltaic Project

Type of analysis: Pre-feasibility | Currency: $ | Cost references: None

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study							
Other - Feasibility study	Cost	0	$ 10,000	$ -		-	-
Sub-total :				$ -	0.0%		
Development							
Other - Development	Cost	0	$ 15,000	$ -		-	-
Sub-total :				$ -	0.0%		
Engineering							
Other - Engineering	Cost	0	$ 10,000	$ -		-	-
Sub-total :				$ -	0.0%		
Energy Equipment							
PV module(s)	kWp	42.72	$ 3,750	$ 160,200		-	-
Transportation	project	0	$ -	$ -		-	-
Other - Energy equipment	Cost	0	$ -	$ -		-	-
Credit - Energy equipment	Credit	0	$ -	$ -		-	-
Sub-total :				$ **160,200**	55.6%		
Balance of Equipment							
Module support structure	m^2	336.4	$ 50	$ 16,819		-	-
Inverter	kW AC	40.0	$ 764	$ 30,560		-	-
Other electrical equipment	kWp	42.72	$ 50	$ 2,136		-	-
System installation	kWp	42.72	$ 1,500	$ 64,080		-	-
Transportation	project	0	$ -	$ -		-	-
Other - Balance of equipment	Cost	0	$ -	$ -		-	-
Credit - Balance of equipment	Credit	0	$ -	$ -		-	-
Sub-total :				$ **113,595**	39.5%		
Miscellaneous							
Training	p-h	6	$ 65	$ 390		-	-
Contingencies	%	5%	$ 274,185	$ 13,709		-	-
Sub-total :				$ **14,099**	4.9%		
Initial Costs - Total				$ **287,894**	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M							
Property taxes/Insurance	project	0	$ -	$ -		-	-
O&M labour	p-h	10	$ 55	$ 550		-	-
Other - O&M	Cost	0	$ -	$ -		-	-
Credit - O&M	Credit	0	$ -	$ -		-	-
Contingencies	%	0%	$ 550	$ -		-	-
Sub-total :				$ **550**	100.0%		
Annual Costs - Total				$ 550	100.0%		

Periodic Costs (Credits)		Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Inverter Repair/Replacement	Cost	25 yr	$ 30,560	$ **30,560**	-	-
			$ -	$ -	-	-
			$ -	$ -	-	-
End of project life		-	$ -	$ -		Go to GHG Analysis sheet

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Figure F.8: Alternate Case Economic Input and Financial Results

RETScreen® Financial Summary - Photovoltaic Project

Annual Energy Balance

Project name		Mt. St. Mary's			
Project location		Maryland	Nominal PV array power	kWp	42.72
Renewable energy delivered	MWh	57.977	Net GHG reduction	t_{CO2}/yr	27.33
Firm RE capacity	kW	-	Net GHG emission reduction - 50 yrs	t_{CO2}	1,366.61
Application type		On-grid			

Financial Parameters

Avoided cost of energy	$/kWh	0.135	Debt ratio	%	50.0%
RE production credit	$/kWh	-	Debt interest rate	%	6.5%
			Debt term	yr	15
GHG emission reduction credit	$/$t_{CO2}$	-	Income tax analysis?	yes/no	No
Energy cost escalation rate	%	5.0%			
Inflation	%	0.0%			
Discount rate	%	5.0%			
Project life	yr	50			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	$	-	O&M	$	550
Development	0.0%	$	-	Fuel	$	-
Engineering	0.0%	$	-	Debt payments - 15 yrs	$	15,309
Energy equipment	55.6%	$	160,200	**Annual Costs and Debt - Total**	**$**	**15,859**
Balance of equipment	39.5%	$	113,595			
Miscellaneous	4.9%	$	14,099	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**287,894**	Energy savings/income	$	7,827
Incentives/Grants		$	91,268			
				Annual Savings - Total	**$**	**7,827**
Periodic Costs (Credits)						
Inverter Repair/Replacement		$	30,560	Schedule yr # 25,50		
		$	-			
		$	-			
End of project life -		$	-			

Financial Feasibility

			Calculate energy production cost?	yes/no	No
Pre-tax IRR and ROI	%	8.4%			
After-tax IRR and ROI	%	8.4%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	27.0			
Year-to-positive cash flow	yr	21.0	Project equity	$	143,947
Net Present Value - NPV	$	158,035	Project debt	$	143,947
Annual Life Cycle Savings	$	8,657	Debt payments	$/yr	15,309
Benefit-Cost (B-C) ratio	-	2.10	Debt service coverage	-	0.50

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APPENDIX G - FIRST COST ANALYSIS

Unit Type	Ground-Source Costs				Water-Source Costs				Air-Source Costs			
	Number	Equipment	Installation	O & P	Number	Equipment	Installation	O & P	Number	Equipment	Installation	O & P
Water-Source Heat Pumps												
1 Ton:	9	$1,200	$325	$300	9	$1,200	$325	$300	0	$0	$0	$0
1.5 Ton:	4	$1,325	$360	$315	4	$1,325	$360	$315	0	$0	$0	$0
2 Ton:	4	$1,375	$385	$340	4	$1,375	$385	$340	0	$0	$0	$0
2.5 Ton:	41	$1,450	$405	$345	41	$1,450	$405	$345	0	$0	$0	$0
Split DX Air-Source Heat Pumps												
1.5 Ton:	0	$0	$0	$0	0	$0	$0	$0	13	$1,575	$535	$440
2 Ton:	0	$0	$0	$0	0	$0	$0	$0	4	$1,600	$540	$435
2.5 Ton:	0	$0	$0	$0	0	$0	$0	$0	21	$1,800	$650	$500
3 Ton:	0	$0	$0	$0	0	$0	$0	$0	20	$2,000	$815	$610
Cooling Tower												
Galvanized Steel Blow Through, Centrifugal - 100 Ton:	0	$0	$0	$0	1	$14,200	$830	$1,870	0	$0	$0	$0
Boiler												
Cast Iron, Gas Fired - 1000 MBH:	0	$0	$0	$0	2	$10,800	$3,450	$2,850	0	$0	$0	$0
Condenser Water Pumps												
Centrifugal - 375 GPM:	2	$6,600	$625	$975	2	$6,600	$625	$975	0	$0	$0	$0
Geothermal Additionals												
Geothermal Distribution Box:	1	$1,725	$800	$1,125	0	$0	$0	$0	0	$0	$0	$0
Vertical Wells:	64	$400	$2,000	N/A	0	$0	$0	$0	0	$0	$0	$0
Totals:		$121,575	$152,560	$22,540		$130,050	$31,490	$28,985		$104,675	$39,065	$30,160
First Cost:	$296,675				$190,525				$173,900			

APPENDIX H - HVAC SYSTEMS CONSTRUCTION SCHEDULE

Act ID	Description	Orig Dur	Rem Dur	Early Start	Early Finish
09D-1020	Prime/Seal 2nd Level	10	10	12SEP07	25SEP07
09D-1050	Finish Coat Lower Level	5	5	12SEP07	18SEP07
09D-1010	Prime/Seal 1st Level	10	10	19SEP07	02OCT07
09D-1080	Finish Coat 3rd Level	10	10	30OCT07	12NOV07
09D-1070	Finish Coat 2nd Level	10	10	06NOV07	19NOV07
09D-1060	Finish Coat 1st Level	10	10	13NOV07	27NOV07
Kone, Inc. Elevators (MARB BLUE)					
14A-1020	Elevator Submittals	10	10	16OCT06 *	27OCT06
14A-1000	Elevator Fabrication	80	80	30OCT06	22FEB07
14A-1010	Elevator Installation	40	40	04JUN07	30JUL07
Bryant Mech. MEP (PURPLE)					
15A-1020	Bryant Submittals & Approvals	20	20	02OCT06	27OCT06
15A-1000	Lower Level Underground Plumbing	10	10	08MAR07	21MAR07
15A-1005	1st Level Underground Plumbing	10	10	08MAR07	21MAR07
15A-1040	Mechanical Equipment Set Up	1	1	03APR07	03APR07
15A-1015	Rough In Mech/Plumb Mech. Room Lower	15	15	04APR07	24APR07
15A-1050	Drill & Grout Geothermal Wells	23	23	15MAY07	15JUN07
15A-1035	Mech/Plumbing Rough In 3rd Level	27	27	16MAY07	22JUN07
15A-1030	Mech/Plumbing Rough In 2nd Level	27	27	23MAY07	29JUN07
15A-1025	Mech/Plumbing Rough In 1st Level	30	30	25MAY07	09JUL07
15A-1120	Set/connect/start fans & units at attic	8	8	25MAY07	06JUN07
15A-1010	Rough In Mech/Plumb Lower Level	15	15	18JUN07	09JUL07
15A-1060	Set Vault and Hook up Geothermal System	15	15	18JUN07	09JUL07
15A-1140	Set/Connect/Heat Pumps 3rd Level	10	10	25JUN07	09JUL07
15A-1150	Set/Connect/Heat Pumps 2nd Level	10	10	02JUL07	16JUL07
15A-1160	Set/Connect/Start Heat Pump 1st Level	10	10	10JUL07	23JUL07
15A-1170	Set/Connect/Start Heat Pumps Lower Level	10	10	10JUL07	23JUL07
15A-1070	Commissioning Mech Room Equipment	2	2	24JUL07	25JUL07
15A-1110	Grilles/Diffuser Lower Level	5	5	16AUG07	22AUG07
15A-1180	Plumbing Fixtures Lower Level	10	10	21AUG07	04SEP07
15A-1220	Air Balancing Lower Level	2	2	27AUG07	28AUG07
15A-1080	Grilles/Diffuser 3rd Floor	5	5	21SEP07	27SEP07
15A-1090	Grilles/Diffuser 2nd Floor	5	5	28SEP07	04OCT07
15A-1210	Plumbing Fixtures 3rd Level	10	10	03OCT07	16OCT07
15A-1100	Grilles/Diffuser 1st Floor	5	5	05OCT07	11OCT07
15A-1200	Plumbing Fixtures 2nd Level	10	10	10OCT07	23OCT07
15A-1250	Air Balancing 3rd Floor	2	2	16OCT07	17OCT07

Start date 02OCT06
Finish date 31DEC07
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