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.

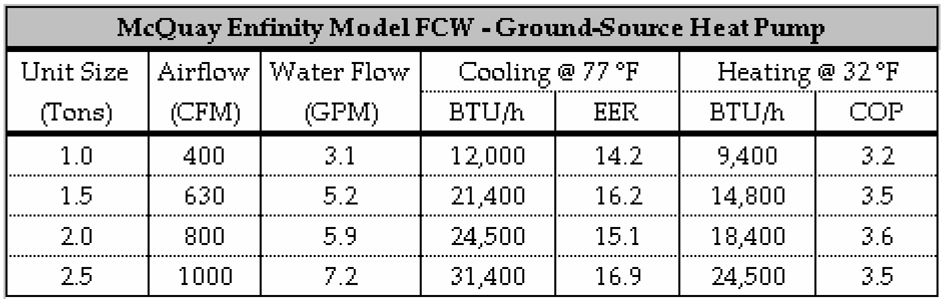
The four systems listed above are all realistic alternatives that merit an investigation into the cost benefits of their application on the Mount St. Mary's project. Careful determination of the locations of the heat rejection apparatus would be necessary due to the aforementioned aesthetic requirements 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	Airflow	Water Flow	Cooling @ 77 °F		Heating @ 32 °F	
(Tons)	(CFM)	(GPM)	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

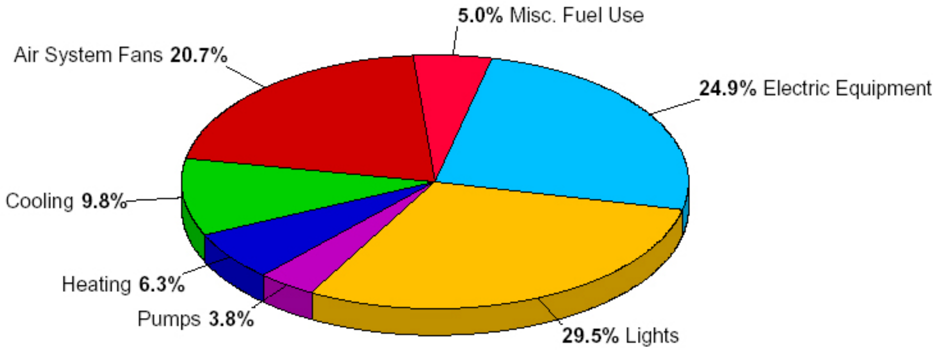
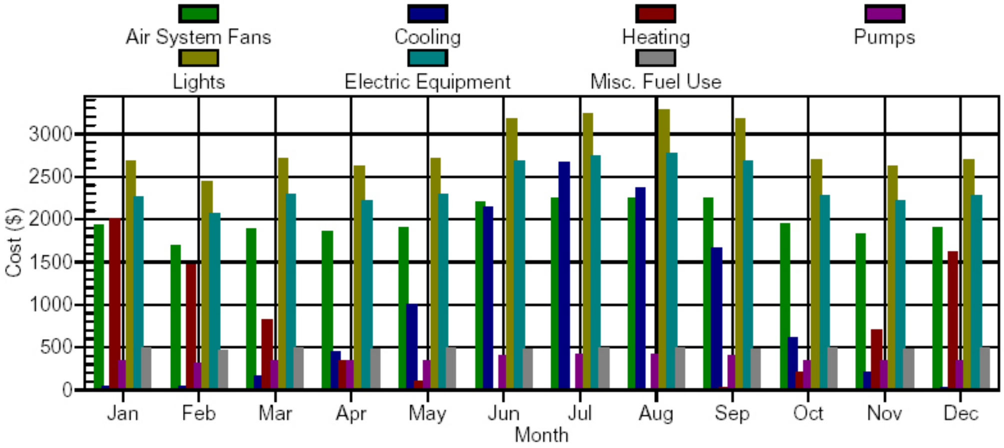


Figure 7.2.2: Monthly Ground-Source Component Cost Totals



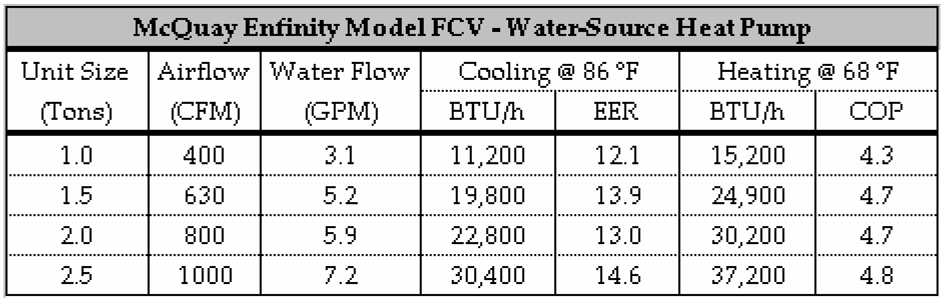
These results were very much in line with what I had been expecting. Lighting and electrical equipment constituted 54.4% of the yearly costs, while cooling and heating loads were kept to lower percentages of 9.8% and 6.3%, respectively. From the graph of the monthly loads, it can be seen that basic electrical 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 (Tons)	Airflow (CFM)	Water Flow (GPM)	Cooling @ 86 °F		Heating @ 68 °F	
			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

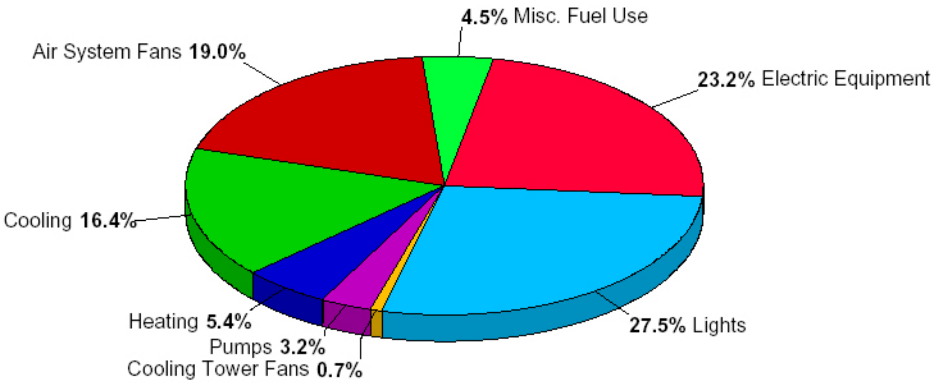


Figure 7.3.2: Monthly Water-Source Component Cost Totals

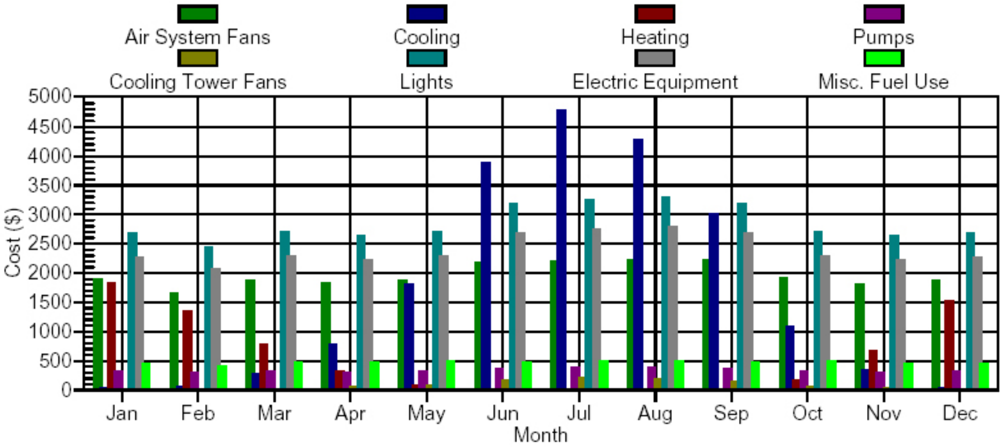
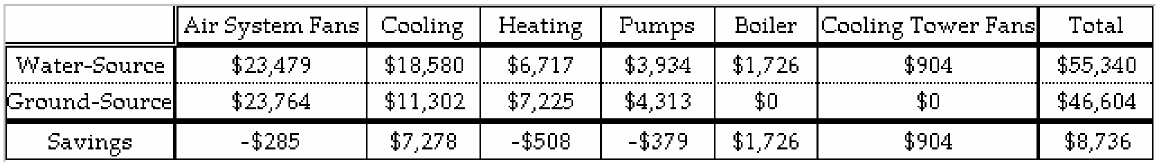


Table 7.3.2 below shows a detailed breakdown of the annual costs of the HVAC components and the savings possible by the geothermal system.

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

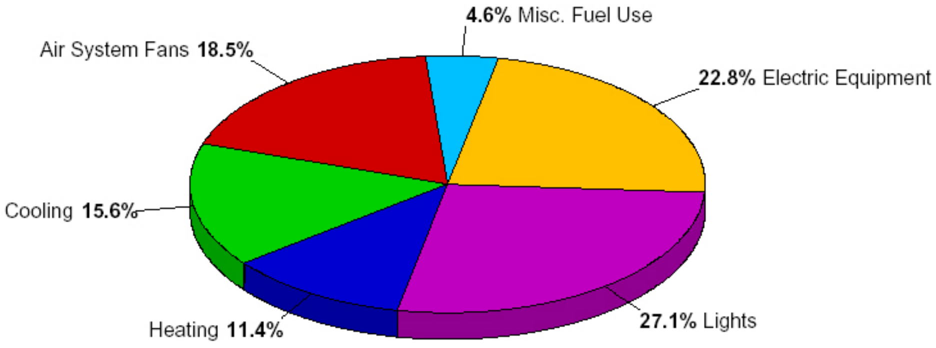


Figure 7.4.2: Monthly Air-Source Component Cost Totals

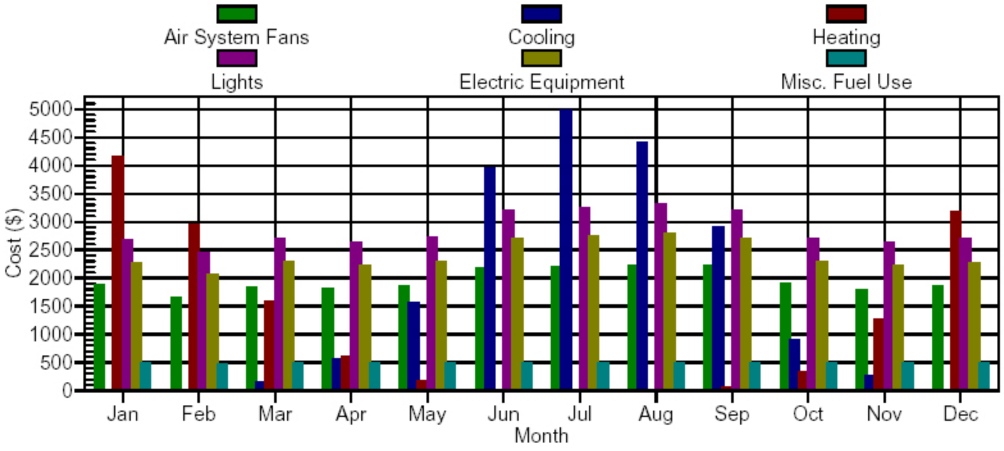


Table 7.4.2 below shows a detailed breakdown of the annual costs of the HVAC components and the savings possible by the geothermal system.

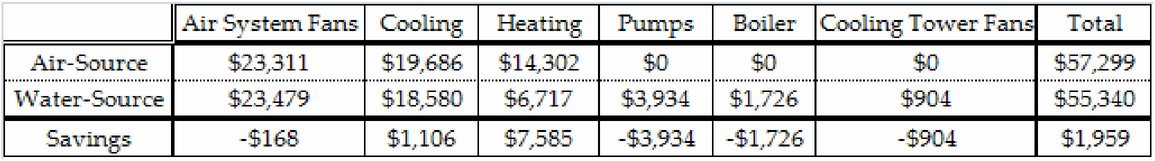
Table 7.4.2: Potential Savings of Geothermal over Air-Source

	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

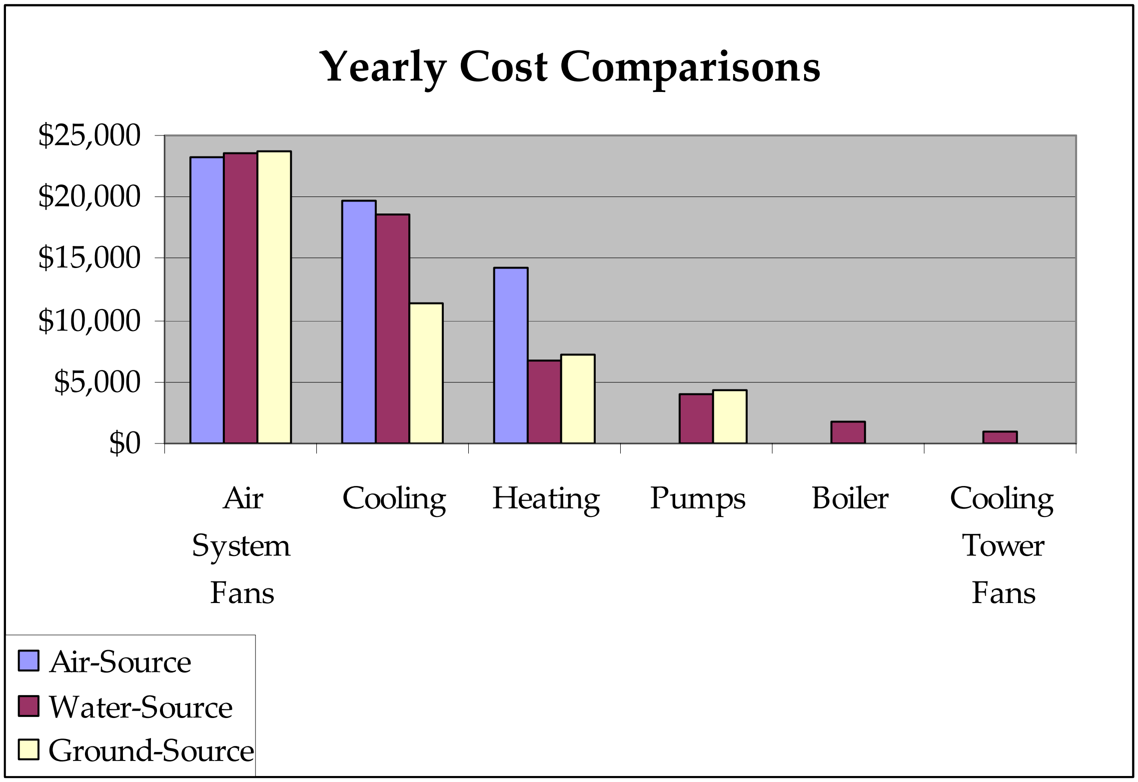
Of the three systems modeled, the geothermal system proved to be the most efficient and economic. A breakdown of the yearly savings possible by each system as well as a comparison of yearly HVAC component costs can be seen in Table 7.6.1 and Figure 7.6.1 below, respectively.

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.