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PRELIMINARY FEASIBILITY STUDY FOR HVAC RETROFIT WITH A GEOTHERMAL HEAT PUMP SYSTEM AT THE CASCADE MEDICAL CENTER, CASCADE, IDAHO

EXECUTIVE SUMMARY

The Geo-Heat Center conducted a preliminary assessment of the feasibility for the Cascade Medical Center to retrofit their heating, ventilating, and air conditioning (HVAC) system to a geothermal heat pump system. We considered two options for the geothermal part of the system: (i) an open-loop system with supply and re-injection well, and (ii) a vertical borehole, closed-loop earth heat exchanger. Direct-use heating with hot groundwater was not considered in this preliminary assessment, as the depth to usable groundwater could be as much as 2,500 to 3,000 ft, and there would be no guarantee that usable groundwater could be found.

Estimation of the Heating and Cooling Loads

The heating and cooling loads were estimated by using a combination of a loads estimation software program and by analyzing energy consumption data. The peak cooling load is estimated at about 26 tons and the peak heating load is estimated at about 500,000 Btu/hr. In averaging all charges, the electricity rate for hospital is about $0.044/kWh. Annual electricity bills from 2003-2004 averaged about $23,800, with about 50-60% ($12,700) being attributed to heating energy costs.

Retrofit of Existing Heating and Cooling Equipment

Since the peak heating load is 60% greater than the peak cooling load, it would be more economical to size the replacement heat pumps for the cooling load, and re-use stages of the existing heating elements in a supplemental capacity. It is estimated that a geothermal heat pump system of this design could meet about 82% of the total annual heating load and 100% of the cooling load. Split heat pumps could be retrofitted into existing ductwork, allowing re-use of existing air handlers. Existing console air-source heat pump units in the patient rooms could be replaced water-source units and tied into the building loop.

Geological Conditions

Based on review of a well log at the adjacent property, the site is underlain by granite with occasional fractured water-bearing zones. This well was drilled to 1,100 ft deep and had a yield of 100 gpm after drilling completion and a groundwater temperature of 81°F. The site geology would be suitable for either an open- or closed-loop geothermal heat exchange system, with some advantages and disadvantages of each. Since the building is heating-dominated, the elevated earth temperature will aid in performance improvements in either type of geothermal heat exchange system.

Open-Loop Geothermal Option

This type of system would consist of a production well and a re-injection well. The groundwater loop would be isolated from the building loop with a plate heat exchanger. Assuming 70°F water could be found, it is estimated that a well yielding 40 gpm could handle the heating and cooling loads.

For the economic analysis, it was assumed that a 500-ft deep well would be sufficient. **The capital cost of an open-loop geothermal heat pump system is estimated to be on the order of $110,000 with a simple payback period of 12.8 years.** A sensitivity analysis of the major cost items shows that a 20% variation in either the drilling or the equipment costs alters the simple payback period by about 1 year.

Closed-Loop Geothermal Option

This type of system would consist of a network of vertical boreholes, each consisting of a HDPE plastic u-tube heat exchanger. The required total borehole heat exchanger length is highly dependent on the average underground earth temperature, of which there is uncertainty caused by the elevated earth temperature at depth.

For the economic analysis, an average underground earth temperature of 65°F was assumed. **The capital cost of a closed-loop geothermal heat pump system is estimated to be on the order of $136,000 with a simple payback period of 14.9 years.** A sensitivity analysis of the major cost items shows that a 20% variation in either the drilling or the equipment costs alters the simple payback period by about 1 to 1.3 years. A sensitivity analysis on the average underground earth temperature shows that the simple payback period would approach 20 years if the average underground temperature was only 55°F. The optimum average underground temperature was found to be 70°F, where the simple payback period could range from 12 to 15 years, depending on drilling costs.

Recommendations

Either an open- or closed loop geothermal heat pump system appears to be a viable HVAC system replacement if the hospital is willing to accept a payback period on the order of 12 to 15 years. An open-loop system would be less intrusive to the site, however.

The most economical option depends on the underground earth temperature and groundwater occurrence. To make a more informed decision, it is recommended that a test hole be planned for 500 ft depth. This will give an indication of the local drilling costs, and will give necessary and valuable information on the site geology. If groundwater of adequate flow rate and chemical quality is encountered before the target depth, the hole could be terminated and an open-loop system would likely be the more logical choice. If at 500 ft depth no groundwater has been encountered, a closed-loop system would likely emerge as the more logical choice, depending on drilling costs. The test hole could then be completed with a 1¼-inch U-tube and a thermal conductivity test done.

Sincerely,

Andrew Chiasson, P.E.

INTRODUCTION

The Geo-Heat Center was contacted by the Idaho Energy Division to conduct a preliminary assessment of retrofitting the Cascade Medical Center's heating, ventilating, and air conditioning (HVAC) system to a geothermal system. Geo-Heat Center staff visited the building in September 2005 and surveyed the existing HVAC systems and equipment. The monthly electric utility data for 2003-2004 were compiled and provided by Mr. Dan Hand, P.E. of Chevron.

For this preliminary study, the Geo-Heat Center considered the feasibility of retrofitting the HVAC system to a geothermal heat pump system. We considered two options for the geothermal part of the system: (i) open-loop earth heat exchange, with a supply and re-injection well, and (ii) a vertical borehole, closed-loop earth heat exchanger.

Direct-use heating with hot groundwater was not considered in this preliminary assessment for two reasons. First, extrapolation of the geothermal gradient observed in a well on the adjacent property implies that a well would have to be drilled to depths of 2,500 to 3,000 ft to intersect groundwater at a usable temperature, and there would be considerable risk involved in drilling for this resource without additional site geological information. Second, there is some interest and potential for development of the geothermal resources in the Cascade area, and additional geological investigations may be done in the future.

ESTIMATION OF THE HEATING & COOLING LOADS

A detailed inventory of the HVAC equipment was not completed for this preliminary study, but during the site visit, it was observed that the existing HVAC system consists of one air-source heat pump serving each of the 6 hospital patient rooms, and DX cooling with electric heat serving the remainder of the building in 4 or 5 zones. It was noted by maintenance staff that outdoor air dampers were no longer functioning.

The heating and cooling loads were estimated by using a combination of a loads estimation software program (*Trane System Analyzer*) and by analyzing the energy consumption data compiled by Chevron. First, the software program was used to estimate the monthly peak and total cooling loads. Assuming an average COP of 2.5 for the cooling equipment, a "base" electrical usage was extracted from the July total energy usage, assuming that no heating was required for that month. This "base" electrical use was assumed to occur for each month of the year. Finally, the monthly heating energy consumption was assumed to be the remaining kWh usage after subtracting the cooling energy consumption and the "base" monthly electrical usage.

From the 2003-2004 energy consumption data provided, the average annual electricity cost for the Medical Center was about *$23,800*. This translates to an average cost of about *$0.044*/kWh. The highest monthly bill occurred in January 2004 at *$3,403*. By comparison, the monthly bill for January 2003 was *$2,601*. The lowest monthly energy costs are seen for July and August, which ranged from *$1,000* to *$1,100*.

The results of the loads analyses are shown graphically in Figures 1 and 2. A review of these figures shows that approximately 56% of the annual electricity expenditure is attributed to heating energy (not including fan energy), at a cost of about *$12,700*. The peak cooling load is estimated at 26 tons. The peak heating load is estimated at 500,000 Btu/hr (or about 150 kW).

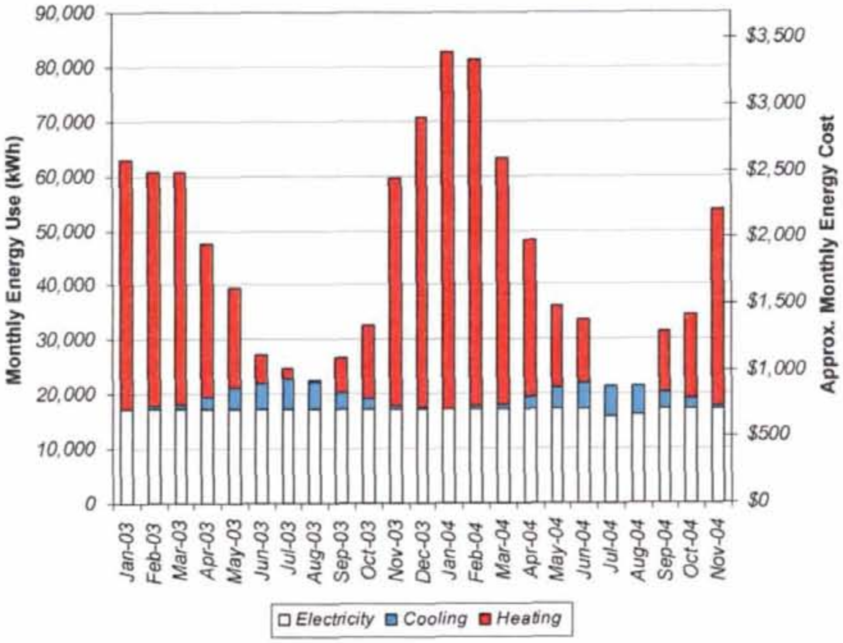

Figure 1. *Estimated breakdown of monthly electrical energy usage and cost for 2003-2004 for the Cascade Medical Center for heating, cooling, and "all other" electricity uses.*

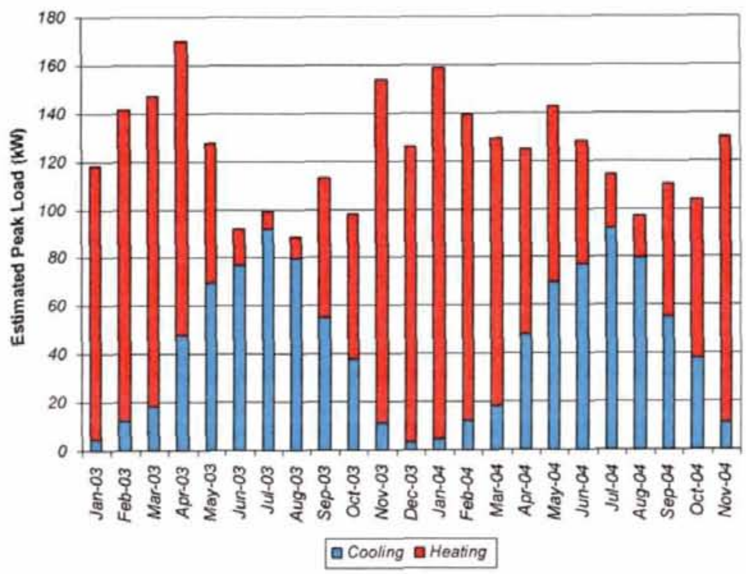

Figure 2. *Estimated monthly peak heating and cooling loads.*

RETROFIT OF EXISTING HEATING & COOLING EQUIPMENT

For retrofit of the existing HVAC system to a geothermal heat pump system, a "split water-source heat pump" would be a good fit for the central zones, and console water-source heat pumps for the hospital rooms. Examples of these types of heat pumps are shown in Figure 3.

Figure 3. *Examples of replacement water-source heat pumps for the Cascade Medical Center. Split unit (left) console unit (right). (Photo credit: www.waterfurnace.com)*

The advantage of retrofit with a split system is that existing air-handling units can remain in place. The existing refrigerant coils should be able to be re-used and connected to the split heat pump, resulting in minimal labor, but this should first be field-verified by an HVAC technician. The top two connections in the split heat pump photo above are optional de-superheater connections for hot water generation in cooling mode. The water-source console heat pumps could directly replace the existing air-source heat pumps in the hospital patient rooms. Fluid transfer piping would need to be brought to each heat pump unit.

Because the peak heating load is much larger than the peak cooling load (about 60% greater), the split units (and therefore the earth heat exchanger) should be sized for the cooling load, and the existing heating elements could be re-used in a supplemental capacity. Assuming the existing electric heating elements are staged, it would have to be field-verified how (or if) these heating elements could be re-used. For example, stage 1 electric heating may only be needed to provide adequate supplemental heating capacity. Sized for the peak cooling load, the geothermal heat pumps could meet about 82% of the annual heating load.

If improvements are made to the HVAC system, the outdoor air dampers will need to be repaired and the proper amount of fresh air introduced into the building. An energy-efficient way of doing this is with a heat recovery unit as shown in Figure 4. On cold days, another split heat pump tied to the earth loop could be used to bring the fresh air exiting the heat recovery unit up to the return air temperature from the building. These units can also be operated on economizer cycles.

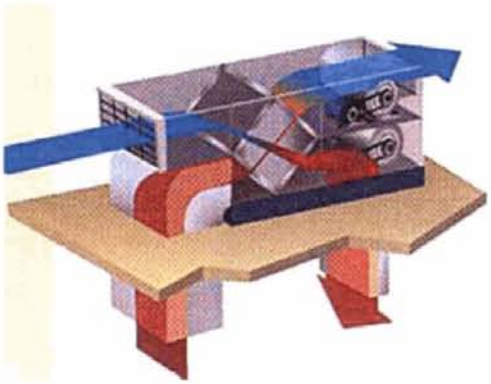

Figure 4. *Example rooftop heat recovery unit for outdoor air handling.*

SITE GEOLOGICAL CONDITIONS

A well log provided by Mr. Ken Neely, a hydrogeologist at the Idaho Department of Water Resources, for a well at the property adjacent to the Medical Center shows that the area is underlain by granite. The lithologic log indicates that the granite is occasionally hard and soft, and occurs in various degrees of fracturing. The well is 1,100 ft deep, with a recorded yield of 100 gpm after 2 hours, but no drawdown measurement was recorded on the well log. The groundwater temperature was recorded at 81°F.

The site geology would be suitable for either an open-loop or closed-loop geothermal heat exchange system, but there are advantages and disadvantages for each type of system.

Regarding open-loop systems, advantages are that chemical quality of groundwater in granite is typically excellent, due to relatively low concentrations of dissolved constituents. Granite is competent rock, and usually a water well installed in granitic rocks needs only to be cased in the upper soil/decayed rock zone, which decreases well completion costs. Granite is also "hard rock" and thus is usually drilled with air methods. Thus, no drilling mud is introduced into the subsurface, which can clog water-bearing zones. The disadvantages regarding open-loop systems in granite are that groundwater flow occurs in fractured zones, and well yields are not high unless the well is relatively deep. Simply stated, a deeper well allows more groundwater to enter the well throughout its entire length. There is some risk in drilling for groundwater in granitic rocks also, in that fractured zones may or not be encountered. The well log from the adjacent property, however, implies that there is a good chance to find groundwater at the Cascade Medical site.

Regarding closed-loop systems, advantages are that granite has one of the highest thermal conductivities of all rock types due to its relatively high density and quartz content. The higher the thermal conductivity, the lower the required heat exchanger loop length. The relatively high density of granite also contributes to its disadvantage regarding closed-loop systems since harder rock types are more costly to drill. As mentioned above, granite is a "hard rock" and is usually drilled with an air method. Air-percussion hammer drilling is a relatively fast and effective method of drilling in granite, but comes at a higher cost. With air drilling methods, a temporary casing is sometimes needed to stabilize the top portion of the borehole and prevent cave-ins.

GEOTHERMAL OPTION 1: OPEN-LOOP SYSTEM

Open-Loop System Description

A conceptual diagram of an open-loop system is shown in Figure 5. The system consists of two "loops" separated by a stainless steel plate heat exchanger, which isolates groundwater from the heating equipment. This configuration reduces any scale or corrosion to one piece of equipment. Routine maintenance and cleaning of the stainless steel plates usually results a trouble-free system. Particularly with granite, groundwater chemical quality is generally excellent, and scaling and corrosion issues are not a significant concern. The building piping loop would be filled with an antifreeze solution, typically a mixture of water and about 15% propylene glycol.

The use of an isolation heat exchanger also allows for energy-efficient control of the well pump. The building loop temperature is allowed to "float" between a heating and cooling setpoint, and when the building loop temperature reaches either of these setpoints, the well pump is energized and moderates the building loop temperature. With this type of control, the required groundwater flow rate is a function of its temperature. Assuming an average groundwater temperature of 70°F, about 25 gpm of groundwater would be required for heating and about 35 gpm would be required for cooling. For energy efficiency, the building loop circulating pump should be variable speed.

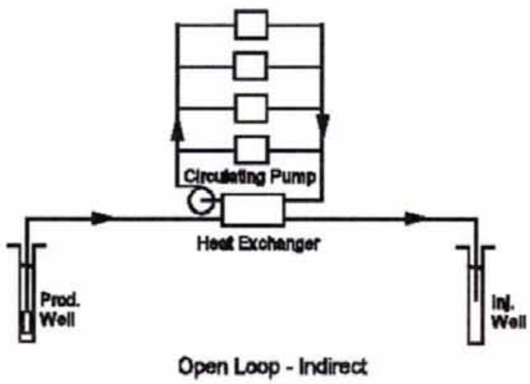

Figure 5. *Conceptual diagram of an open-loop geothermal heat pump system.*

Open-Loop System Economics

For estimating purposes, we assumed that a supply well at 500 ft depth could meet the required flow rate, and that an injection well would be required at the same depth. Included in the economic analysis is consideration of initial costs, annual costs, and periodic costs. The initial costs included engineering design fees, heat pump and associated equipment and installation costs (roughly estimated by an HVAC technician), and geothermal installation costs and well flow testing. Annual cash flows included incremental O&M costs and annual energy savings. Estimated energy use in the open-loop geothermal heat pump system included heat pump, circulating pump, and well pump electricity consumption. Periodic cash flows included estimates of repair costs. Details of the estimated costs are shown in Table 1. An annual energy cost escalation rate of 2% was assumed.

Based on the cost assumptions shown in Table 1, **the simple payback on an open-loop geothermal heat pump system is 12.8 years.**

A sensitivity analysis was conducted on the major cost items. The cost parameters varied included the drilling cost, the equipment cost, the annual heating energy savings, and the annual cooling energy savings. The results of the sensitivity analysis are shown in Figure 6. The percent change in each cost item is shown on the *x-axis*, and the simple payback is shown on the *y-axis*. From the slope of the lines, it is evident that the most important item impacting the payback period is the annual heating energy savings. A 20% increase in the heating energy savings decreases the payback period to about 11.2 years, while a 20% decrease in the savings increases the payback to 15.6 years. The simple payback period is next most sensitive, as one would expect, to the drilling cost and the equipment cost. Since each of these cost items were approximately the same value (see Table 1), they each have a similar effect on the payback period. A 20% change in each item alters the simple payback period by about 1 year.

TABLE 1
Cost Estimate Details for an Open-Loop Geothermal Heat Pump System

	Unit	Quantity	Unit Cost	Amount	TOTALS	Comments
INITIAL COSTS						
Design						
Thermal conductivity test	lump	0	$5,000	$0		
Site visit for retrofit analysis	hr	12	$100	$1,200		
Engineering design and bidding	hr	40	$100	$4,000		
Construction oversight	hr	25	$50	$1,250		
				$6,450		
Equipment & Installation						
Heat pumps + controls	kW	92	$300	$27,587		
Well pumps + controls	kW	2.5	$750	$1,857		
Circulating pumps	kW	1.46	$824	$1,207		
Circulating fluid	m^3	0.1	$3,000	$371		
Plate heat exchangers	kW	92	$12.50	$1,149		
Trenching and backfilling	m	100	$6.00	$600		
Drilling, well completion	m	304.8	$164.04	$50,000		
Fittings and valves	kW	92	$14	$1,287		
Internal piping & insulation	kW	92	$40	$3,678		
Well flow testing	lump	1	$1,500	$1,500		
Retrofit demo/installation	hr	252	$50	$12,600		
				$101,837		
					$108,287	
ANNUAL COSTS						
Energy use savings				$7,594		
Incremental O & M				$500		
					$8,094	
PERIODIC COSTS	Years					
Outdoor condenser replacement	12			-$5,000		- enter savings as negative
Heat pump compressor repair	15			$0		-Assume condenser repairs are off-setting with conventional

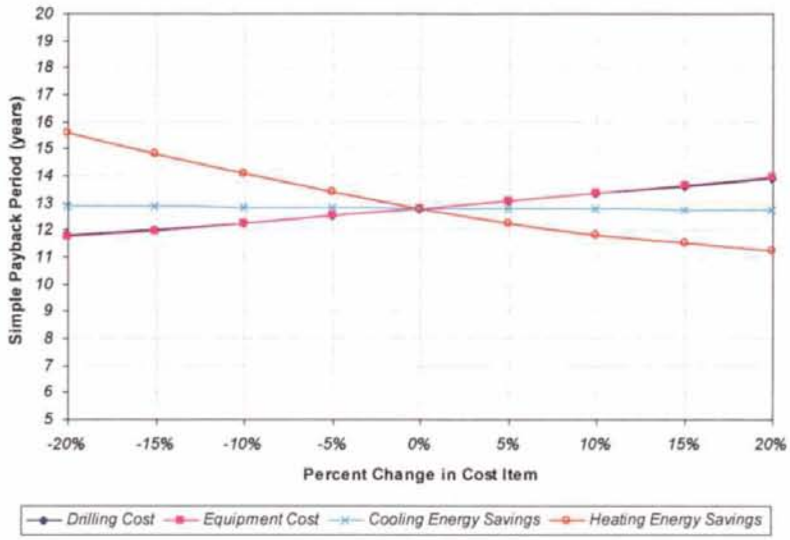

Figure 6. *Sensitivity analysis of major cost items of an open-loop geothermal heat pump system.*

GEOTHERMAL OPTION 2: CLOSED-LOOP SYSTEM

Closed-Loop System Description

A conceptual diagram of a closed-loop system is shown in Figure 7. The closed-loop heat exchanger consists of a network of high-density polyethylene (HDPE) plastic u-tubes installed in vertical boreholes at depths of 200 to 500 ft deep. The entire ground loop is filled with a antifreeze solution, typically a water + 15% propylene glycol mixture, which circulates through both the building and ground loops. For energy efficiency, the circulating pump should be variable speed.

The length of the borehole heat exchanger system is a function mainly of the building thermal loads profile and the thermal properties of the ground. In systems of the size that would be anticipated at the Medical Center, it is recommended that an in-situ thermal conductivity test be done to determine these thermal properties to aid in a proper design of the borehole network.

The average underground earth temperature strongly impacts the length of the borehole heat exchanger. Because of this sensitivity, and the fact that the average underground temperature could be as high as 80°F, we used a software program (*GlhePro*) to size the closed ground loop at various average underground earth temperatures, ranging from 55 to 80°F. The smallest total closed-loop borehole length of 5,300 ft was calculated at an average underground temperature of 70°F. At an average underground temperature of 55°F, the total closed-loop borehole length increases to about 9,800 ft, and at an average underground temperature of 80°F, the total closed-loop borehole length increases to about 8,900 ft. The reason for such varied lengths is that the building is heating-dominated and thus, the warmer the earth temperature is, the less loop is required, up to a ground temperature where cooling load becomes important and begins to dominate the required loop length.

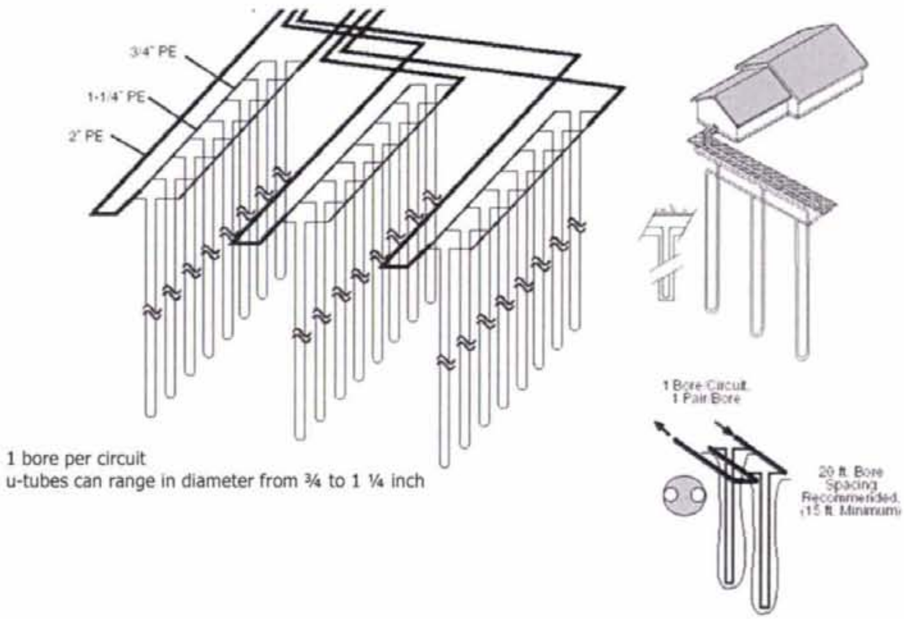

Figure 7. *Conceptual diagram of a closed-loop geothermal heat pump system.*

Closed-Loop System Economics

First, it should be noted that there are different cost scales for well drilling versus closed-loop installation drilling. The main reason is that closed-loop installers rely on economies of scale, and thus charge less per foot of drilling. For estimating purposes, we assumed that a closed-loop system in granite could be installed for $12/ft (as opposed to $50/ft for water wells), and that the average underground earth temperature is 65°F. The cost of $12/ft includes all underground work. The economic analysis included consideration of initial costs, annual costs, and periodic costs. The initial costs included engineering design fees and a thermal conductivity test, heat pump and associated equipment and installation costs (roughly estimated by an HVAC technician), and geothermal installation costs. Annual cash flows included incremental O&M costs and annual energy savings. Energy use in the closed-loop geothermal heat pump system included heat pump and circulating pump electricity consumption. Periodic cash flows included estimates of repair costs. Details of the estimated costs are shown in Table 2. An annual energy cost escalation rate of 2% was assumed.

Based on the cost assumptions shown in Table 2, **the simple payback on a closed-loop geothermal heat pump system is 14.9 years.**

A sensitivity analysis of the simple payback period was conducted on the major cost items, including the drilling cost, the equipment cost, the annual heating energy savings, and the annual cooling energy savings. In addition, a sensitivity analysis of average underground earth temperature on the simple payback period was conducted. The results of the sensitivity analysis are shown in Figures 8 and 9.

Figure 8 is a contour map of the simple payback period as a function of closed-loop installation cost (per foot of vertical borehole) and the average underground earth temperature. A review of Figure 8 shows that the shortest simple payback would be achieved if the average underground temperature was found to be 70°F. The shortest payback period would be 11 to 12 years in this case if drilling and loop installation could be completed for as low as $8/ft of vertical borehole. At the "base case" cost assumption of $12/ft of vertical borehole, the simple payback period would increase to 19 years if the average underground temperature were only 55°F.

Figure 9 shows the sensitivity of the simple payback period to other parameters. The percent change in each cost item is shown on the *x-axis*, and the simple payback is shown on the *y-axis*. From the slope of the lines, it is evident that the most important item impacting the payback period is the annual heating energy savings. A 20% increase in the heating energy savings decreases the payback period to about 12.7 years, while a 20% decrease in the savings increases the payback to 18.0 years. The simple payback period is next most sensitive to the drilling cost, and then to the equipment cost. A 20% change in the drilling affects the simple payback period by about 1.3 years, while a 20% change in the equipment cost affects the simple payback period by about 1 year.

TABLE 2
Cost Estimate Details for a Closed-Loop Geothermal Heat Pump System

	Unit	Quantity	Unit Cost	Amount	TOTALS	Comments
INITIAL COSTS						
Design						
Thermal conductivity test	lump	1	$5,000	$5,000		
Site visit for retrofit analysis	hr	12	$100	$1,200		
Engineering design and bidding	hr	40	$100	$4,000		
Construction oversight	hr	25	$50	$1,250		
				$11,450		
Equipment & Installation						
Heat pumps + controls	kW	92	$300	$27,587		
Well pumps + controls	kW	0	$750	$0		
Circulating pumps	kW	1.46	$824	$1,207		
Circulating fluid	m^3	0.8	$3,000	$2,354		
Plate heat exchangers	kW	0	$12.50	$0		
Trenching and backfilling	m	0	$6.00	$0		- included in drilling costs
Drilling, u-tube install, grouting	m	1935	$39.37	$76,200		
Fittings and valves	kW	92	$14	$1,287		
Internal piping & insulation	kW	92	$40	$3,678		
Well flow testing	lump	0	$1,500	$0		
Retrofit demo/installation	hr	240	$50	$12,000		
				$124,313		
					$135,763	
ANNUAL COSTS						
Energy use				$8,074		
Incremental O & M				$500		
					$8,574	
PERIODIC COSTS	Years					
Outdoor condenser replacement	12			-$5,000		- enter savings as negative
Heat pump compressor repair	15			$0		-Assume condenser repairs are
TOTAL						off-setting with conventional

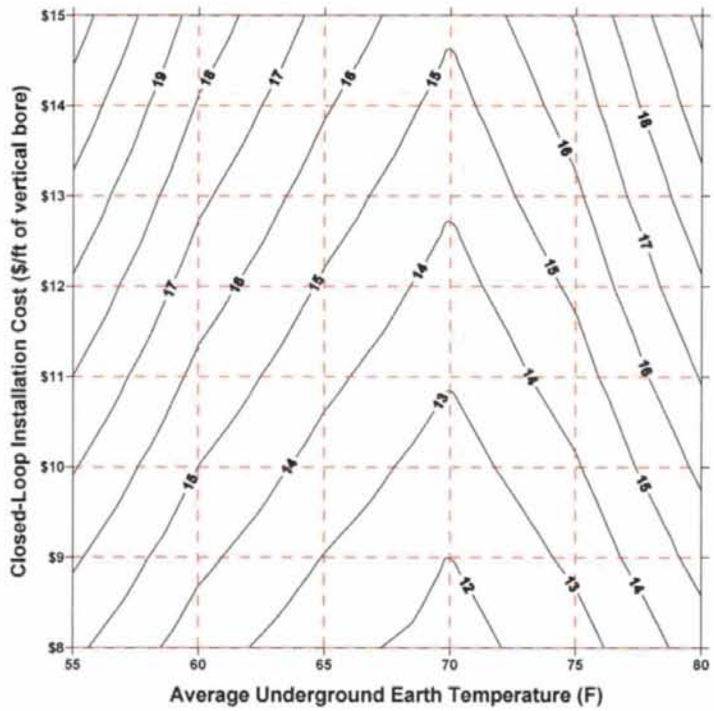

Figure 8. *Contour map of simple payback period (in years) as a function of average underground temperature and closed-loop installation cost in $ per foot of vertical borehole. Note that this cost per foot includes all underground work.*

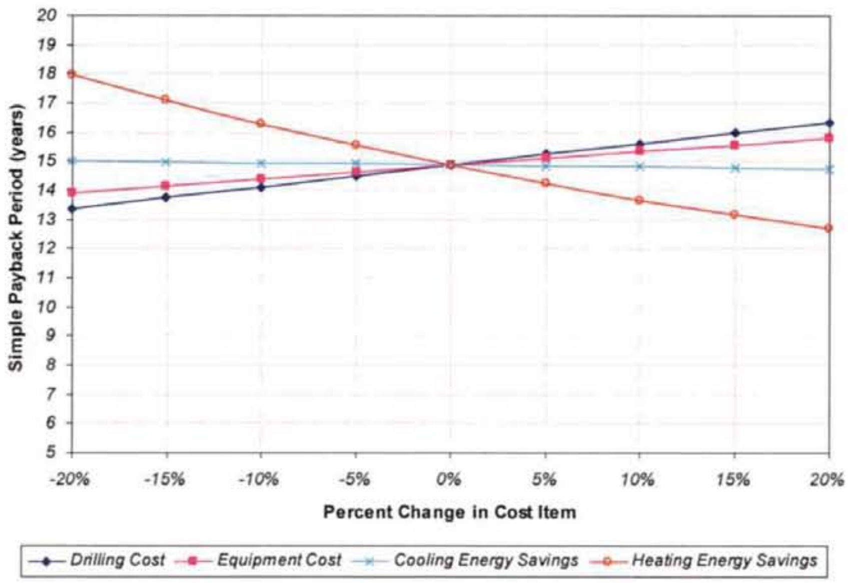

Figure 9. *Sensitivity analysis of major cost items of a closed-loop heat pump geothermal system.*

CONCLUSIONS AND RECOMMENDATIONS

This preliminary feasibility assessment of retrofitting the HVAC system at the Cascade Medical Center included an estimate of monthly total and peak heating and cooling loads, and a simple payback analysis of open- and closed-loop geothermal heat pump system options.

From the heating and cooling loads analysis, we suggest sizing the replacement heat pumps for the cooling load, and re-using stages of the existing heating elements in a supplemental capacity. It is estimated that a geothermal heat pump system of this design could meet about 82% of the total annual heating load and 100% of the cooling load. Split heat pumps could be retrofitted into existing ductwork, allowing re-use of existing air handlers. Existing console air-source heat pump units in the hospital rooms could be swapped out for water-source units and tied into the building loop.

Based on a number of assumptions, the open-loop option has a simple payback period of about 12.8 years, while the closed-loop option has a simple payback period of about 14.9 years. The initial project cost is estimated to be on the order of $110,000 for an open-loop system, and on the order of $136,000 for a closed-loop system. Sensitivity analyses on both the open- and closed-loop systems show that a variation in equipment or drilling costs of 20% alters the simple payback period by about 1 to 1.3 years. The payback period on the closed-loop system is strongly dependent on the average underground earth temperature ultimately encountered. The underground earth temperature yielding the minimum closed-loop length (and therefore the shortest payback period) was found to be 70°F.

So, what's next? It appears that either an open- or closed loop geothermal heat pump system is a viable HVAC system replacement if the hospital is willing to accept a payback period on the order of 12 to 15 years. An open-loop system would be less intrusive to the site. A more detailed study could be done, but to make a more informed decision, it is recommended that a test hole be planned for 500 ft depth. This will give an indication of the local drilling costs, and will give necessary and valuable information on the site geology and underground earth temperature. If groundwater of adequate flow rate and chemical quality is encountered before this depth, the hole could be terminated and an open-loop system would likely be the more logical choice. If at 500 ft depth no groundwater has been encountered, a closed-loop system would likely emerge as the more logical choice. The test hole could then be completed with a 1¼-inch U-tube and a thermal conductivity test done.