

Abstract

Direct use geothermal heating systems commonly utilize warm water in single-pass heating applications because they are relatively inexpensive to build and easy to implement. This project looked for opportunities to improve energy utilization and water conservation by comparing an existing small scale district heating system to a theoretical semi-recirculation design.

The heating performance and water use of a commercial 40,000 ft² building containing 20 fan-coil heating units was evaluated. Entering and exiting water temperatures and flow rates were examined at various locations.

A 6°F temperature differential reveals the current single-pass system utilizes 120,168 Btu/h of the estimated 398,640 Btu/h sensible heat capacity from the constant 40 gpm of warm water necessary to concurrently supply all the fan-coil units. Only 30% of the stored thermal energy from the water volume discharged is used. 86% of the geothermal water's original 112°F heating potential remains in the discharge water.

At a 50% recycle ratio the mixed water temperature would stabilize at 98.3°F, which is a 31% decrease from the maximum heating capacity of the source water and could still provide 274,480 Btu/h of heat, a 56% increase over what the system currently uses. Recycling the discharge water back into the heating loop at this ratio would save 28,800 gallons per day or 2.65 acre-feet per month.

Single-pass geothermal heating systems lack the ability to adjust water usage based on varying heating demands and with a relatively simple design change could substantially reduce water consumption without impacting the system's ability to heat the building.

Introduction

Direct use geothermal heating systems utilize warm water from deep wells to heat commercial and residential buildings. The water is directed through various heat exchange devices to extract the stored energy from this valuable resource. Geothermal heat sources can be an inexpensive and clean alternative to burning fossil fuels.

Single-pass geothermal heating systems are relatively easy to build and implement, but rarely utilize the heat resource to its full potential. Large quantities of warm water are necessary to supply fan-coil heat exchangers with enough energy to facilitate the heat transfer from the water to the atmosphere of the building. The discharged water contains a fair amount of useable heat when exiting the system because of efficiency limits of the fan-coil units, challenges balancing water flow to all the units, and not all heating units will require warm water at the same time.

This project will study a local 40,000 ft² commercial building heated by a warm (112°F) geothermal well since the late 1960's. When originally constructed, the designers directed the warm water through galvanized steel pipe imbedded in the concrete floor. The radiant floor system was relatively efficient, extracting anywhere from 20-35°F of heat energy from the water into the building while discharging a comparatively small quantity of water into a ditch. The water eventually soaked into the ground, evaporated or discharged into the Rio Grande River. Over time the galvanized plumbing corroded and ruptured necessitating the conversion to an overhead fan-coil based design.

This project will look for evidence of opportunities to improve energy utilization and water conservation by comparing an existing small scale district heating system to a semi-recirculation design.

Problem

The significant amount of discharge water required for a single pass geothermal heating system to function properly still contains a considerable quantity of usable heat and is difficult to dispose of.

Engineering Goals

The goal of this project is to compare the heat extraction performance and water consumption of single-pass geothermal heating systems to a theoretical semi-recirculation system.

Hypothesis

A semi-recirculation geothermal warm water heating system will improve upon single-pass systems by maximizing heat extraction from the water while minimizing the amount of water discharged.

Materials List

- Fluke 561 infrared thermometer with model 80PK-11 Velcro pipe temperature probe
- Ashcroft Analogue Dial Thermometer (installed in heating system)
- GPI Model TM150-N flow meter (installed in heating system)
- McQuay Air Conditioning Catalog 720-2, for Seasonmaker Thinline Fan-Coil Units
- Texas Instruments TI-84 Plus scientific calculator
- Microsoft Excel software
- Measuring tape
- Ladder

Procedure

1. Assess existing single-pass warm water geothermal heating system
 - a. Record temperature differential at the supply and discharge, flow rates, and pressure
 - b. Evaluate heat load characteristics of entire building
2. Evaluate heating performance of a sample fan-coil unit
3. Create general mathematical assessment describing heating characteristics and water usage of current single-pass system
4. Evaluate a theoretical semi-recirculation system model
 - a. Estimate the potential improvement in heat extraction and discharge rates
5. Develop cost / benefit comparison of various improvement options

Discussion

Main Building Assessment

A survey of the existing geothermal heating system was conducted mid-January 2009 when the heating requirements of the building were relatively high.

- Water enters building heating system at 112°F
- Water exits building heating system at 106°F
- Average 40 gallons per minute (gpm) flowing through entire system
- Outside air temperature, Min -6°F, Max 28°F, average 11°F

Only a 6°F decrease in water temperature was observed after the water passed through the entire heating system once before being discharged from the building. The following equation calculates the amount of heat transferred from the geothermal water into the building and is expressed as British thermal units per hour (Btu/h).

$$\text{Heat Transferred (Btu/h)} = \text{Mass (lbs/hr)} * \text{Specific heat capacity of water (Btu/lbs } ^\circ\text{F)} * \text{Temperature change } (\Delta T \text{ } ^\circ\text{F)} T_{out} - T_{in}$$

Water flowing at a rate of 1 gpm has a mass of 500.7 lbs each hour; therefore 40 gpm is equal to 20,028 lbs/hr. The specific heat of water (constant) is equal to 1 Btu/lb °F. At a temperature differential (ΔT) of 6°F, the total amount of heat energy released into the building from the geothermal water is:

$$120,168 \text{ Btu/h} = 20,028 \text{ lbs/hr} * 1 \text{ Btu/lb } ^\circ\text{F} * (106 \text{ } ^\circ\text{F} - 112 \text{ } ^\circ\text{F})$$

To maintain a comfortable working environment within any structure the amount of input heat must offset the rate at which the building loses heat. An estimate known as the design-heating load represents the rate a building loses heat during minimum outdoor temperature. Many variables are taken into account when determining this value, some examples are:

Table 1 – Examples of building heat loss and heat gain

Sources for Heat Loss	Sources for Heat Gain
Windows, Doors, and Skylights	Human Activity
Outside Wall Area	Lights
Outside Air Infiltration	Machines
Un-insulated Foundation	Computers
Construction Type (Brick, Metal, Wood, etc.)	Electrical Equipment

Based on estimates from various sources anywhere from 5 Btu/h to 25 Btu/h per square foot is required to comfortably heat a commercial building in the Colorado climate. This is dependent on many factors including those mentioned in *Table 1* and is unique to every building. The building in this study is 40,000 ft² therefore:

Table 2 – Heating demand verses current energy supplied comparison for 40,000 ft² building

Btu/ft²	Estimated Total Heat Energy Required (Btu/h)	Energy Supplied by Warm Geothermal Water (Btu/h)	Estimated Energy Deficit (Btu/h)
5	200,000	120,168	79,832
10	400,000	120,168	279,832
15	600,000	120,168	479,832
20	800,000	120,168	679,832
25	1,000,000	120,168	879,832

Historically this building has struggled to meet the heat demand on the coldest winter days, but a majority of the time it is able to maintain a comfortable working environment. The only logical explanation is the current heating system is heavily supplemented by human activity and heat producing devices that counter the estimated energy deficit. (See *Table 2*)

Fan-Coil Units

20 fan-coil heat exchange units of differing makes and models are distributed throughout the various sized retail spaces within the building. Each unit consists of a fan that blows ambient air across a fin-tube heat exchange assembly warmed by the geothermal water flowing through it. 40 gallons of water flow through the entire system every minute. At this stage of the analysis we will estimate that each fan-coil unit continually receives an average of 2 gpm of warm water.

The McQuay TSC081 fan-coil is the most common unit in the building. From the manufacturer’s specifications of this model it is possible to determine the Btu/h output at any water flow rate and water to air temperature differential. Using the data from a single unit we estimate from *Table 3* that:

Table 3 – Heating capacity estimate of sample fan-coil unit

McQuay TSC081 Fan-Coil Heat Output Heater Fan Setting – High		Entering Air	68°F
		Entering Water	112°F
		Temp Differential (ΔT)	44°F
Flow Rate			
Volume Flow (gpm)	Velocity (ft/sec)	Base Rating	Sensible Heating Capacity (Btu/h)
0.5	0.817	216	9,504
1	1.634	334	14,696
1.5	2.451	357	15,708
2	3.268	453	19,932
3	4.902	513	22,572
4	6.536	539	23,716
5	8.170	565	24,860
6	9.084	584	25,696
7	11.438	593	26,092

- *Sensible Heating Capacity (Btu/h) = Base Rating * (Entering Water – Entering Air)*

Table 3 shows a theoretical working scenario where 112°F water from the geothermal well is flowing at 2 gpm through the fan-coil unit, entering ambient air temperature of 68°F, and the fan speed on high. Given these parameters 19,932 Btu/h will be transferred from the water into the building from one unit. If all 20 fan-coils in the building were operating under identical conditions at the same time, there could be a maximum of 398,640 Btu/h extracted from the water. In reality, not every unit will have the same heating demands at the same time because they individually respond thermostatically to the heat requirements of the room the unit is located in; the demand will be different based on variables such as room size, number of occupants, occupant activity level, lights, machinery, sunlight infiltration, etc. This is apparent in the difference between the maximum heat extraction potential (398,640 Btu/h) and the actual heat utilization (120,168 Btu/h); leaving an unused heat potential of 278,472 Btu/h from the discharge water, a net energy waste of 70%.

Evaluating Sample Fan-Coil Unit Performance

Two easily accessible fan-coil units located in different areas of the building were tested. The water temperature was measured using a thermocouple contact probe on the copper water supply and return piping, and an infrared thermometer measured the ambient air temperature in the room. Since a water flow-meter is not available at each fan-coil unit, the 2 gpm water flow estimated from the main building assessment will be used to predict the Btu/h output of each unit.

Refer to *Table 4* for results.

Table 4 – Water and ambient air temperature observations of sample fan-coil units

	Water In (°F)	Water Out (°F)	Water ΔT (°F)	Ambient Air (°F)	Btu/h Output @ 2 gpm
Heater 1	102	93	9	65	16,761
Heater 2	105	92	13	68	16,761

Water Distribution System

Knowing the actual water flow-rate within the fin-tube assembly is critical in determining the true heating performance of each fan-coil unit. The water distribution system within the building does not provide a balanced supply of water to every unit because of different pipe dimensions and materials, lengths, fittings, joints, valves, elevation changes, and distance from the pumping source.

Given the ambient air temperature, water temperature entering and exiting the fin-tube assembly, and correlating with the sensible heating capacity chart from the fan-coil manufacturer, we can estimate the flow rate within a specific unit. *Table 5* describes the relationship between water flow rate, sensible heating capacity, and the change in exiting water temperature of Heater 2.

Table 5 – Relationship between water flow rate and exiting water temperature of Heater 2

Observed Water Temp In (°F) = 105		Observed Water Temp Out (°F) = 92			
Volume Flow (gpm)	Flow Rate (fps)	Water Mass (lb/h)	Sensible Heat (Btu/h)	Predicted Water Temp Out (°F)	Change in Water Temp - ΔT (°F)
0.5	0.82	250.4	7,992	73	32
1	1.63	500.7	12,358	80	25
1.5	2.45	751.1	13,209	87	18
2	3.27	1001.4	16,761	88	17
3	4.90	1502.1	18,981	92	13
4	6.54	2002.8	19,943	95	10
5	8.17	2503.5	20,905	97	8
6	9.80	3004.2	21,608	98	7
7	11.44	3504.9	21,941	99	6

(Specific Heat of Water (Btu/lb °F) = 1

- $$\text{Water Temp Out (°F)} = (-\text{Sensible Heat (Btu/h)} / \text{Specific Heat of Water (Btu/lb °F)} * \text{Water Mass (lb/h)}) + \text{Water Temp In (°F)}$$

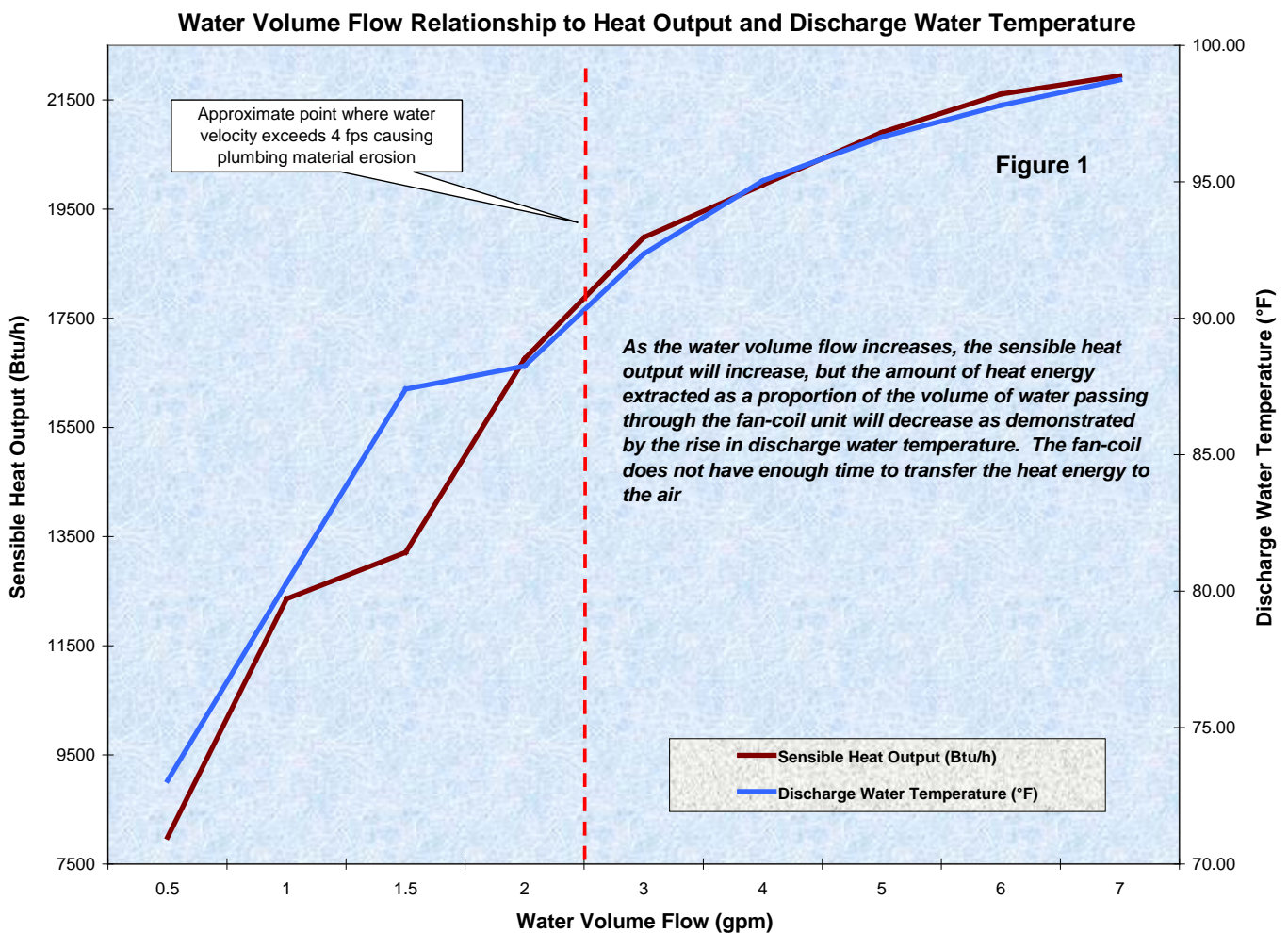
Example:

- $$92°F = (-18,981 \text{ Btu/h} / 1 \text{ Btu/lb °F} * 1,502.1 \text{ lb/h}) + 105°F$$

Table 5 shows that the observed 92°F water discharge temperature correlates with 3 gpm volume flow. Obviously the estimated 2 gpm average is too low for this unit and the information strongly suggests that the flow in the entire system is not balanced. Furthermore, the data indicates that the flow velocity is approximately 4.90 feet per second within Heater 2. This information is important for two reasons:

- If one fan-coil unit is receiving more than its optimal proportion of the 40 gpm volume flowing through the entire system, then other units will lack their share of the available water
- The calculated flow rate exceeds the recommended maximum velocity of 4 fps that can cause plumbing materials to erode, decreasing the lifespan of the heating unit.

Figure 1 shows that as the water volume flow increases, the sensible heat output will increase but the amount of heat energy extracted as a proportion of the volume of water passing through the fan-coil unit will decrease as demonstrated by the rise in discharge water temperature.



Evidence Supporting Semi-Recirculation Design

It is apparent that the current direct use single-pass heating system is not taking full advantage of the available heat source and is discharging a significant amount of valuable water.

- Only a 6°F water temperature differential is occurring after one pass through the entire building's heating system.
- The stored thermal energy from 70% of the total volume of water discharged is not being used
- The system can not adapt to changes in heat demand because 40 gpm of warm water is always required to keep the system full regardless of the heating requirements of the various areas in the building
- Unbalanced flow rates at the fan-coils affect their ability to efficiently extract the available heat energy and potentially impacts the units' longevity

Table 6 shows the sensible heating capacity of the re-circulated water based on a new entering water temperature after only one pass through the entire heating system. The 106°F water temperature reentering the system after the 1st pass still contains 86% of the sensible heating capacity of the original 112°F supply water.

Table 6 – Heating performance of individual fan-coil unit utilizing re-circulated water

McQuay TSC081 Fan-Coil Heat Output Heater Fan Setting - High			1 st Pass		2 nd Pass	
			Entering Air	68°F	Entering Air	68°F
			Entering Water	112°F	Entering Water	106°F
			ΔT	44°F	ΔT	38°F
Flow Rate			Sensible Heating Capacity (Btu/h)	Sensible Heating Capacity (Btu/h)		
Volume Flow (gal/min)	Velocity (ft/sec)	Base Rating				
0.5	0.817	216	9,504	8,208		
1	1.634	334	14,696	12,692		
1.5	2.451	357	15,708	13,566		
2	3.268	453	19,932	17,214		
3	4.902	513	22,572	19,494		
4	6.536	539	23,716	20,482		
5	8.170	565	24,860	21,470		
6	9.804	584	25,696	22,192		
7	11.438	593	26,092	22,534		

Re-circulating the same water multiple times will decrease the temperature differential between the water and the ambient air to a point that the building occupants will feel cool air blowing from the fan-coil units even though some heat may still be entering the room. These operational limitations are common to all low temperature water heating applications.

Semi-Recirculation Design Evaluation

In a theoretical semi-recirculation heating system, a supply of warm water would continuously circulate within the main building loop to deliver every fan-coil unit with the correct volume flow of warm water at all times. As needed, the individual fan-coil units would extract heat from the circulating water, decreasing the temperature in the return line to a point that a thermally actuated four-way mixing valve would discharge a varying quantity of return water from the main loop, and be replaced with fresh warm water from the geothermal well.

The goal would be to mix the water at a ratio that would maintain a stable system temperature adequate for the fan-coil units to operate efficiently. A constant operational temperature at various recycle ratios was determined using an iterative calculation to estimate starting and return water temperature, mixed water temperature, and sensible heating capacity. The example in *Table 7* shows that at a recycle ratio of 50%, the mixed water temperature would stabilize at 98.3°F, which is a 31% decrease from the maximum 112°F heating capacity of the source water.

Table 7: Example of stable water temperature of one fan-coil unit at 50% recycle rate

Constants					
Volume Flow (gpm)					2
Percent Water from Well					50%
Percent Re-Circulated Water					50%
Mass of Water (lb/h)					1001.4
Source Water Temperature (°F)					112
Fan-Coil Base Rate (from manufacturer reference)					453
Ambient Air Temp (°F)					68
Iteration Cycle	Starting Water Temperature (°F)	Mixed Water Temperature (°F)	Air / Water ΔT (°F)	Sensible Heating Capacity (Btu/h)	Returning Water Temp (°F)
1	112	112.0	44	19932	92.1
2	92	102.0	34	15424	86.6
3	87	99.3	31	14189	85.2
4	85	98.6	31	13851	84.7
5	85	98.4	30	13759	84.6
6	85	98.3	30	13733	84.6
7	85	98.3	30	13726	84.6
8	85	98.3	30	13725	84.6
9	85	98.3	30	13724	84.6
10	85	98.3	30	13724	84.6
11	85	98.3	30	13724	84.6
12	85	98.3	30	13724	84.6
13	85	98.3	30	13724	84.6
14	85	98.3	30	13724	84.6

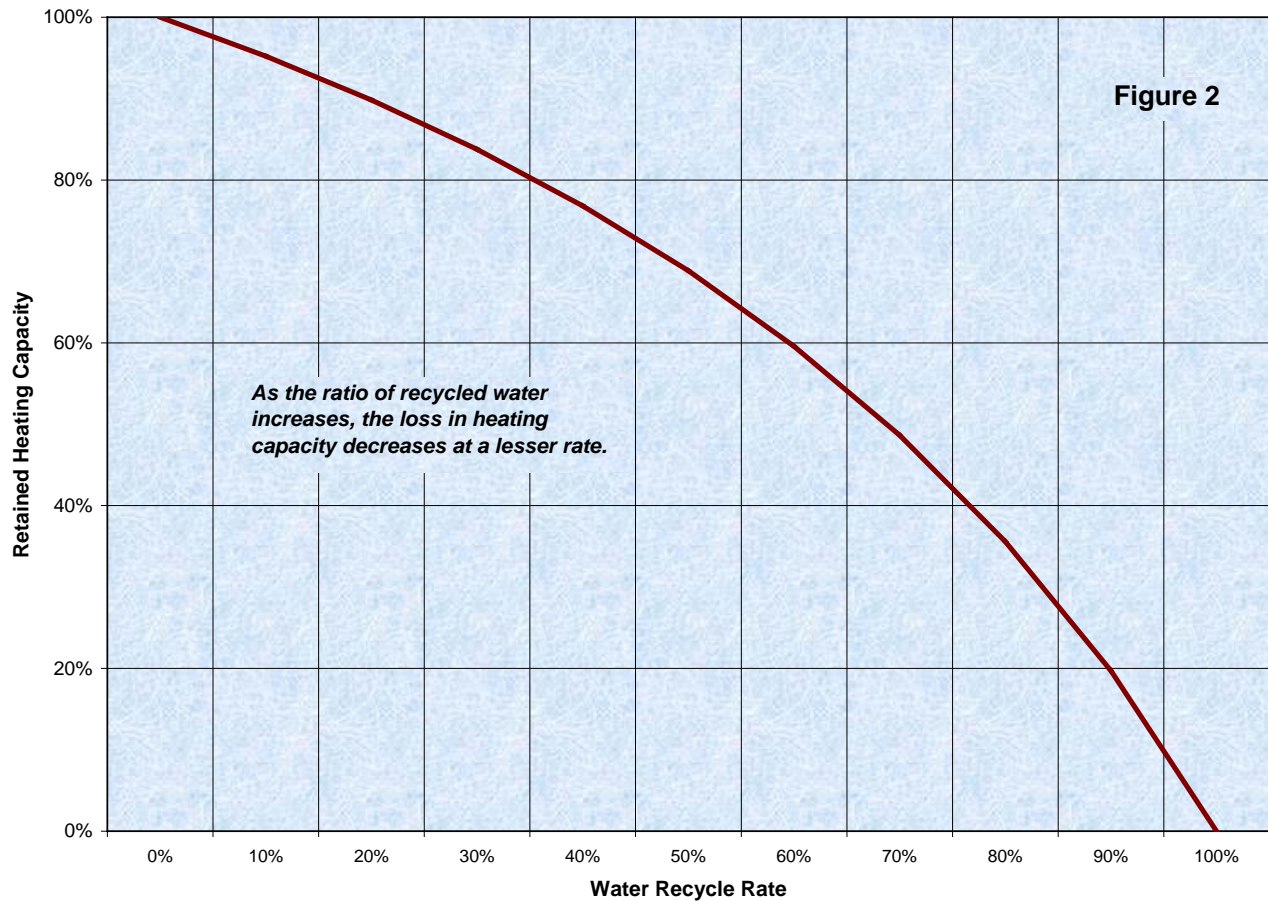
This example describes the performance of only one fan-coil unit. The maximum heating capacity for the entire system at various mixing ratios must be determined to verify if enough heat energy is available to recycle the water. *Table 8* shows the total heating capacity of the entire system at various mixing ratios if all 20 fan-coil units were operating under similar conditions at the same time.

Table 8 – Mixed water temperature and heating capacity at various recycle ratios

Water Recycled gpm	Water Recycled %	Mixed Water Temperature (°F)	Sensible Heating Capacity (Btu/h)	Returning Water Temperature (°F)	Heating Capacity Retained	Heating Capacity Loss
0	0%	112.0	398,640	92.1	100%	0%
4	10%	109.9	379,560	90.9	95%	5%
8	20%	107.5	358,140	89.6	90%	10%
12	30%	104.9	333,900	88.2	84%	16%
16	40%	101.8	306,280	86.5	77%	23%
20	50%	98.3	274,480	84.6	69%	31%
24	60%	94.2	237,500	82.4	60%	40%
28	70%	89.4	193,940	79.7	49%	51%
32	80%	83.7	141,900	76.6	36%	64%
36	90%	76.7	78,600	72.8	20%	80%
40	100%	68.0	0	68.0	0%	100%

At a 50% recycle ratio, the mixed water temperature would provide 274,480 Btu/h of heat which is a 56% increase over what the system is currently using. In Figure 2 it is noticeable that as the ratio of recycled water increases, the loss in heating capacity decreases at a lesser rate.

Retained Heating Capacity at Various Water Recycle Rates



Water Conservation

In reality it would be unlikely that all 20 fan-coil units would be operational at the same time. Because of this, the actual energy extraction dynamics of the system as a whole would favor higher water conservation rates because the system would adapt to the actual changing needs of the building throughout the day. Additionally, the operational temperature set point could be adjusted based on seasonal variations, potentially increasing water savings further.

Table 9 illustrates the substantial water savings possible by utilizing a semi re-circulation design.

Table 9 – Water usage and potential savings at various discharge rates

Fill Rate (gpm)	Circulation Rate (gpm)	Discharge Rate (gpm)	Gallons Used per Day	Water Savings	Gallons Saved per Day	Acre Feet Save per Month
40	40	40	57,600	0%	0	0
30	40	30	43,200	25%	14,400	1.33
20	40	20	28,800	50%	28,800	2.65
10	40	10	14,400	75%	43,200	3.98
0	40	0	0	100%	57,600	5.30

Cost / Benefit Analysis

The Main Building Assessment shows the entire heating system is only extracting 120,168 Btu/h of heat energy from the geothermal source at any given point in time. Historically this appears to be a minimally adequate supply of heat energy. The design heating recommendation for this building is actually 400,000 Btu/h. The estimated cost to purchase the equivalent heating energy from the local utility is shown in *Table 10*:

Table 10 – Estimated cost of equivalent energy commodities

	Btu/h Rate	Natural Gas (per month)	Electricity (per month)
Observed	120,168	\$371.04	\$720.62
Maximum	400,000	\$1,190.14	\$2,331.78

At this point many options are available to improve the energy extraction and water conservation of the current system. Table 11 outlines those options:

Table 11 – Current system improvement options

Option	Estimated Cost	Benefit	Disadvantage
Do Nothing	\$0	No expenditure	Continue to struggle with poor heat distribution in building and excessive discharge water
Balance Water Flow	\$3,490	Improved warm water distribution to all heat units. Reduced erosion of plumbing system. Increase occupant comfort	Cost
Semi-Recirculation System	\$3,400	Conserve water and reduce discharge	Cost
Convert to Natural Gas System	\$10,000	Closed system, no discharge water to manage	High annual expense to operate. Must still balance flow and construct re-circulation system
Ground Re-injection System	\$70,000	Discharge water is returned to aquifer	Extremely expensive to develop. Water must be treated. Complicated regulations and expensive system monitoring

Conclusion

Compelling evidence suggests that a semi-recirculation system would improve upon the heat extraction characteristics of direct use single-pass heating systems and reduce the discharge water issue.

Key points learned from this study:

- A 6°F temperature differential reveals the current single-pass system utilizes 120,168 Btu/h of the estimated 398,640 Btu/h sensible heat capacity from the constant 40 gpm of warm water necessary to concurrently supply all the fan-coil units.
- Only 30% of the stored thermal energy from the water volume discharged is used.
- 86% of the geothermal water's original 112°F heating potential remains in the discharge water
- At a 50% recycle ratio the mixed water temperature would stabilize at 98.3°F, which is a 31% decrease from the maximum heating capacity of the source water and could still provide 274,480 Btu/h of heat, a 56% increase over what the system currently uses.
- Recycling the discharge water back into the heating loop at this ratio would save 28,800 gallons per day or 2.65 acre-feet per month.
- A semi-recirculation heating system has the ability to adjust water usage based on varying heating demands
- Converting from a single-pass to a semi-recirculation system would be a relatively simple design change that could substantially reduce water consumption without impacting the system's ability to heat the building.

Water conservation in semi-arid climates must be a top priority when utilizing this valuable resource, even when considering the economic and environmental advantages of geothermal heat sources over burning fossil fuels.

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Works Cited

Primary Sources

Burt, Eric. Personal interview. 6 Dec 2008.
Owner, Kristi Mountain Sports (Villa Mall Tennant)

Haverfield, Alan. Personal interview. 8 Dec 2008.
Owner, Haverfield Plumbing

Haverfield, Alan. Personal interview. 25 Mar 2009.
Owner, Haverfield Plumbing

Lewis, Darrell. Personal interview. 2 Apr 2009.
Designer, Public Service Company of Colorado

Owens, Bob. Telephone interview. 27 Feb 2009.
Owner, Villa Mall

Skinner, John. Personal interview. 17 Mar 2009.
Well Commissioner, Colorado Division of Water Resources

Sveum, Larry. Personal interview. 22 Mar 2009.
Retired Chemistry Professor

Thompson, Kirk. Personal Interview. 16 Dec 2008.
Professional Engineer, Agro Engineering

van de Boogaard, Erik. Personal interview. 20 Mar 2009.
Associate V.P. for Facilities Planning Design and Construction, Adams State College

Secondary Sources

"Advanced Hydronics, Inc." Geo-Exchange. 13 January 2009
<<http://advancedhydronics.com/geoexchange.htm>>.

"BTU Calculator." HearthNet. 10 Mar 2009 <<http://www.hearth.com/calc/btucalc.html>>.

"Climatological Report (Daily)." National Weather Service. 12 Jan 2009. National Weather Service. 10 Mar 2009 <<http://www.weather.gov/climate/getclimate.php?wfo=pub>>.

"Colorado-Electric." Xcel Energy. 1 Apr 2009. Public Service Company of Colorado. 7 Apr 2009 <http://www.xcelenergy.com/SiteCollectionDocuments/docs/psco_elec_entire_tariff.pdf>.

"Colorado-Gas." Xcel Energy. 1 Apr 2009. Public Service Company of Colorado. 5 Apr 2009 <http://www.xcelenergy.com/SiteCollectionDocuments/docs/psco_gas_entire_tariff.pdf>.

Danielson, Jeris A.. State of Colorado. Division of Water Resources: Office of the State Engineer. Geothermal

Well Rules. Denver, CO: 1992.

"Direct Use of Geothermal Energy." Energy Kid's Page. July 2008. Energy Information Administration. 9 Mar 2009 <<http://www.eia.doe.gov/kids/energyfacts/sources/renewable/geothermal.html#Uses>>.

"Geothermal Technologies Program." Aug 2004. U.S. Department of Energy Efficiency and Renewable Energy. 9 Mar 2009 <<http://www.nrel.gov/docs/fy04osti/36316.pdf>>.

"High Performance HVAC." High Performance HVAC Hydronic Piping Systems. 12 January 2009 <<http://highperformancehvac.com/boiler-hot-water-loops.html>>.

"Latent Heat and Sensible Heat." 3D Plumbing. 8 Mar 2009 <http://www.3dplumbing.net/ontplumbing/latent_heat.htm>.

McFadden, D.H.. Historical Use Analysis. Alamosa, CO: 2002.

Seasonmaker Thinline Fan-Coil Units. Catalog 720-2. Minneapolis, MN: McQuay Air Conditioning, 1983.

"Specific Heat Capacity." The Engineering ToolBox. 2005. The Engineering ToolBox. 9 Mar 2009 <http://www.engineeringtoolbox.com/specific-heat-capacity-d_339.html>.

"Units of Heat - BTU, Calorie and Joule." The Engineering ToolBox. 2005. The Engineering ToolBox. 7 Mar 2009 <http://www.engineeringtoolbox.com/heat-units-d_664.html>.

Appendix A – Well Freeflow and Pump Test

		Pump Draw		Well Recovery (Return to Freeflow)	
		Flow Rate (GPM)	Pressure (PSI)	Flow Rate (GPM)	Pressure (PSI)
Freeflow		21.8	10		
Start		45.5	21	50	22.5
Time	30	47.5	23	12.5	8
1	00	49.1	23.5	20.8	7.5
1	30	49.4	24	22.7	7.5
2	00	49.5	23.5	24.1	7
2	30	49.8	23.5	25.0	7.5
3	00	49.5	23.5	25.3	8
3	30	49.7	23	25.7	8
4	00	49.8	23	26.0	8
4	30	50	23	26.1	8
5	00	50	23	26.3	8
5	30	50	23	26.4	8
6	00	50	23	26.4	8
6	30	50	23	26.5	8
7	00	50	23	26.7	8
7	30	50	23	26.8	8
8	00	50	23	26.8	8
8	30	50	23	26.8	8
9	00	50	23	26.4	8
9	30	50	22.5	26.4	8
10	00	50	22.5	26.7	8

Appendix B – Construction Cost Estimates

	Item	Quantity	Cost	Extension
Balancing Flow	Butterfly Balancing Valve	20	\$12	\$240
	Flow Meter	20	\$50-100	\$1,500
	Labor		\$1,750	\$1,750
	Total			\$3,490
Semi Recirculation System	40 gpm Pump	1	\$700	\$700
	2" Tekmar 4-Way Mixing Valve (Brass)	1	\$700	\$700
	Actuating Motor	1	\$500	\$500
	Labor		\$1,500	\$1,500
	Total			\$3,400
Natural Gas Heating System	Hot Water Boiler	1	\$10,000	\$10,000
	Monthly Natural Gas Charge	6	\$500	\$3,000
	Total			\$13,000
Ground Re-injection System	4 " steel cased well	1000	\$40	\$40,000
	Engineering, plumbing, pump, treatment system, annual operations cost	1	\$30,000	\$30,000
	Total			\$70,000

Appendix C - Interviews

Saturday, December 6, 2008 – Owner of Kristi Mountain Sports showed and explained to me how the plumbing in the Villa Mall works. The water is coming from the well into the heating system at around 110 degrees F; it exits the system at approximately 105 degrees F. The flow rate is approximately 47 gallons per minute (with a pump). There is a 4 foot rise and drop of the piping to go over a sky light.

Monday, December 8, 2008 – Had a meeting with Alan Haverfield about geothermal artesian heating systems. We talked about what could be the problem with the current plumbing configuration. An easy fix would be to eliminate the immediate return of the water and have everything run to the end of the building before it is pumped back to the discharge – called a reverse return. This would most likely cause all the heaters to receive warm water. Another possible problem he pointed out is the high mineral concentration of the water; it could be scaling up the inside of the pipes. He talked about closed systems and how running the hot water through the heating units multiple times would increase the amount of heat we would draw out of the water. We talked about if flow rate effects how much heat is transferred into the heating units. If the water is run too slow, by the time it reaches the heaters at the end of the building, the water is too cool. If the flow rate is higher than roughly 4 ft/sec you risk erosion of the pipes.

Tuesday, December 16, 2008 – Met with Kirk Thompson of Agro Engineering and discussed the problems in the Villa Mall. He agreed to help me model the heating system. He instructed me to measure all the pipes length and width. He also thought it would be beneficial to take a temperature reading at the input and output of each of the heating cabinets as well as write down model name/number.

Tuesday, March 17, 2009 – Met with John Skinner of the Division of Water Resources. I learned that it is 40-50 feet to the bottom of the unconfined aquifer. Beneath that is about 500 feet of clay, and beneath that is the artesian or confined aquifer. He gave me a diagram that shows this. I also got information on the artesian wells around the area. Another thing we discussed is re-injecting the water currently being used in the system. If it is used in a system such as the one in place in the Villa Mall you must treat the water before putting it back into the ground. A 4" diameter well would be large enough but the cost would be approximately \$30-45 per foot.

Friday, March 20, 2009 – Met with Erik van de Boogaard, Associate V.P. for Facilities Planning Design & Construction at Adams State College. We discussed a theoretical geothermal heating system that could be used to heat about 20 of the college's buildings. It would tap into the same artesian aquifer that the Villa Mall runs off of but the well could be anywhere from 2,500-5,000 feet deep. They are trying to find 120-140 degree F water. I learned that currently if you want to drill a well into the artesian aquifer it must not change the quality, quantity, or pressure of the water in the aquifer. Meaning it cannot be a direct use system and the water must be re-injected back into the aquifer. You do not have to drill the reinjection well the same depth as the pickup side, just deep enough to get back into the same aquifer.

Wednesday, March 25, 2009 – Met with Alan Haverfield of Haverfield Plumbing. The first thing we talked about were components needed to balance the flow to all heaters. The optimal system would use a globe or butterfly valve and a flow meter at each fan-coil unit. Approximate cost per valve, \$12, flow meter, \$50-100, plus labor (total \$3,000-4,000). Next we discussed the characteristics and costs of a recirculation system. Because the theoretical system would constantly be discharging and refilling with water, a pump has to be used instead of a circulator. He suggested using an automated Tekmar 4-way mixing valve to balance the temperature of the water running through the system. Approximate cost would be \$1200. The valve will automatically blend the water to maintain a desired temperature. To switch to a natural gas heating system it would cost approximately \$10,000 (boiler + piping + labor) plus fuel costs.

Thursday, April 2, 2009 – Met with Darrell Lewis of Xcel Energy. Discussed the heating needs of the Villa Mall if the system ever has to be converted to a natural gas system. In Alamosa the closest building in terms of size and heating requirements is the old K-Mart building. Currently it costs \$1500 monthly to heat it. I learned that 1 therm = 100,000 Btu. 1 therm is approximately \$.67. 1 Kw/h = 34015.18 Btu. He created a formal heating evaluation for the mall and will send it to me tomorrow.

Appendix D - Miscellaneous Notes and Reference Material

* See Following Pages