REHAU MONTANA ECOSMART HOUSE PROJECT
Bozeman, MT
RMEH 01 Test Report

Geothermal Performance of Helix vs. Vertical Borehole


F. Javier Alvarez, LEED GA
Kevin Amende, P.E.
Mechanical and Industrial Engineering Department
Montana State University

5/15/2015

Executive Summary

According to the US Department of Energy, "Geothermal energy is heat derived below the earth's surface which can be harnessed to generate clean, renewable energy. This vital, clean energy resource supplies renewable power around the clock and emits little or no greenhouse gases – all while requiring a small environmental footprint to develop." – www.energy.gov

Geothermal technology has proven itself time and time again, through thousands of installations. Experience has led to great strides in the efficiency and durability of ground source heat pumps, but the ground loop heat exchangers have remained relatively unchanged since the industry's inception.

One innovative ground loop solution utilizes cross-linked polyethylene (PEXa) pipes specifically manufactured and certified for geothermal applications. PEXa pipe provides superior resistance to impact, rock impingement and the stresses of earth movement. For vertical systems using closed-loop pipes encased inside boreholes, the flexibility of PEXa pipe allows a continuous length of pipe to be factory-formed in a tight 180-degree U-bend, creating a continuous loop of piping down the borehole and back. The PEXa double U-bend extracts more energy than the typical vertical loop, while offering a higher degree of security against loop failure.

A further innovation using PEXa tubing is the helical vertical ground loop (the "Helix"), which is inserted into a 18 ft deep hole created by an earth auger, and then backfilled with naturally compacted native soil instead of grout. The typical helix uses 130 ft of 1" PEXa tubing. The tubing is formed into the helix shape in the factory using a special process so that the pipe stays in this configuration, allowing a high volume of pipe to be installed in a relatively compact and inexpensive hole. The helix is attractive for jobsites where space for horizontal trenching is restricted and drilling of boreholes is not possible for geological or financial reasons.

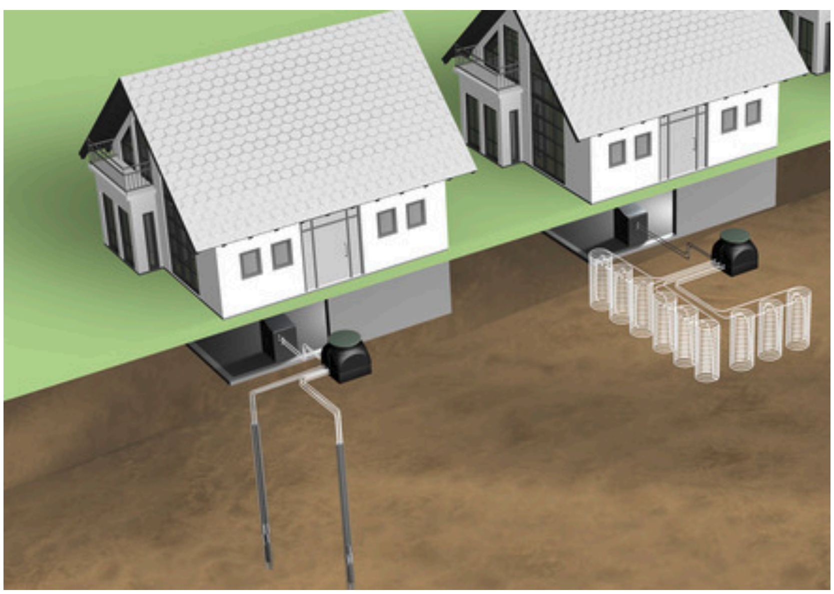

Figure 1. Illustration of PEX double U-bends (left) and helix coils (right)

The REHAU Montana Ecosmart House in Bozeman is a LEED®-certified house with high levels of insulation and low heat loss, resulting in a certified HERS score of just 32. RMEH was constructed using four 300 ft-deep vertical boreholes with 1" PEXa double U-bends and three 1" PEXa helix coils.

Experiment RME01 measured the heat transfer of both the double U-Bends (300 ft deep) and the helix coils (18 ft deep) on the same property with the same conditions, to compare the heat exchange.

The experiment demonstrates that in these soil conditions the approximate equivalency of the helix coils to the double U-Bends is 5:1. In other words, 5 helix coils deliver the equivalent heat exchange as one 300 ft double U-bend.

Experiment Description

The purpose of this experiment was to evaluate the geothermal heat pump performance utilizing the RAUGEO helix and the RAUGEO vertical borehole configurations to demonstrate the relative performance of different installation methods. Two sets of cooling mode tests (trials 1 & 2 – for redundancy) were run during the summer of 2014 and one set of heating mode tests were run during the winter of 2015 (see Appendix B. Experiment Notes for exact dates). Data pertaining geothermal field and heat pump operation were recorded using several DAQ systems. Fairly constant loads and power input were applied to the system so near steady states could be reached. Recommendations published by ASHRAE for performing thermal conductivity tests [7] were followed when possible. The water-to-water ground-source heat pump (GSHP) has two 2.9 ton digital scroll compressors and two plate heat exchangers for hot/chilled water production and geothermal fluid circulation. The geothermal field comprises three 18-feet deep 1" PEXa pipe helical probes and four 300-feet deep 1" PEXa pipe double-U bend vertical boreholes that can be independently isolated through manifolds. Each scenario was run over a minimum of 4 days.

Results

A performance overview of RAUGEO helix and borehole systems can be seen below in Table 1.

Table 1. Performance Analysis

System	Mode	Probe vertical length (ft)(*)	Total pipe (ft)	Heat Rate			
				(Btu/ hr.probe)	(W/ probe)	(Btu/hr.ft-depth)	(Btu/hr.ft-pipe)
Helical Probe (Trial 1)	Cooling	12	131	2158	633	180	16
Helical Probe (Trial 2)		12	131	2519	738	210	19
2-U Vertical Borehole (Trial 1)		300	1200	7465	2188	25	6
2-U Vertical Borehole (Trial 2)		300	1200	14871	4358	50	12
Helical Probe	Heating	12	131	3651	1070	304	28
2-U Vertical Borehole		300	1200	12926	3788	43	11

(*) This refers to the probe length. Total borehole depth is this length plus approximately 6 to 10 feet.

The output performance of the RAUGEO helix in cooling mode was 2158 Btu/hr (633 W) per helix during Trial 1 (Figure 2) and 2519 Btu/hr (738 W) per helix during Trial 2 (Figure 3). Details of the experiment setup can be found in the “Experiment Data Sheet” section. Figure 2 and Figure 3 show a graphical representation of the Entering / Leaving Water Temperature (EWT / LWT), power input to the unit and performance output of the geothermal loops. Note on Figure 3 how the test was run for 168 hrs (7 days) and the temperature on the geothermal field was very stable.

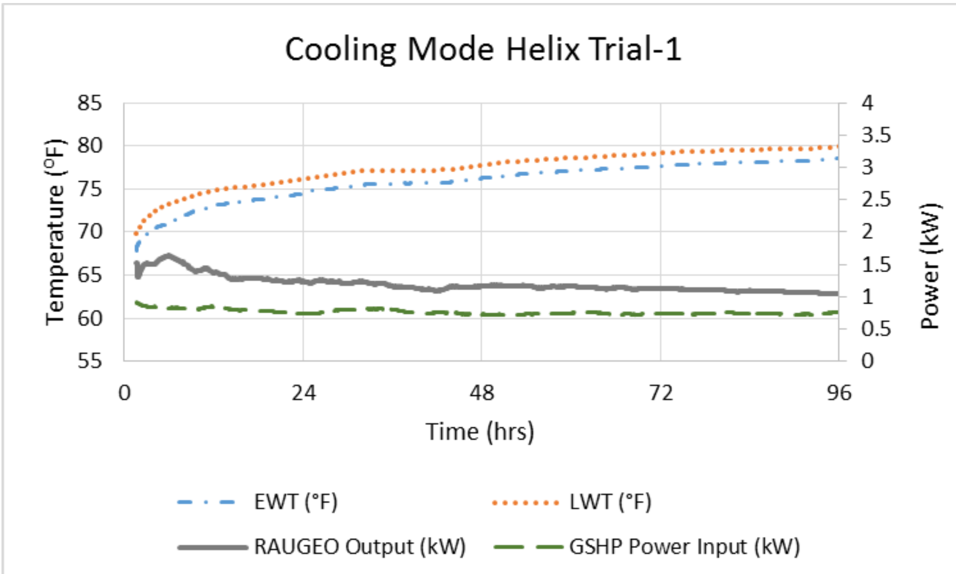

Figure 2. Cooling performance analysis of RAUGEO helix during Trial 1

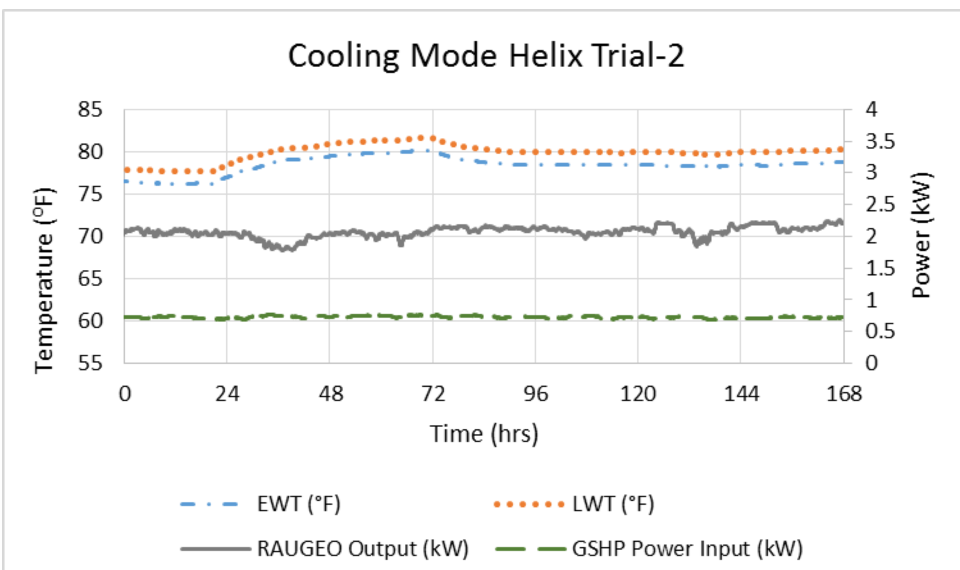

Figure 3. Cooling performance analysis of RAUGEO helix during Trial 2

The output performance of the RAUGEO 2-U bend vertical borehole in cooling mode was 7465 Btu/hr (2188 W) per borehole during Trial 1 (Figure 4) and 14871 Btu/hr (4358 W) during Trial 2 (Figure 5). Details of the experiment setup can be found in the "Experiment Data Sheet" section. Figure 4 and Figure 5 show a graphical representation of the EWT / LWT, power input to the unit and performance output of the geothermal loop. Note the difference in power input from Trial 1 to Trial 2: 1.22 kW vs. 2.32 kW averaged during the last 24 hrs respectively. This was due to different compressor speed setups during the trials.

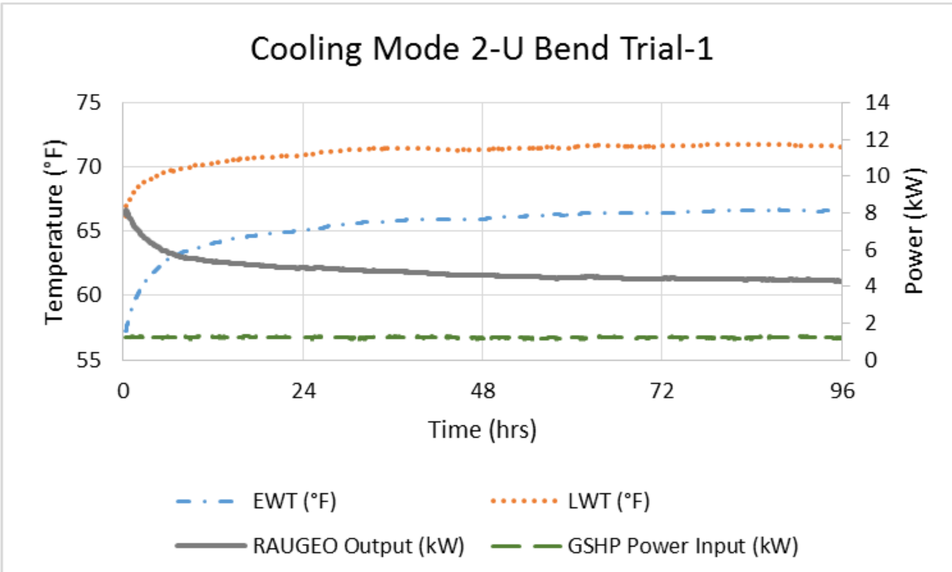

Figure 4. Cooling performance analysis of RAUGEO borehole during Trial 1

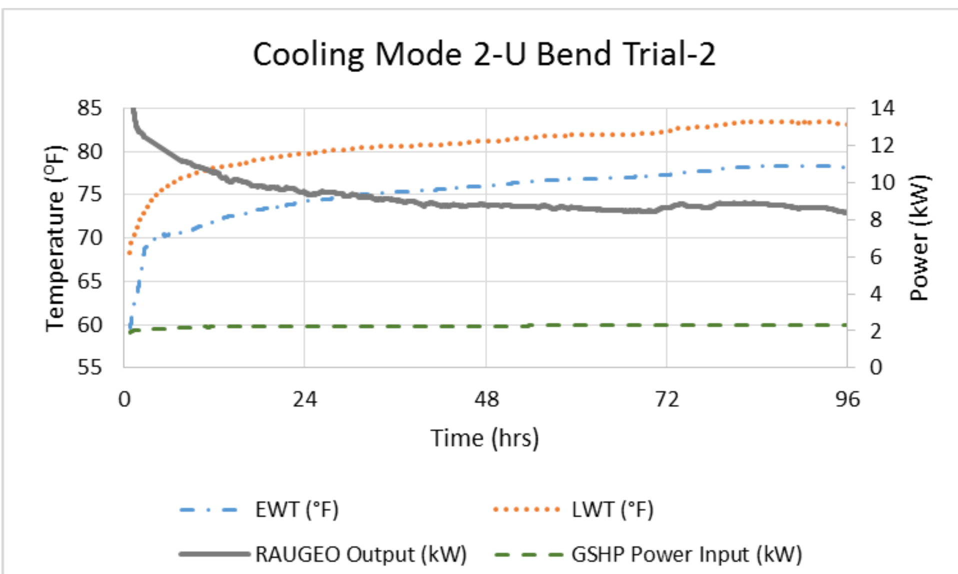

Figure 5. Cooling performance analysis of RAUGEO borehole during Trial 2

The output performance of the RAUGEO helix in heating mode was 3651 Btu/hr (1070 W) per Helix vs. 12926 Btu/hr (3788 W) per RAUGEO vertical 2U-Bend. Details of the experiment setup can be found in the "Experiment Data Sheet" section. Figure 6 and Figure 7 show a graphical representation of the EWT / LWT, power input to the unit and performance output of the geothermal loop.

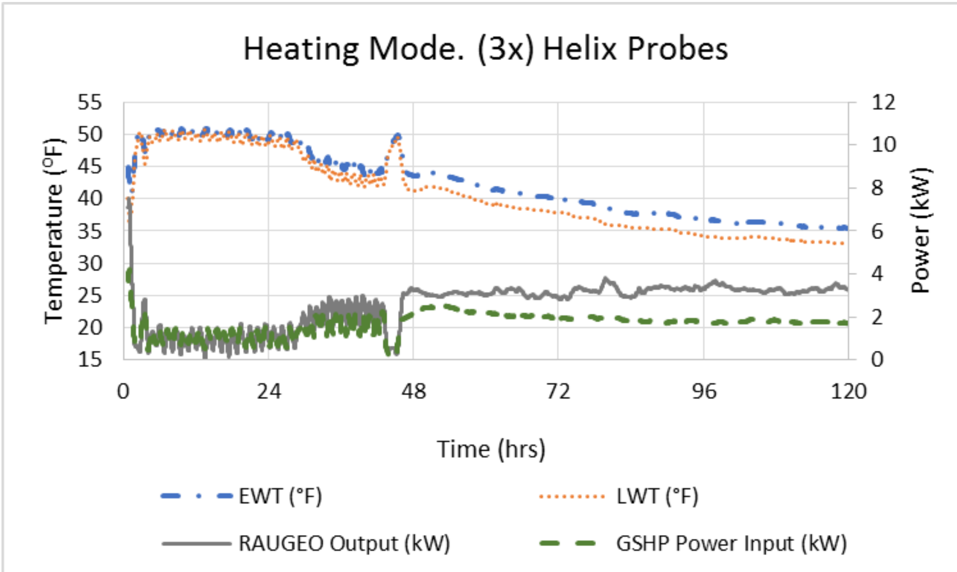

Figure 6. Heating performance analysis of RAUGEO helix

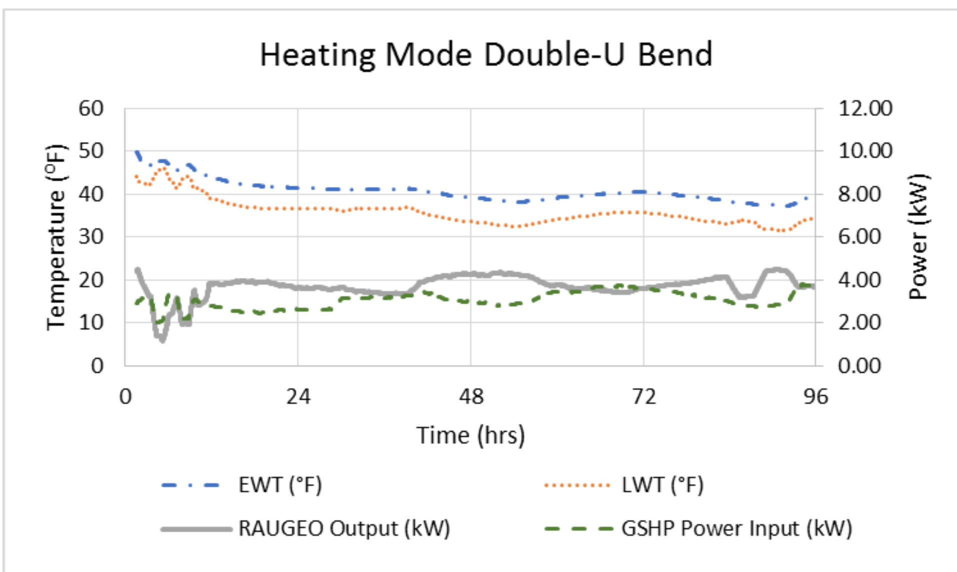

Figure 7. Heating performance analysis of RAUGEO borehole

It appears as if the helical probes performed better in heating mode than in cooling mode; in heating mode they were able to extract 1070 W per probe from the ground under greater power input. However, the ground loop temperatures (EWT/LWT) were already close to 32°F and the trending was still down although stabilizing. It would be reasonable to think that extraction rates around 700-750W/probe could have been achieved seamlessly. In cooling mode, a heat rate of 738W was sustained throughout 168 hours with temperatures on the ground loops consistently around 80°F.

Double U-bend vertical probes were able to dump up to 4358 W per probe into to the ground in cooling mode under a greater power input, but data shows that the trend in ground temperatures was not totally stable and still going up. In heating mode, 3788 W/probe were absorbed by the geo field with temperatures being sustained in the range of 32-38°F (LWT/EWT) and up. It would be safe to assert that a heat rate of 3700W/probe would be sustainable for double U-bend vertical boreholes in this conditions.

Overall, the experiment showed that approximately five (5) helix probes make up for one (1) 2U bend vertical probe. Should one or the other method be more convenient to implement will depend on soil conditions, available space and many other site specific variables. I.e., taking 738 W/helix as an average performance rate, we have:

$$5\ Helix \times 725\ W/Helix = 3625\ W \ \cong 1\ Double\ U\ Bend$$

Experiment Data Sheet

It follows a compendium of relevant experimental conditions for each of the scenarios and trials included in this experiment.

Table 2. Cooling Mode Helix Probe Trial 1 Data Sheet

Name of Trial	***Cooling Mode Helix Probe Trial 1***
Dates and Total Length of Test	*Aug 1 to 5, 2014 (4 days)*
Average Outdoor Air Temperature during Test	*74.7°F*
Ground Undisturbed Temperature	*51°F*
Bore depth / Probe Length	*18 ft / 12 ft*
Pipe Length per Probe	*131 ft*
Borehole Diameter	*18”*
Grouting / Backfilling	*Backfilled with same soil*
Borehole Spacing	*11 ft*
Soil Formation Thermal Conductivity	*1.26 Btu/hr-ft-°F ([1])*
Soil Formation Thermal Diffusivity	*0.89 ft^2/day ([1])*
Number of Probes used in the Test	*3*
Number and Speed of Compressors used	*One Comp. @ 15% capacity*
Time over which following Data was Averaged	*Last 24 hr*
Heat Pump Power Input	*736 W*
Flow Rate of the Geothermal Loop Pump	*9 gal/min*
Average EWT/LWT achieved	*78.1°F / 79.6°F*

([1]) Thermal properties from vertical borehole

Table 3. Cooling Mode Helix Probe Trial 2 Data Sheet

Name of Trial	***Cooling Mode Helix Probe Trial 2***
Dates and Total Length of Test	*Oct 10 to 18, 2014 (8 days)*
Average Outdoor Air Temperature during Test	*51.9°F*
Ground Undisturbed Temperature	*55°F*
Bore depth / Probe Length	*18 ft / 12 ft*
Pipe Length per Probe	*131 ft*
Borehole Diameter	*18"*
Grouting / Backfilling	*Backfilled with native soil*
Borehole Spacing	*11 ft*
Soil Formation Thermal Conductivity	*1.26 Btu/hr-ft-°F ([1])*
Soil Formation Thermal Diffusivity	*0.89 ft^2/day ([1])*
Number of Probes used in the Test	*3*
Number and Speed of Compressors used	*One Comp. @ 15% capacity*
Time over which following Data was Averaged	*Last 168 hr*
Heat Pump Power Input	*684 W*
Flow Rate of the Geothermal Loop Pump	*9.8 gal/min*
Average EWT/LWT achieved	*77.6°F / 79.1°F*

([1]) Thermal properties from vertical borehole

Table 4. Cooling Mode 2-U Bend Vertical Borehole Trial 1 Data Sheet

Name of Trial	***Cooling Mode Vertical Borehole Trial 1***
Dates and Total Length of Test	*Jul 18 to 22, 2014 (4 days)*
Average Outdoor Air Temperature during Test	*77.7°F*
Ground Undisturbed Temperature	*56.4°F*
Bore depth / Probe Length	*306 ft / 300 ft*
Pipe Length per Probe	*1200 ft*
Borehole Diameter	*6.5"*
Grouting / Backfilling	*200 lb sand/50 lb bentonite (0.88 Btu/hr-ft-°F)*
Borehole Spacing	*19 ft*
Soil Formation Thermal Conductivity	*1.26 Btu/hr-ft-°F*
Soil Formation Thermal Diffusivity	*0.89 ft^2/day*
Number of Probes used in the Test	*2*
Number and Speed of Compressors used	*One Comp. @ 50% capacity*
Time over which following Data was Averaged	*Last 24 hr*
Heat Pump Power Input	*1222 W*
Flow Rate of the Geothermal Loop Pump	*6 gal/min*
Average EWT/LWT achieved	*66.6°F / 71.7°F*

Table 5. Cooling Mode 2-U Bend Vertical Borehole Trial 2 Data Sheet

Name of Trial	*Cooling Mode Vertical Borehole Trial 2*
Dates and Total Length of Test	*Aug 26 to 30, 2014 (4 days)*
Average Outdoor Air Temperature during Test	*69.6°F*
Ground Undisturbed Temperature	*58.0°F*
Bore depth / Probe Length	*306 ft / 300 ft*
Pipe Length per Probe	*1200 ft*
Borehole Diameter	*6.5"*
Grouting / Backfilling	*200 lb sand/50 lb bentonite (0.88 Btu/hr-ft-°F)*
Borehole Spacing	*19 ft*
Soil Formation Thermal Conductivity	*1.26 Btu/hr-ft-°F*
Soil Formation Thermal Diffusivity	*0.89 ft^2/day*
Number of Probes used in the Test	*2*
Number and Speed of Compressors used	*One Comp. @ 100% capacity*
Time over which following Data was Averaged	*Last 24 hr*
Heat Pump Power Input	*2327 W*
Flow Rate of the Geothermal Loop Pump	*12 gal/min*
Average EWT/LWT achieved	*78.1°F / 83.2°F*

Table 6. Heating Mode Helix Probe Data Sheet

Name of Trial	*Heating Mode Helix Probe*
Dates and Total Length of Test	*Feb 9 to 14, 2015 (5 days)*
Average Outdoor Air Temperature during Test	*43.9°F*
Ground Undisturbed Temperature	*53.6°F*
Bore depth / Probe Length	*18 ft / 12 ft*
Pipe Length per Probe	*131 ft*
Borehole Diameter	*18"*
Grouting / Backfilling	*Backfilled with native soil*
Borehole Spacing	*11 ft*
Soil Formation Thermal Conductivity	*1.26 Btu/hr-ft-°F ([1])*
Soil Formation Thermal Diffusivity	*0.89 ft^2/day ([1])*
Number of Probes used in the Test	*3*
Number and Speed of Compressors used	*Variable then One Comp. @ 60% capacity*
Time over which following Data was Averaged	*Last 72 hr*
Heat Pump Power Input	*1945 W*
Flow Rate of the Geothermal Loop Pump	*9.9 gal/min*
Average EWT/LWT achieved	*38.7°F / 36.4°F*

([1]) Thermal properties from vertical borehole

Table 7. Heating Mode 2-U Bend Vertical Borehole Data Sheet

Name of Trial	***Heating Mode Vertical Borehole***
Dates and Total Length of Test	*Mar 2 to 6, 2015 (4 days)*
Average Outdoor Air Temperature during Test	*27.0°F*
Ground Undisturbed Temperature	*54.4°F*
Bore depth / Probe Length	*306 ft / 300 ft*
Pipe Length per Probe	*1200 ft*
Borehole Diameter	*6.5"*
Grouting / Backfilling	*200 lb sand/50 lb bentonite (0.88 Btu/hr-ft-°F)*
Borehole Spacing	*19 ft*
Soil Formation Thermal Conductivity	*1.26 Btu/hr-ft-°F*
Soil Formation Thermal Diffusivity	*0.89 ft^2/day*
Number of Probes used in the Test	*1*
Number and Speed of Compressors used	*Variable then Two Comp. @ 55% capacity*
Time over which following Data was Averaged	*Last 66 hr*
Heat Pump Power Input	*3171 W*
Flow Rate of the Geothermal Loop Pump	*5.3 gal/min*
Average EWT/LWT achieved	*39.7°F / 34.7°F*

Calculations

Output performance calculations are based on the following formula. Note this equation is valid for steady state systems.

$$\dot{q} = \dot{m} \cdot C_p \cdot \Delta T$$

Where,

$\dot{q}$: Heat output from geothermal field (Btu/hr)
$\dot{m}$: Mass flow of heat carrying fluid (lbm/hr)
C_p: Specific heat of fluid (Btu/lbm-°F)
ΔT: Averaged temperature difference between EWT and LWT (°F) during the closest to steady state time period on each test scenario.

In turn,

$$\dot{m} = \dot{Q} \cdot \rho$$

Where,

$\dot{Q}$: Volumetric flow of the fluid (gal/min or GPM)
ρ: Density of the fluid (lbm/gal)

Example: Helical Probe Trial 1 scenario

$$\dot{m} = 9.86\frac{gal}{min} \cdot 0.1337\frac{ft^3}{gal} \cdot 62.72\frac{lbm}{ft^3} \cdot \frac{60min}{hr} = 4961\frac{lbm}{hr}$$

And,

$$\dot{q} = 4961\frac{lbm}{hr} \cdot 0.964\frac{Btu}{lbm \cdot °F} \cdot 2.29°F = 10952\frac{Btu}{hr}$$

Temperature differences were calculated from temperature measurements from various sensors. In general, whenever there was redundant sensors available for the same temperature, an average was calculated to increase accuracy.

Appendix A. Test Schedule Sheet

System Performance
Data Collection

REHAU ECOSMART HOUSE
Bozeman, MT

lee2289

Test Number: RMEH 01-001

Description: Evaluate the geothermal heat pump performance utilizing the RAUGEO helix and the RAUGEO vertical borehole configurations to demonstrate the relative performance of various installation methods and ultimate performance of each method.

Objectives:

1. Determine actual capacity of Helix system in BTU/Hr/ft (heating and cooling)
2. Determine actual capacity of Borehole field in BTU/Hr/ft (heating and cooling)
3. Determine capacity of each system per installed cost (heating and cooling)
4. ~~Evaluate each system with and without use of buffer tank~~
5. Confirm performance versus calculated design

Data Collection Parameters:

	Description	Source
1	RAUGEO EWT	RSC
2	RAUGEO RWT	RSC
3	HP SWT	RSC
4	HP RWT	RSC
5	Buffer Tank Temp	RSC
6	OA Temp	RSC
7	Borehole Temps	MSU
8	Geo Field Flow Rate	MSU
9	Heat Pump Flow Rate	MSU
10	Heat Pump Energy Usage	MSU
11		
12		
13		
14		
15		
16		
17		
18		

Test Duration:

Length 4 days each configuration
Start Date ____________
End Date ____________

Deliverables:

1. Provide analysis of output performance of RAUGEO Double U-Bend
2. Provide analysis of output performance of RAUGEO Helix
3. Provide overview of system operation temperatures and flow rates
4. Determine energy usage of heat pump during operation
5.

Notes: Tests to be run in heating and cooling modes. MSU to have access to RSC sensors and data. Tests to be conducted using buffer tank as installed.

MSU Notes: ***testing in March*** based on heat pump rework. Additional summer 2014 testing to occur with permission from homeowner.

Page 1 REHAU Proposed Research Projects_Rev1_022813

Appendix B. Experiment Notes

Data for experiment RMEH 01 was collected during the following dates:

- Cooling Helix Trial 1: 01-Ago-14 – 05-Ago-14
- Cooling Helix Trial 2: 10-Oct-14 – 18-Oct-14
- Cooling Vertical Borehole Trial 1: 18-Jul-14 – 22-Jul-14
- Cooling Vertical Borehole Trial 2: 26-Ago-14 – 30-Ago-14
- Heating Helix: 09-Feb-15 – 14-Feb-15
- Heating Vertical Borehole: 02-Mar-15 – 06-Mar-15

Appendix C. Data Collection Parameters

REHAU Smart Controls (RSC), National Instruments (NI), Micro Control Systems (MCS) and eGauge data acquisition (DAQ) systems were used to collect data for this experiment. The most important data points collected were the following (the rest provided redundancy and/or additional information):

RSC Data Points

- RAUGEO Entering Water Temperature (EWT)
- RAUGEO Leaving Water Temperature (LWT)
- Heat Pump Supply Water Temperature (SWT)
- Heat Pump Return Water Temperature (RWT)
- Buffer Tank Temperature
- Outdoor Air Temperature

NI Data Points

- Boreholes Temperatures
- Geo Field Flow Rate
- Heat Pump Flow Rate
- Heat Pump Energy Usage

Appendix D. Experiment Setup

Figure 8. Drilling operations during construction

Figure 9. Installation of a helix probe

Figure 10. Sensor installation on a vertical 2-U bend probe with spacers.

Figure 11. Trenching works towards the house

Appendix E. References

1. REHAU United Polymer Solutions (2014, December). Product Submittal 153. RAUGEO™ Helix. Retrieved from http://www.rehau.com/download/866708/ps153-raugeo-helix.pdf

2. Baroid IDP (2011). BAROID Barotherm® Gold. Product Data Sheet. Retrieved from http://www.barodidp.com/public_idp/pubsdata/Data_Sheets/A_H/BAROTHERM%20GOLD.pdf

3. Zarrella A., De Carli M. (2012) Heat transfer analysis of short helical borehole heat exchangers. *Appl Energy*, http://dx.doi.org/10.1016/j.apenergy.2012.09.012

4. Geothermal Resource Technologies, Inc. (2011). Helix Thermal Test and Data Analysis. Analysis for Montana State University. Test Location: Helix Bore #11 REHAU Montana Ecosmart House, Bozeman, MT. GRTI. Bowie, TX.

5. Geothermal Resource Technologies, Inc. (2011, September). Formation Thermal Test and Data Analysis. Analysis for Montana State University. Test Location: Vertical Bore #2 REHAU Montana Ecosmart House, Bozeman, MT. GRTI. Bowie, TX.

6. Montana State University (2011). Well Log Report Rehau Montana Ecosmart House Project Hoy Residence. Montana State University. Bozeman, MT.

7. ASHRAE (2011). *2011 ASHRAE Handbook – HVAC Applications*. American Society of Heating, Refrigerating and Air- Conditioning Engineers, Inc. Chapter 34. Geothermal Energy.