Efficiency and Performance Analysis of Residential Geothermal HVAC systems in New York State

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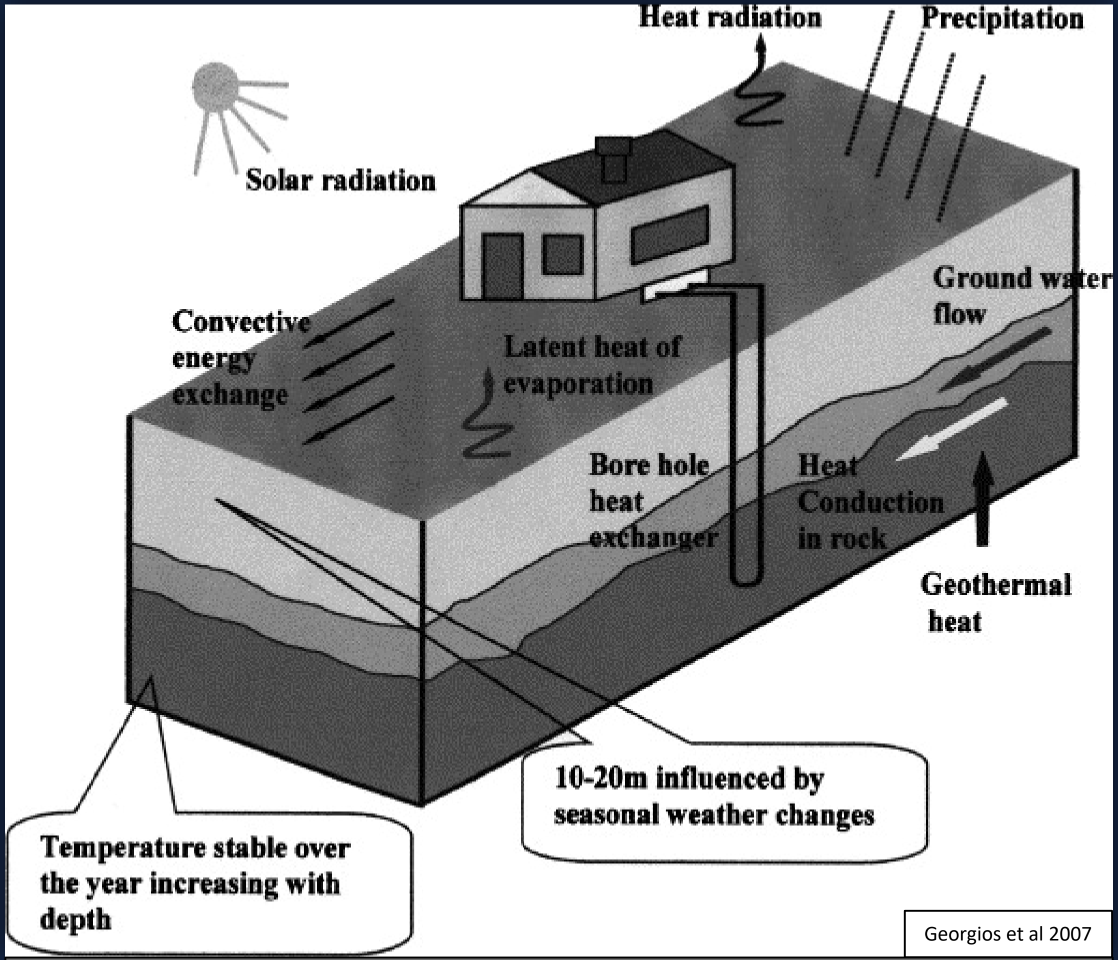
Introduction:

Geothermal Energy:

- Considered an environmentally friendly, renewable resource (Axelsson et al 2003; Blum et al 2013)
- Can be found nearly anywhere within the earth's interior (Keçebas 2012)
- Geothermal energy is used in three ways (Wu et al 2009)
  - Electricity Generation
  - Direct heating
  - Indirect heating and cooling via geothermal heat pumps



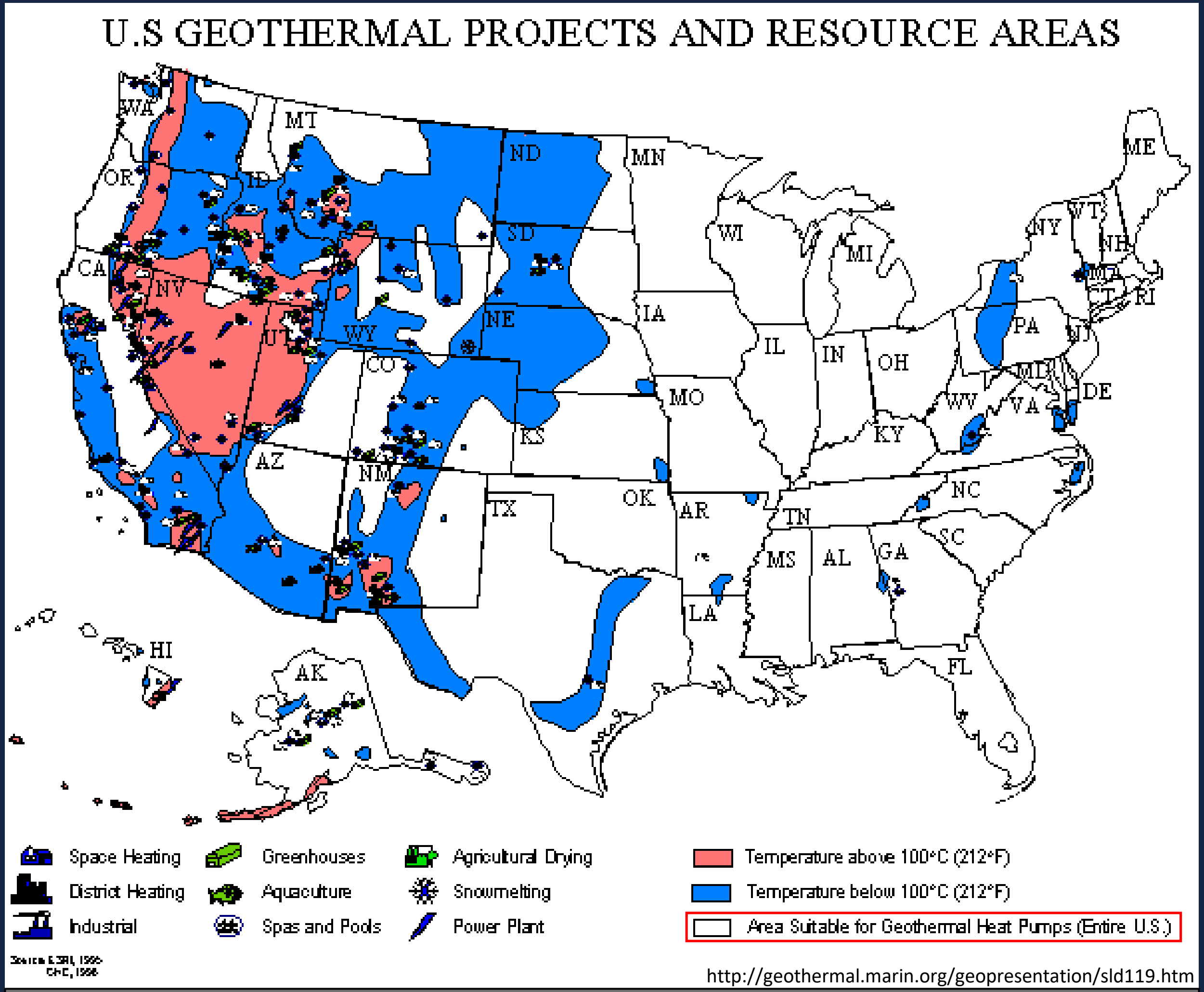
Natural processes of environment around geothermal system

Growth Potential in United States:

- $10 billion invested into geothermal projects by 46 countries between 2005-2009
  (Lund et al 2011)

- 20% of U.S. energy use is expended for space and hot water heating

- More installation needed to achieve full potential of geothermal energy
  (Thorsteinsson et al 2010)



Regions of the United States that are suitable for geothermal usage

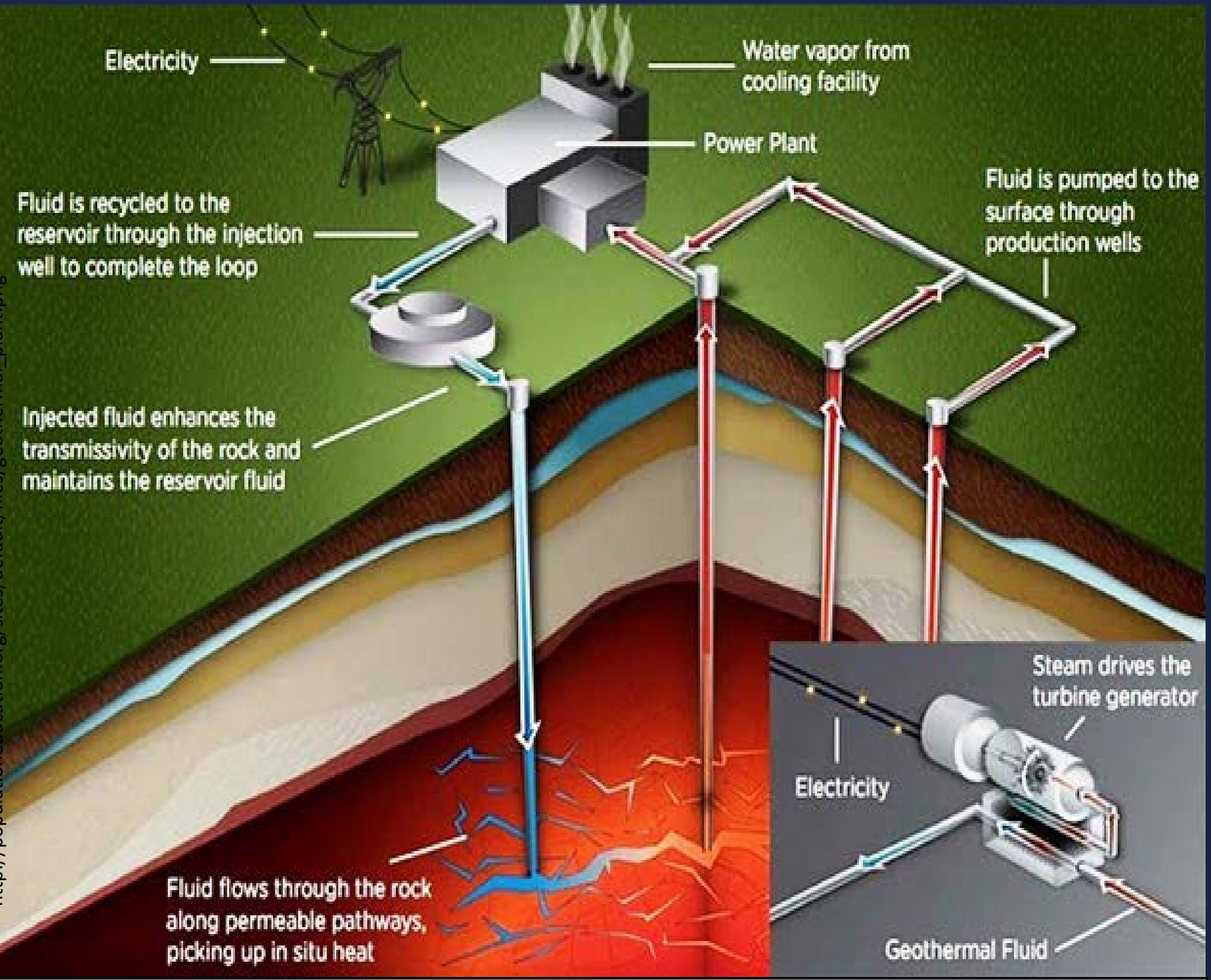
Forms of Geothermal Energy:

"High Grade" Geothermal:

- Temperatures near or exceeding 212°F (boiling point)
- Found near geysers and other hydro-geothermal reservoirs
- Primarily used to generate electricity

"Low Grade" Geothermal:

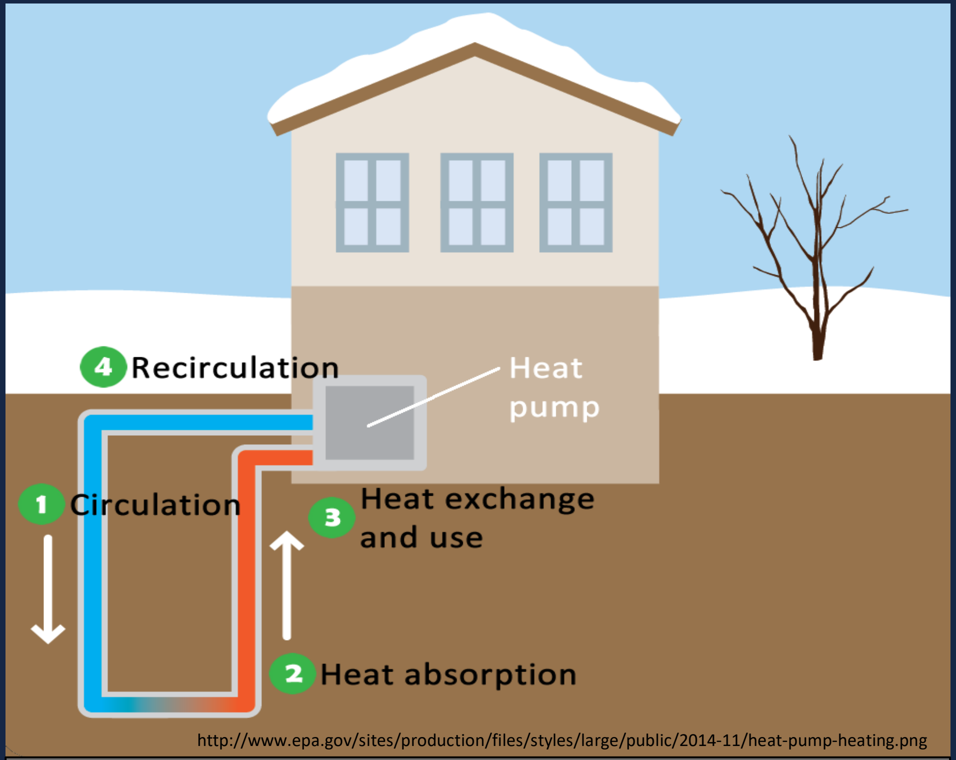
- Temperatures (less than 120°F)
- Uses heat pumps to move heat
- Typically used with HVAC systems



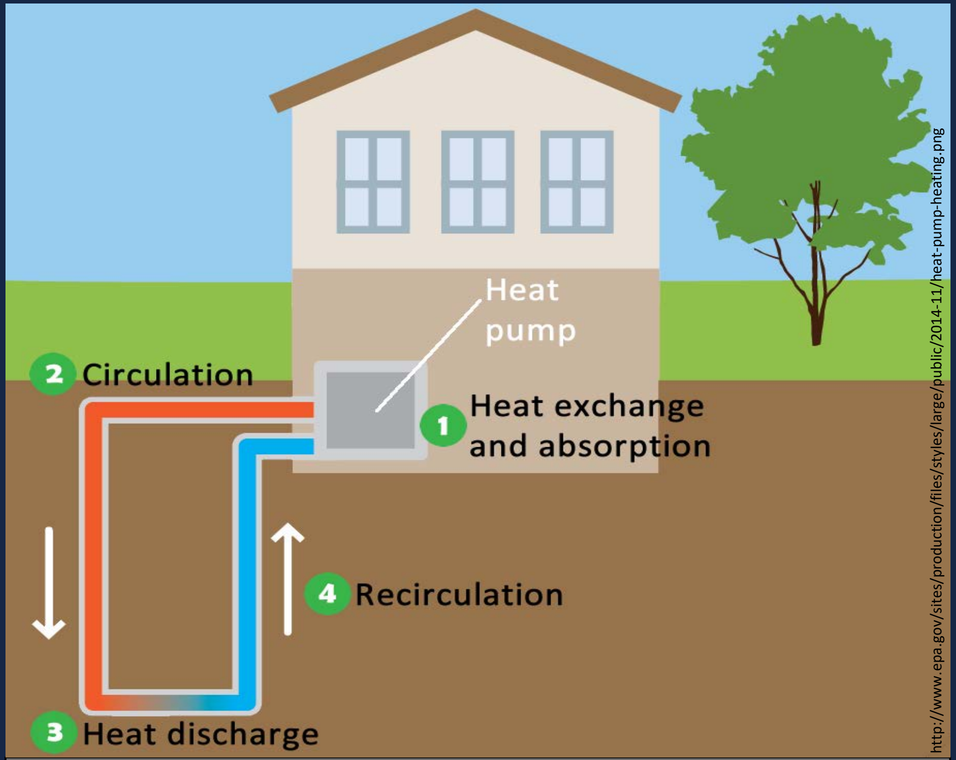
http://populationeducation.org/sites/default/files/geothermal_plant.png

High Grade Geothermal

Functions of Loops and Heat Pumps:



Heating Mode



Cooling Mode

Types of Geothermal Systems:

Fundamentals

Open Loop:

- Ground water is drawn directly into the building for heating and cooling
- Ground water must be free of minerals and contaminants

Florides et al 2007

Fundamentals

Closed Loop:

- Dedicated fluid loop circulates through ground/pond to exchange energy (Ballard et al 2012)
- The ground/pond water and loop water do not mix (Cui et al 2011)

Design

Open Loop:

- Air passes through underground tubes (pre-heating/cooling)
- Two wells are usually required
  Extraction well
  Injection well

Ballard et al 2012

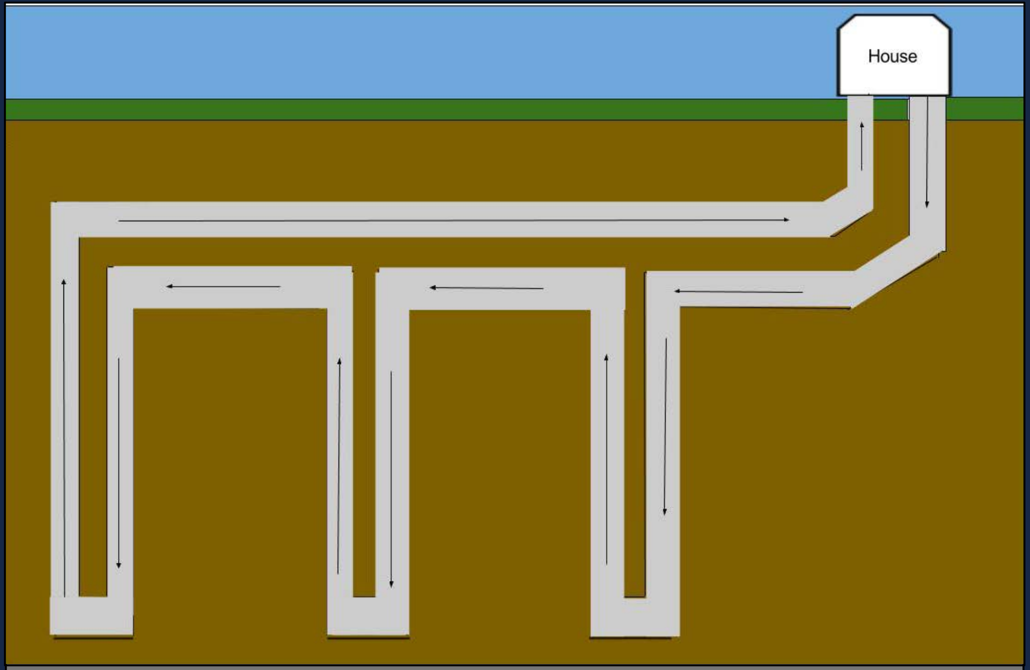
Design

Closed Loop:

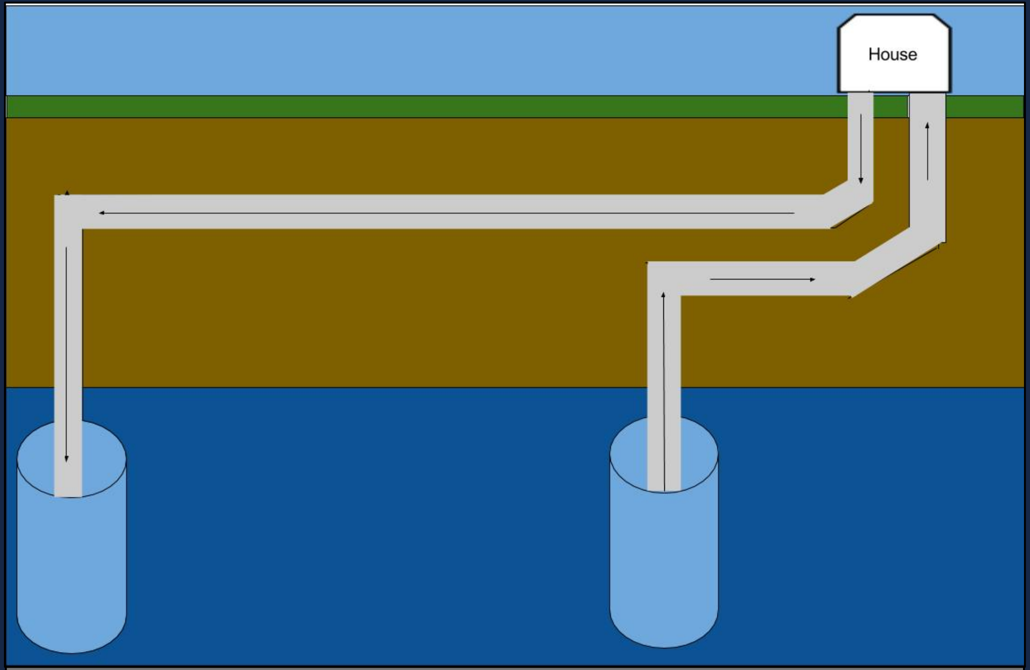
- Variations in design
  - Horizontal
  - Vertical (more costly, less piping)
  - Diagonal
  - Slinky (especially in U.S.)

Florides et al 2007

Design of Geothermal Systems:



Closed Loop



Open Loop

Installation and Operational Costs:

- 40-50% of the total investment cost of projects are the drilling of production
- Materials are bought when commodities are at their lowest prices (Sveinbjornsson et al 2012)
- Typical R.O.I. is 6-20 years (Dowlatabadi et al 2007)
- Low-interest loans and incentives are available for geothermal installation

Table 2.

Comparison of economic parameters for various heating systems in several locations.

		Alberta		Ontario		Nova Scotia	
Heating system	Capital cost ($)	Annual heating cost ($)	Present worth ($)	Annual heating cost ($)	Present worth ($)	Annual heating cost ($)	Present worth ($)
Geothermal HP	9000	601	21,020	328	15,560	649	27,230
Air source HP	4900	813	21,160	444	13,780	877	27,940
Electric baseboard	1550	2257	46,690	1231	26,170	2432	50,190
Natural gas furnace [a]	1500	1276	27,020	2344	48,380	1885	44,750
Natural gas furnace [b]	1900	1109	24,080	1049	22,880	1653	40,460

Monetary units are in 2009 Canadian dollars.

Self et al 2011

Capital costs to install geothermal heat pumps

Research Question:

In New York State, what type of geothermal system is most efficient when annually heating a suburban residence?

Hypotheses:

In New York State, what type of geothermal system is most efficient when annually heating a suburban residence?

- H_0: In New York State, it is inefficient to geothermally heat a suburban residence.
- H_1: In New York State, it is more efficient to geothermally heat a suburban residence with a closed loop system than an open loop system, as the C.O.P. of a closed loop system meets or exceeds its expectations.
- H_2: In New York State, it is more efficient to geothermally heat a suburban residence with an open loop system than a closed loop system, as the C.O.P. of an open loop system meets or exceeds its expectations.

Project Timeline:

- Client/system identification
- Heat exchanger analysis
- System performance collections
- Search for server errors in data collection
- Calculate weekly, monthly, and seasonal C.O.P. averages
- Compare client seasonal C.O.P. averages to heat exchanger standard
- Conclusion

Client/System Identification:

- Each client was given an alias to keep their anonymity
- Loop type and location was obtained for analysis purposes

Loop Name	Loop Type	Loop Location
Alpha	Hybrid Open Loop/ Standing Column shown with primary ground loop including drywell	Tivoli, New York
Bravo	Hybrid Open Loop/ Standing Column shown with primary ground loop including drywell	Rhinebeck, New York
Charlie	Closed Loop System Closed Loop water to air	New Paltz, New York
Delta	Closed Loop System Closed Loop water to air	New Paltz, New York

Heat Exchanger Analysis:

- The heat exchangers of each client were identified
- During the data analysis, each system's C.O.P. was compared to the typical heat exchanger C.O.P.
  - Heat exchanger C.O.P. values were obtained from the manufacturer's manual

Loop Name	Heat Exchangers
Alpha	Climate Master Tranquility 27 Model 72 – Full Load
Bravo	Climate Master Tranquility 27 Model 49 – Part Load
Charlie	Water Furnace Envision Series NSW
Delta	Water Furnace Envision Series NSW

System Performance Data Collection:

- Data collection method: online server
- Data duration: 10/1/14 – 3/1/15
  - 5-day charts
  - Monthly
  - Seasonal (10/1 – 3/1)
- Primary variables:
  - Air temperature (outside)
  - Water input
  - Coefficient of performance (C.O.P.)
- Truth value indicated status of system
  - (1) = online
  - (0) = offline
- Offline system data was excluded

Date	Time	WaterIn 1	WaterOut	Air In.0	Air Out.0	Outside.0	Super Hea	Y1(Stage	Y2(Stage	O(Cooling	F(Fan).0	System C	HeatPump
12/4/2014	11:45:34	46.85	49.44	61.59	69.13	39.09	50.56	1	0	0	1	4.2931	5.333
12/3/2014	4:59:04	46.51	49.33	62.49	72.28	34.25	50.90	1	0	0	1	4.2192	5.4456
12/2/2014	23:50:34	46.18	48.88	62.94	71.94	33.13	50.11	1	0	0	1	4.0652	5.2912
12/1/2014	20:48:04	47.19	49.78	62.60	72.16	37.18	51.01	1	0	0	1	4.0492	5.5738
12/4/2014	20:42:04	46.06	48.20	61.48	72.39	29.75	49.66	1	0	0	1	3.6163	4.5802
11/30/2014	10:10:04	44.26	46.85	62.04	73.40	37.96	48.43	1	0	0	1	3.5727	5.1164
12/2/2014	10:48:34	45.61	48.20	62.83	73.06	30.76	49.89	1	0	0	1	3.5372	4.53
12/1/2014	4:40:34	46.63	48.76	61.70	71.60	39.99	50.00	1	0	0	1	3.5076	4.3853
11/30/2014	1:07:34	47.30	49.10	61.14	68.90	30.43	50.11	1	0	0	1	3.4533	4.7617
11/30/2014	18:49:34	45.28	47.64	63.39	74.08	37.29	49.44	1	0	0	1	3.4253	4.5277
12/2/2014	0:20:04	47.86	49.33	61.70	68.68	34.25	49.78	1	0	0	1	3.4171	4.453
12/1/2014	9:24:04	48.20	49.89	62.60	69.46	45.28	50.68	1	0	0	1	3.408	4.5318
11/30/2014	16:50:34	46.06	48.76	61.93	70.81	37.06	50.34	1	0	0	1	3.3997	6.5494
12/3/2014	10:01:04	47.08	50.79	62.15	69.24	38.53	52.36	1	0	0	1	3.3734	8.2687
12/2/2014	18:55:34	46.40	48.65	62.15	71.49	31.89	50.00	1	0	0	1	3.3511	4.3586
12/4/2014	15:11:04	48.43	50.00	61.36	68.11	40.10	50.45	1	0	0	1	3.2684	4.8389
12/3/2014	21:20:04	46.74	39.65	63.39	88.59	39.09	37.40	1	0	0	1	3.208	4.0913

Sample of a client's system performance data

Coefficient of Performance Rates:

- C.O.P. rates are strong indicators of a system's heat pump efficiency (Ozgener et al 2012)
- C.O.P. rates can be calculated for both heating and cooling processes (Hamilton 2013)
- Two components compose the COP
  - Heat supplied/removed (Q)
  - Work conducted by heat pump (W)
- Client C.O.P. rates were automatically calculated by the server

$$COP = \frac{Q}{W}$$

Hamilton 2013

Coefficient of Performance Formula

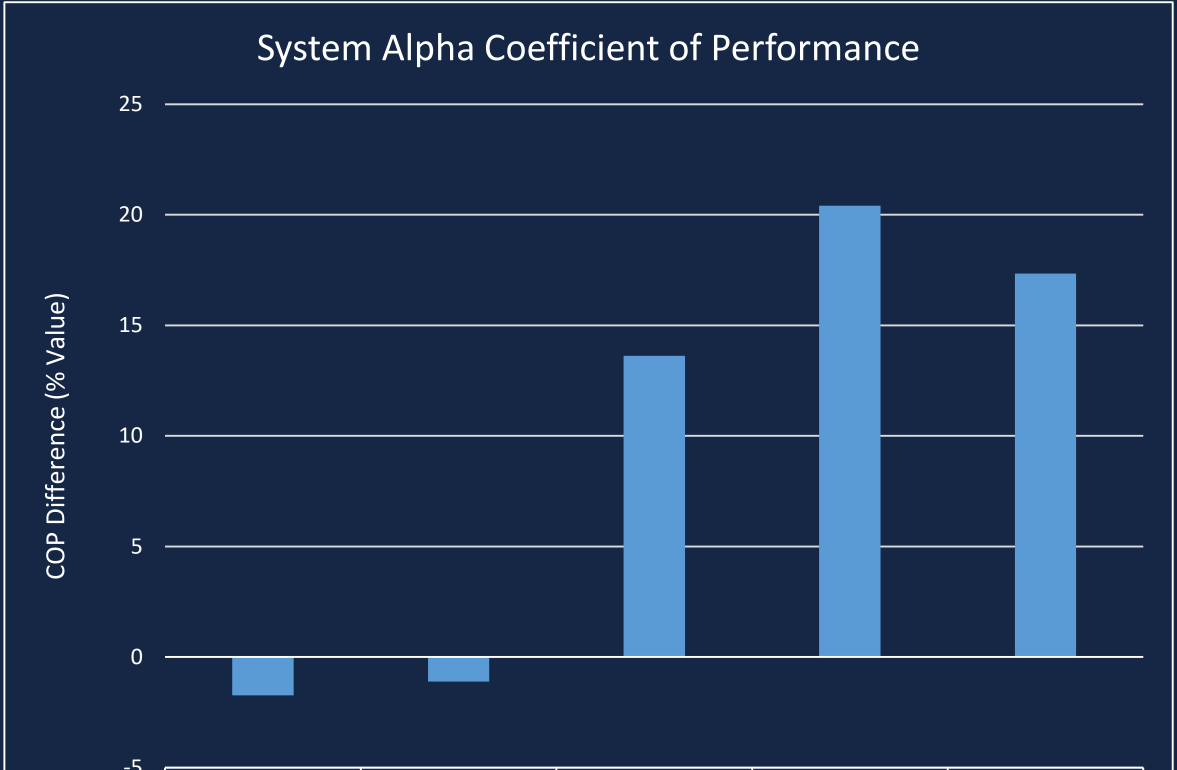
Coefficient of Performance Comparison:

- Actual C.O.P. values were compared to expected C.O.P. values
- Expected C.O.P. values obtained from heat exchanger manuals
- Deviation actual C.O.P. and expected C.O.P. calculated
- Percent Error is negative: system C.O.P. did not meet expectations
- Percent Error is positive: system C.O.P. exceeded expectations

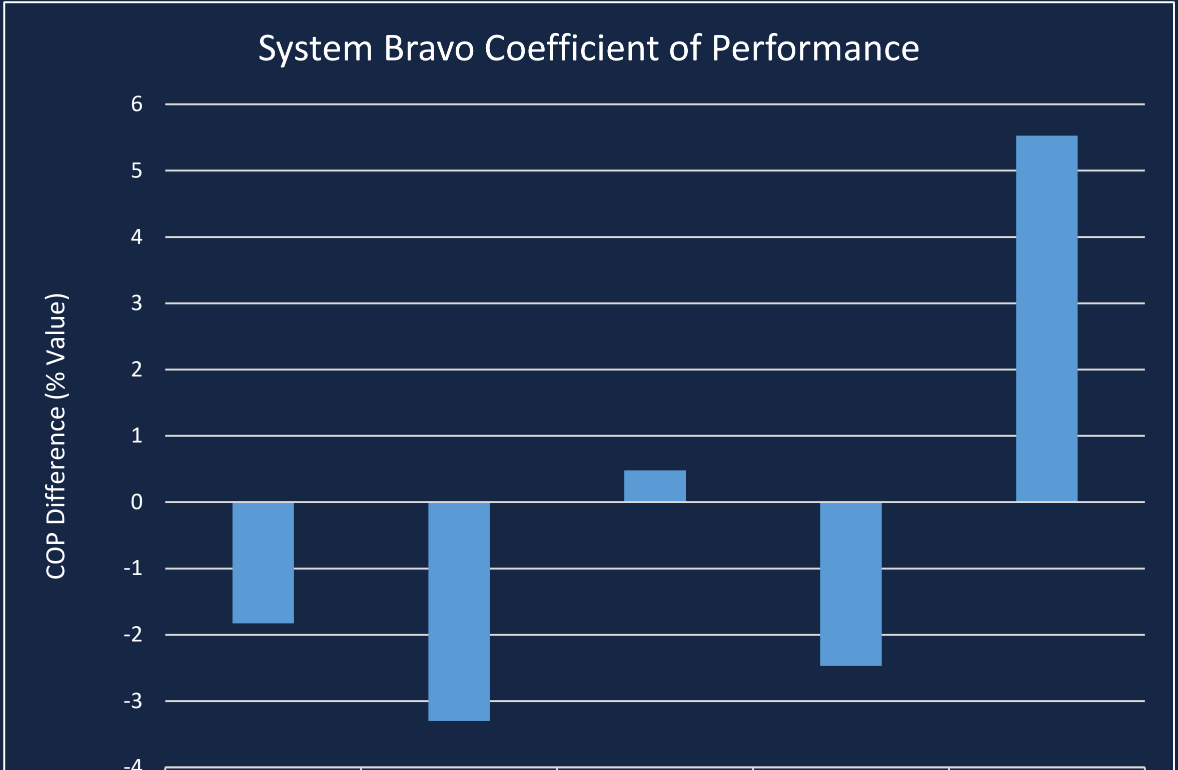
$$\left(\frac{Measured\ C.O.P. - Expected\ C.O.P.}{Expected\ C.O.P.}\right) \times 100\%$$

Percent Error Formula

Data:

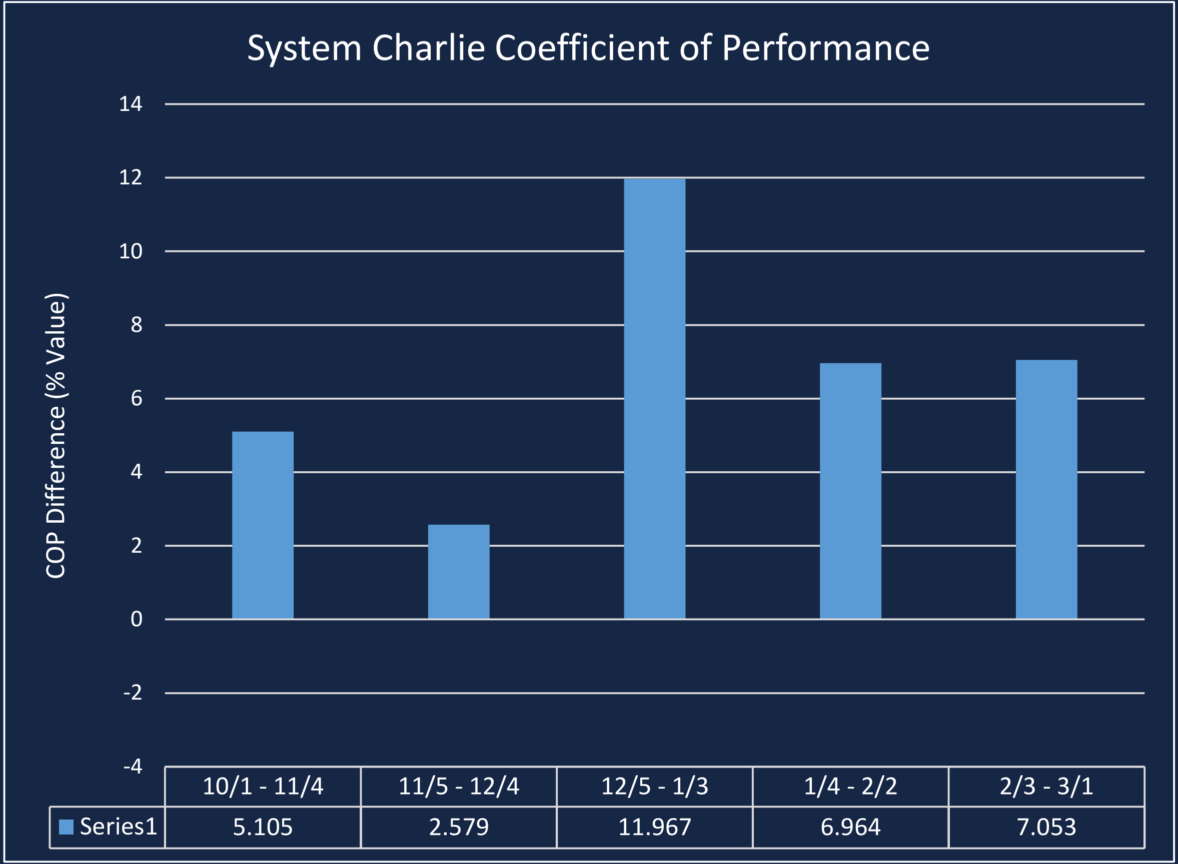


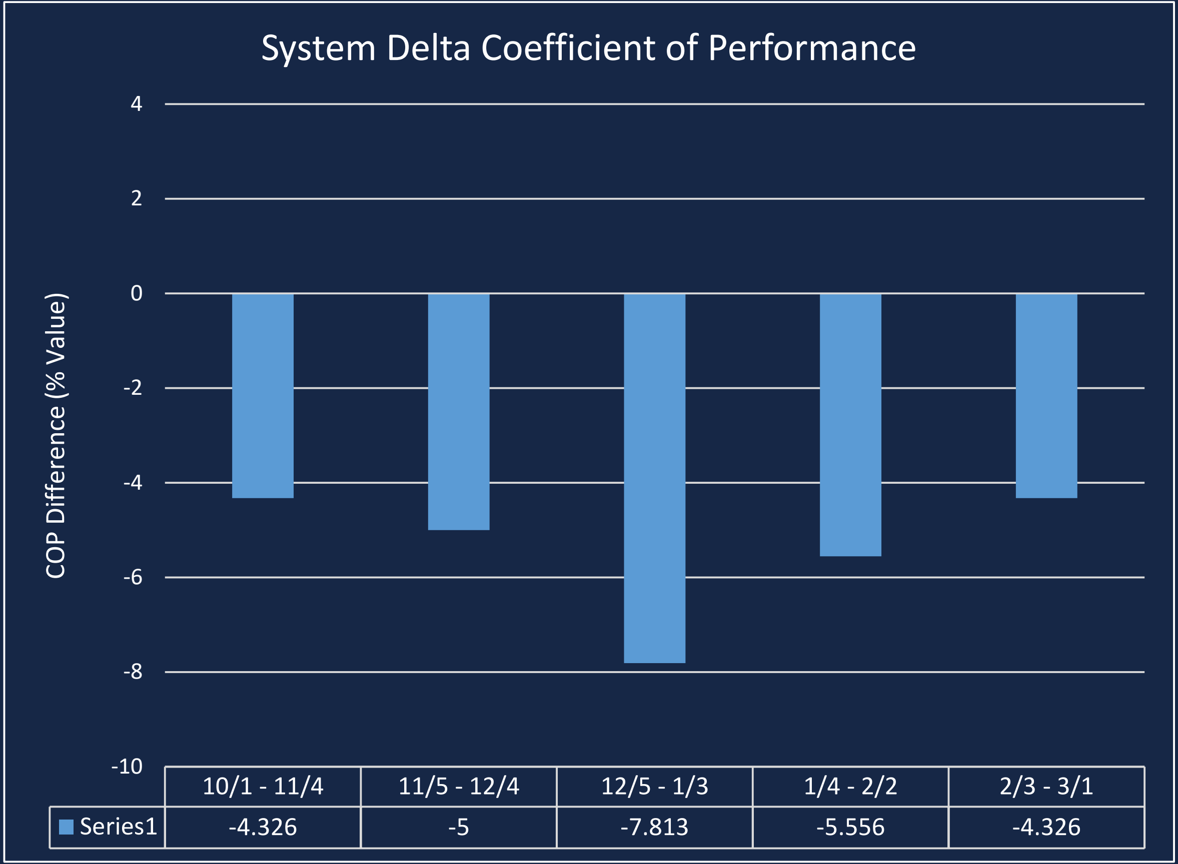
	10/1 - 11/4	11/5 - 12/4	12/5 - 1/3	1/4 - 2/2	2/3 - 3/1
Series1	-1.734	-1.107	13.623	20.407	17.338



	10/1 - 11/4	11/5 - 12/4	12/5 - 1/3	1/4 - 2/2	2/3 - 3/1
Series1	-1.83	-3.3	0.48	-2.47	5.53

Data:


System Charlie Coefficient of Performance
COP Difference (% Value)
14
12
10
8
6
4
2
0
-2
-4
10/1 - 11/4
11/5 - 12/4
12/5 - 1/3
1/4 - 2/2
2/3 - 3/1
Series1
5.105
2.579
11.967
6.964
7.053


System Delta Coefficient of Performance
COP Difference (% Value)
4
2
0
-2
-4
-6
-8
-10
10/1 - 11/4
11/5 - 12/4
12/5 - 1/3
1/4 - 2/2
2/3 - 3/1
Series1
-4.326
-5
-7.813
-5.556
-4.326

Data:

System	Average C.O.P.	Average Temp. (F˚)	Average Water Temp. (F˚)	Expected C.O.P.	C.O.P. Deviation
Alpha	3.83368	30.967	47.84574	3.5	+9.534%
Bravo	4.40103	33.171	48.76398	4.5	-2.199%
Charlie	3.30874	30.653	49.17464	3.1	+6.734%
Delta	2.93247	23.369	46.06254	3.1	-5.404%

Seasonal System Performance Values (10/1/14 – 3/1/15)

Data Analysis Results:

- System with highest positive C.O.P. deviation: Alpha (open loop)
- System with most consistent performance: Charlie (closed loop)
- System with highest negative C.O.P. deviation: Delta (closed loop)
- System with highest average water temperature: Charlie (closed loop)
- System with lowest average water temperature: Delta (closed loop)

Sources of Error:

- Sample size (only four clients participated)
- Internal server errors
  - Possible errors in calculations of C.O.P. and variables
- Lack of knowledge regarding thermostat preferences
  - Desired temperature of client is unknown
- Terrain varied among the four locations
  - Possibility for difference in soil composition, temperature, etc.

Conclusions:

- Most efficient system: System Charlie
- System Charlie exceeded expectations every month throughout the study
- System Alpha most exceeded its expected C.O.P. rates, but it was not consistent
  - Exceeded expectations 60% of the time
  - When it did not exceed expectations, it fell short of them
- Therefore, in New York State it is more efficient to geothermally heat a suburban residence with a closed loop system than an open loop system, as they perform more consistently and are more likely to exceed/meet performance expectations

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Lloyd Hamilton

Jefferson Tester

Mr. Inglis

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