Geothermal Earth Loop Options

Is there a single "best" approach?

An overview of the different types of geothermal loops and their various cold climate adaptations

PRESENTER:
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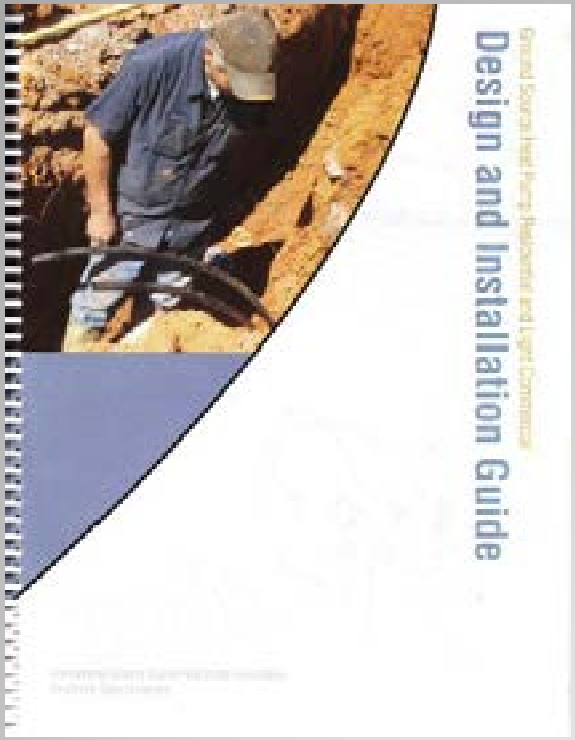
1. The Geothermal Heat Pump Concept

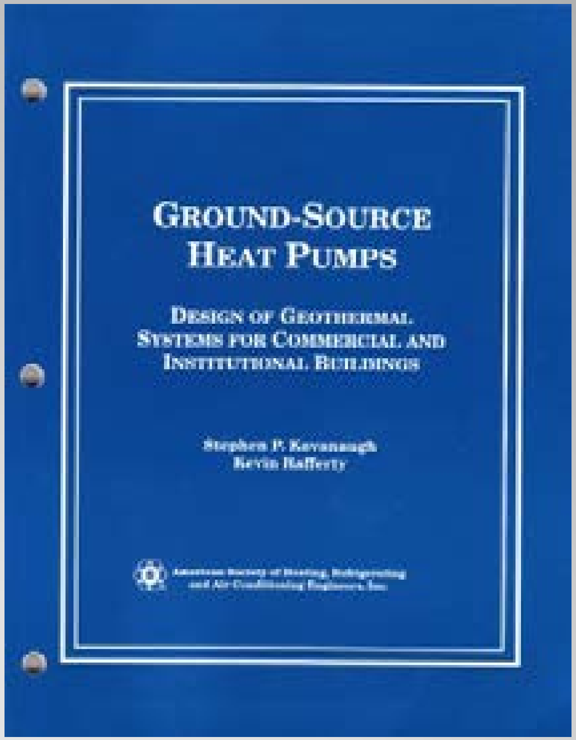
INTRODUCTION: The Simple Logic of a "Ground Source" Approach

Recommended References



Design and Installation Guide

Ground Source Heat Pump Residential and Light Commercial Design and Installation Guide; Remund et. al, International Ground Source Heat Pump Association, Oklahoma State University, Stillwater, 2009.



GROUND-SOURCE
HEAT PUMPS

DESIGN OF GEOTHERMAL
SYSTEMS FOR COMMERCIAL AND
INSTITUTIONAL BUILDINGS

Stephen P. Kavanaugh
Kevin Rafferty

Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings; Kavanaugh and Rafferty, American Society of Heating, and Air-Conditioning, Inc., 1997.

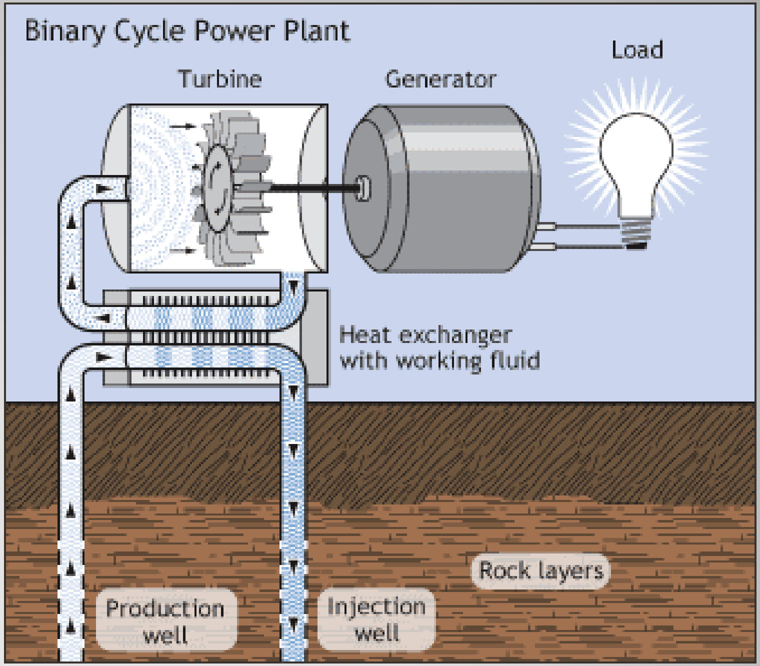
A *common air conditioner* is a simple Air-to-Air Heat Pump—exchanges 74°F indoor air with outdoor temperatures that fluctuate broadly and can often swing to over 100°F.

An *air source heat pump* adds Air-to-Air heating capability—it exchanges 70°F indoor air with outdoor temperatures that can swing well below 20°F (common ASHP operating range limit).

Where might we find temperatures close-by that are far more stable and efficient?

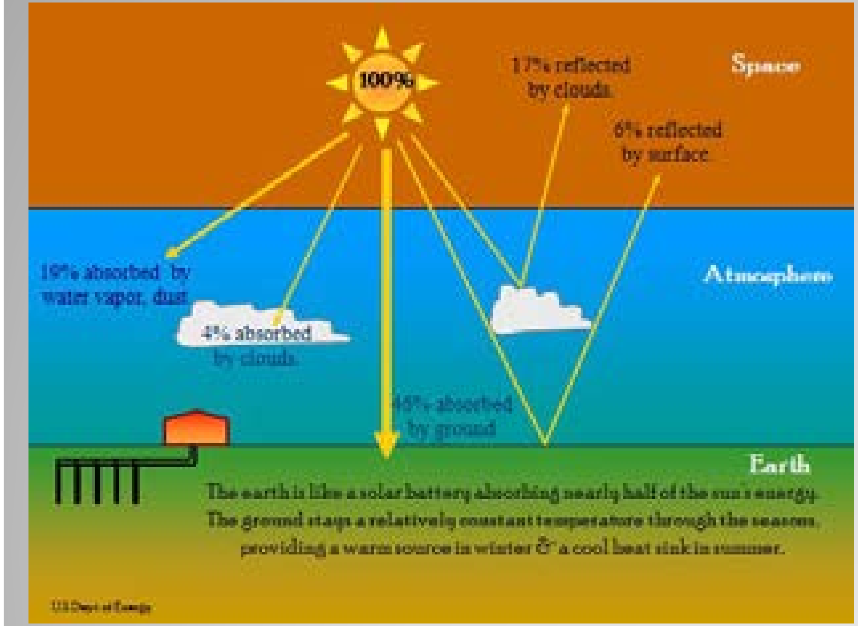
Old Faithful Geyser

“Hot Rocks” Power



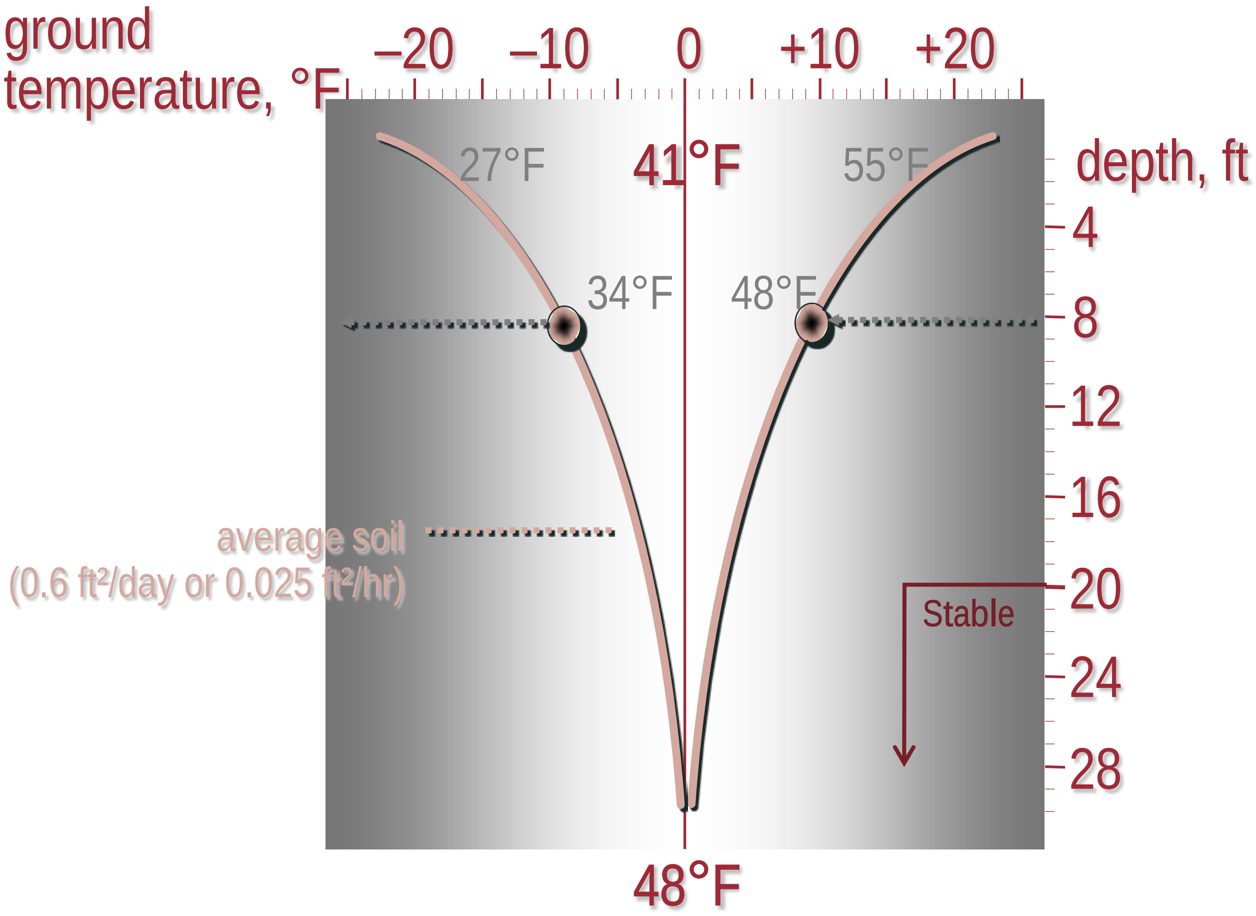
High Grade Geothermal Energy

“Solar” Geothermal



GeoExchange Systems

Low Grade Geothermal Energy



DULUTH SOIL STATISTICS:

MEAN SURFACE TEMPERATURE 1 ft. = 41°F

ANNUAL SWING = 28°F

DAYS TO MINIMUM = 37

DEEP EARTH TEMPERATURE = 48°F

Surface ground temperature swing is much narrower than seasonal air temperature above and gradually becomes stable.

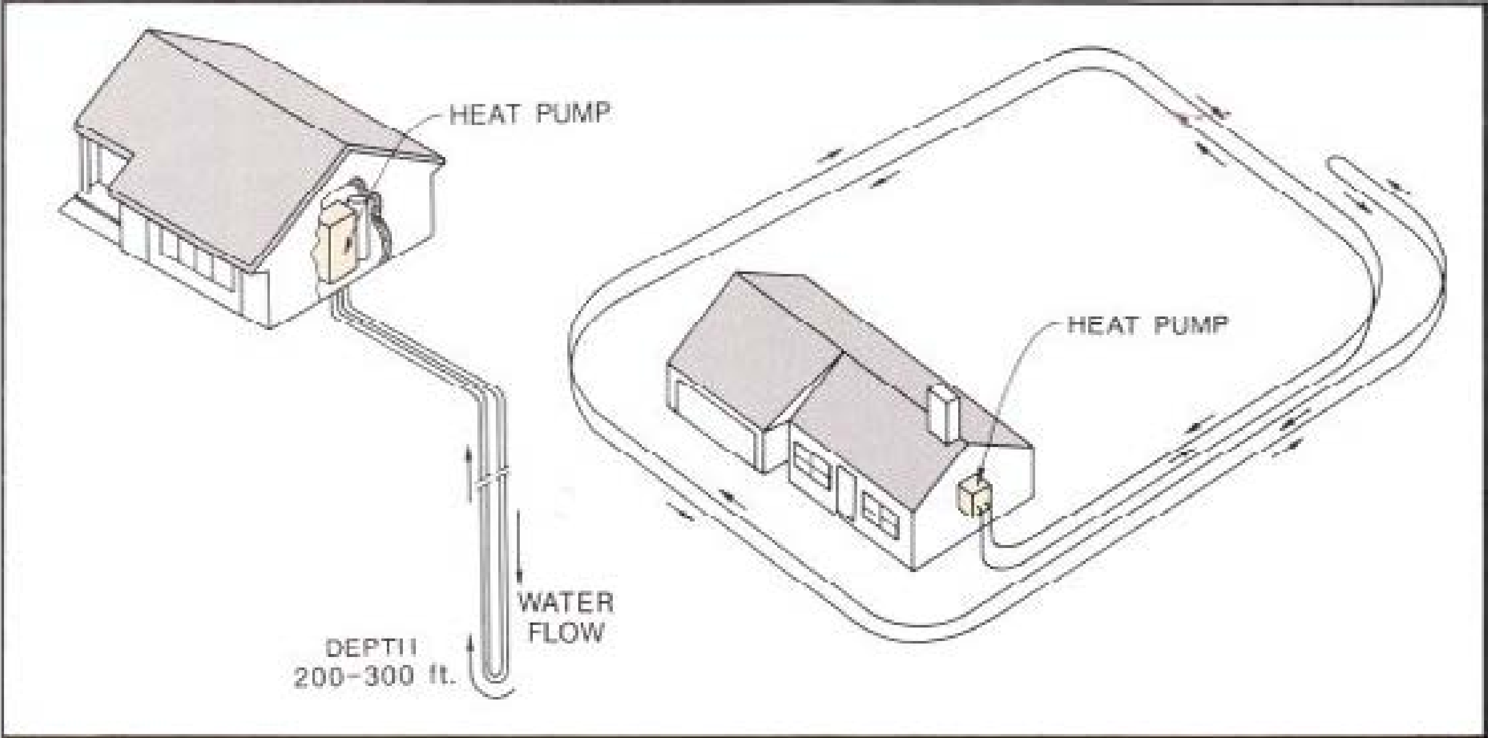
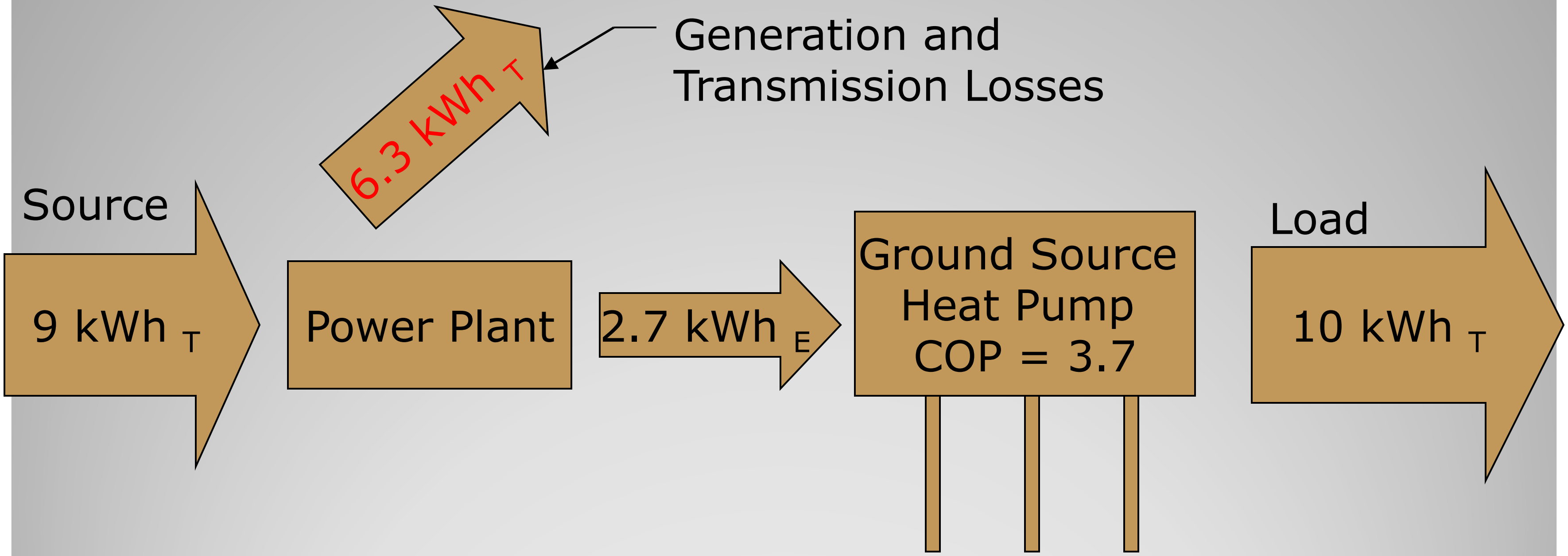


FIGURE 1.3: System Configurations

Heat pump technology logically goes…underground!

Load to Source: Sustainability Factor



6.3 kWh_T

Generation and Transmission Losses

Source

9 kWh_T

Power Plant

2.7 kWh_E

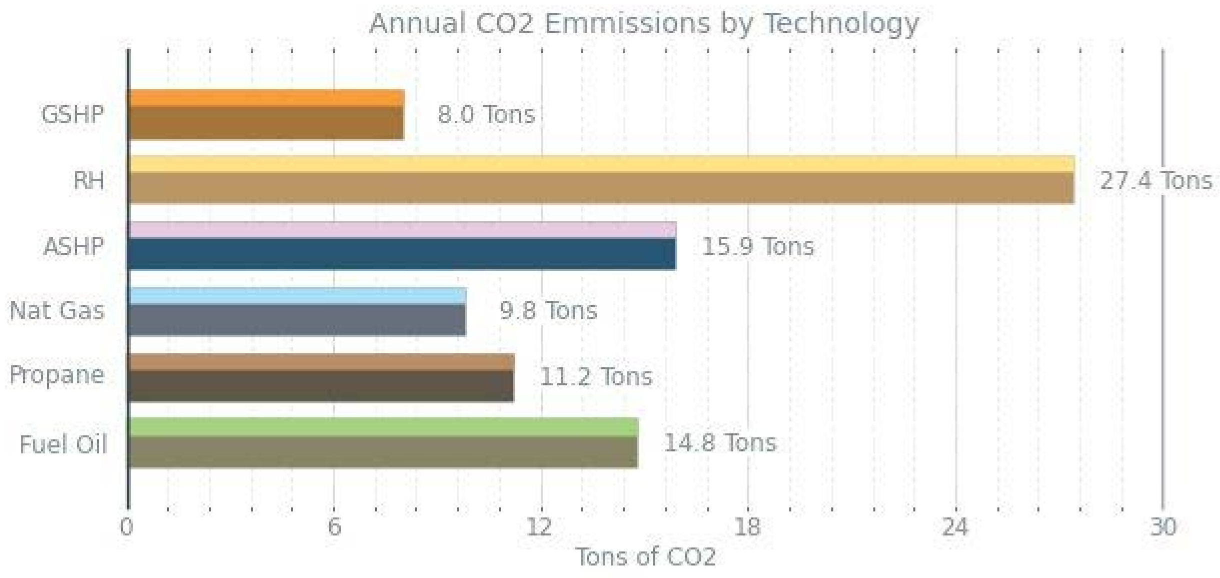
Ground Source Heat Pump COP = 3.7

Load

10 kWh_T

GSHP requires only 9 kWh_T from the source to provide 10 kWh_T to the building since they can provide a COP of 3.7

50,000 BTUH Heating Load (Typical)
Duluth, Minnesota



GSHPs create no <u>direct</u> emissions—

BUT…

Like other electric technologies, GSHPs create "upstream" carbon emissions…

Entirely dependent on the <u>method</u> of power generation in the area

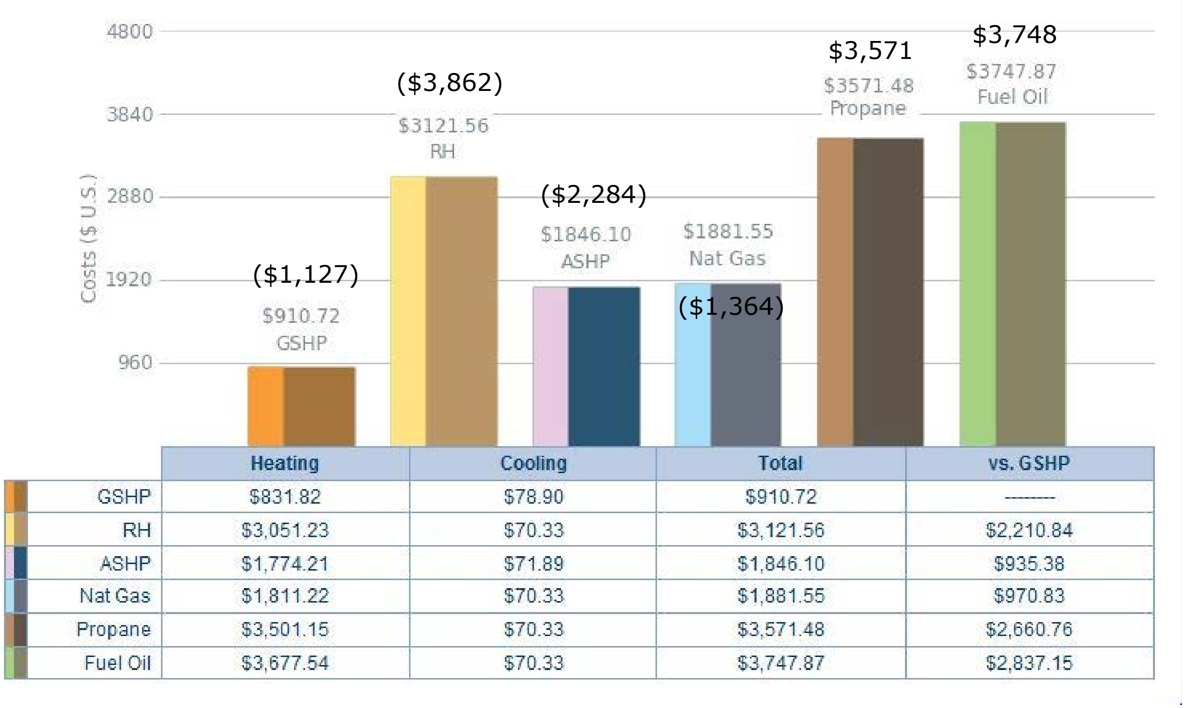
[NOTE: Fossil fuels represented on this chart are "point of use" only!]

<u>Environmental Benefits</u>—Great!…

But Tend to Be Geographically Specific

50,000 BTUH Heating Load (Typical)
Duluth, Minnesota

(NOTE: Rate Changes Reflected Since 2011)



	Heating	Cooling	Total	vs. GSHP
GSHP	$831.82	$78.90	$910.72	--------
RH	$3,051.23	$70.33	$3,121.56	$2,210.84
ASHP	$1,774.21	$71.89	$1,846.10	$935.38
Nat Gas	$1,811.22	$70.33	$1,881.55	$970.83
Propane	$3,501.15	$70.33	$3,571.48	$2,660.76
Fuel Oil	$3,677.54	$70.33	$3,747.87	$2,837.15

Savings compared to WHAT?...

System Cost compared to WHAT?...

Cost of Ownership =

Total System Design & Installation Cost…

--PLUS--

System Operating & Mtce. Cost Over Time

…COMPARED TO SOMETHING ELSE!

Economic Benefits—Vary depending on

Energy Cost Savings per Net System Cost

2013 Geothermal Rebate Programs
Regional Northeastern Utilities

- Minnesota Power

$200/T Closed Loop ($100/T Open Loop) + $200 ECM

[BONUS: Now Through 08/31/2013 … $50/T GSHP + $50 ECM]

Great River Energy Affiliates:

Cooperative Light & Power
Lake Country Power
East Central Energy
Arrowhead Electrical Cooperative

$400/T Closed or Open Loop + $100 ECM

Consider that GSHP installation costs and benefits are *scalable!*

Common Misconceptions About Geo'

- Take 50°F from the ground and deliver it to the house, then make up the remaining "difference" with supplemental heat
- Geothermal heat pumps are not well suited for extremely cold climates—you just don't get enough benefit from them
- Simply replaces a conventional furnace or boiler…and <u>everything else remains equal</u>

2. Understanding the Technology

How Geothermal Heating & Cooling Works (in 3½ minutes or less!)

Water to Air GHP
(Forced Air)

Water to Water GHP
(Hydronic)

Ground Source Heat Pumps

Simple Heat Pump

Mechanical energy from the human is used to **compress** air inside the tube of a simple tire pump.

Simple Heat Pump

Mechanical energy from the human is used to compress air inside the tube of a simple tire pump.

Air inadvertently gets **hot** as it is compressed to higher pressure.

Simple Heat Pump

Mechanical energy from the human is used to compress air inside the tube of a simple tire pump.

Air inadvertently gets **hot** as it is compressed to higher pressure.

In process of pumping air…
heat is also being pumped.

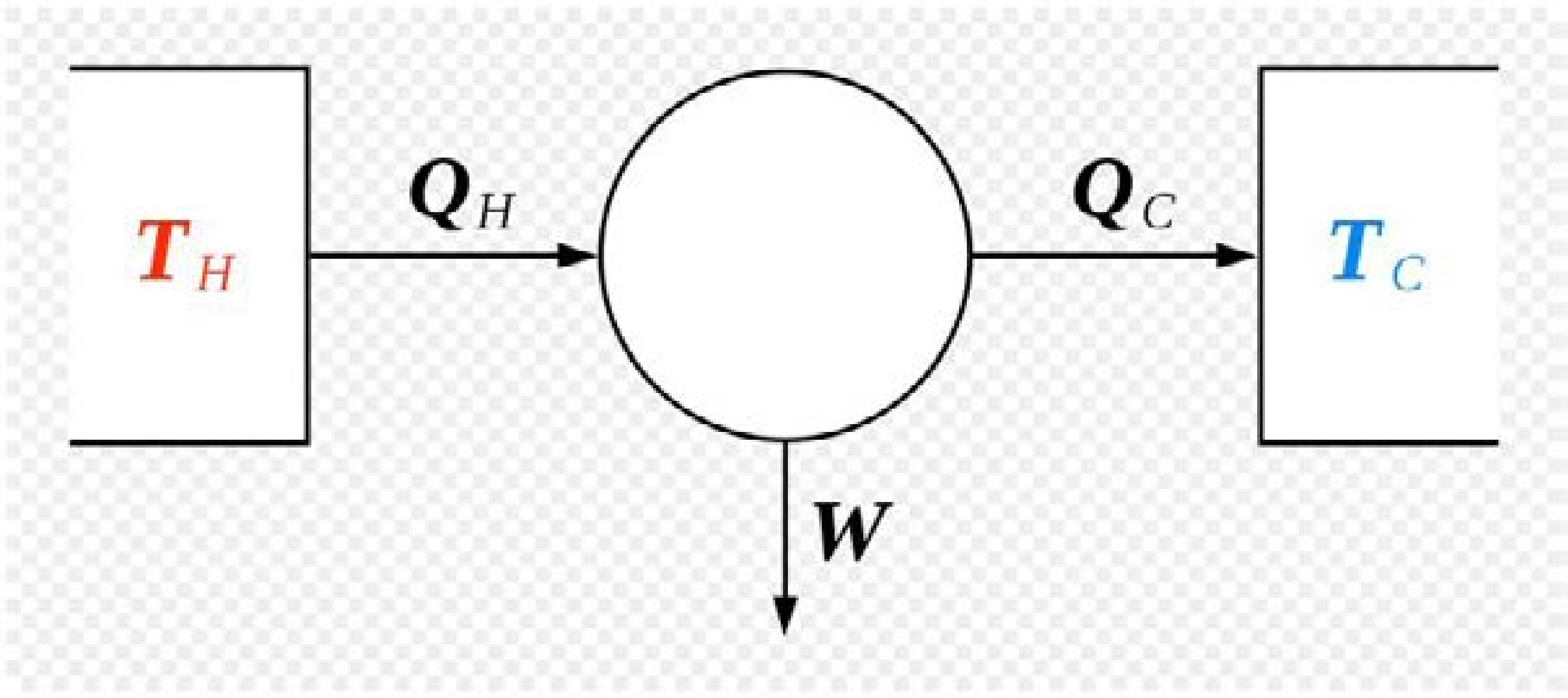
Introducing: The Compressor

The Compressor is the GSHP's **primary working unit** where gas is compressed, heated, and "pumped" to its heat exchange delivery point.

A **refrigerant** gas (with much better heat concentrating properties than air) is used.

SCROLL COMPRESSOR

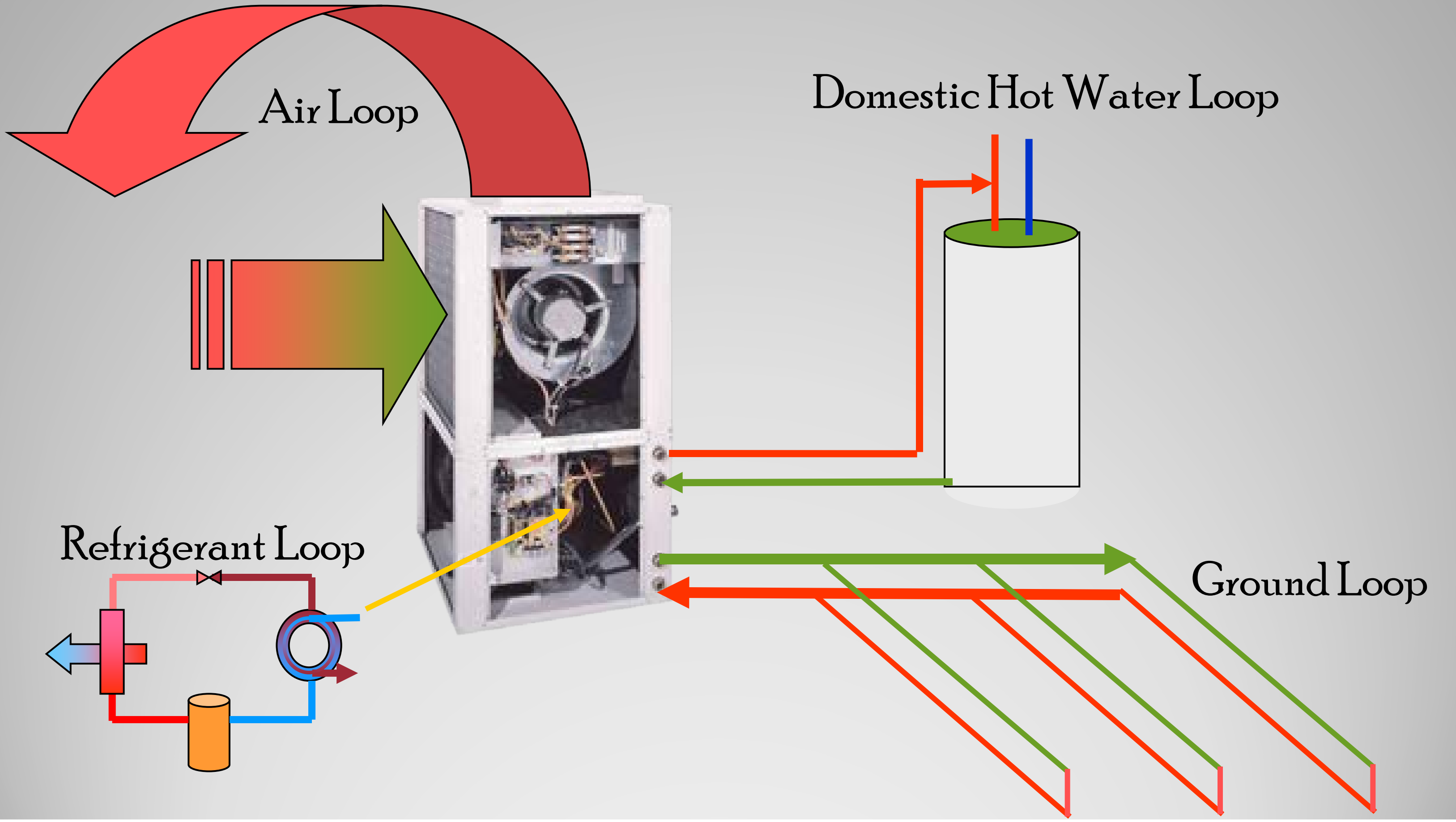
SCROLL: TOP VIEW



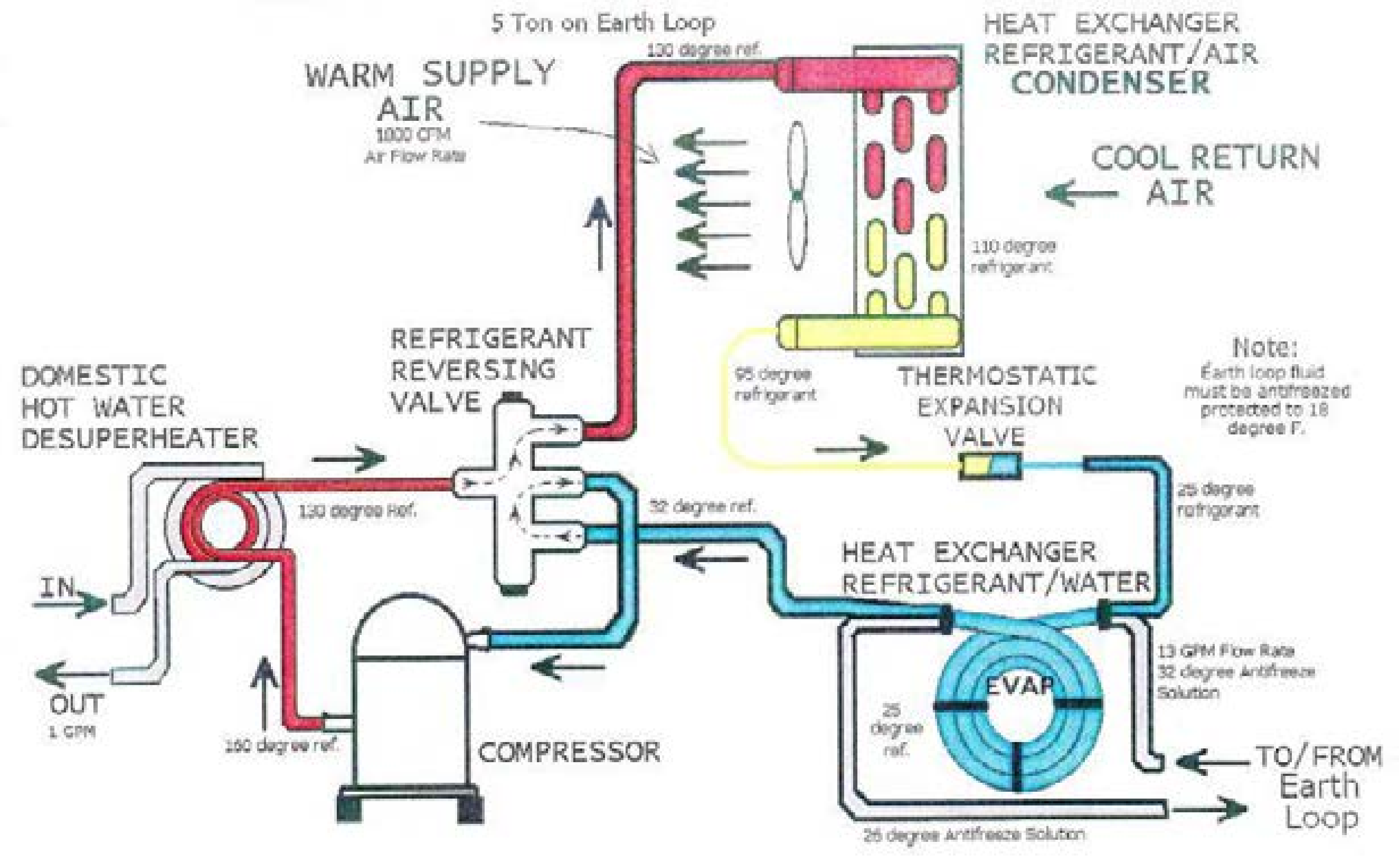
WIKIPEDIA: When two systems…are brought in diathermic contact with each other they exchange heat to establish a thermal equilibrium between each other.

SIMPLE INTERPRETATION: **Heat moves to Cold…Always!**

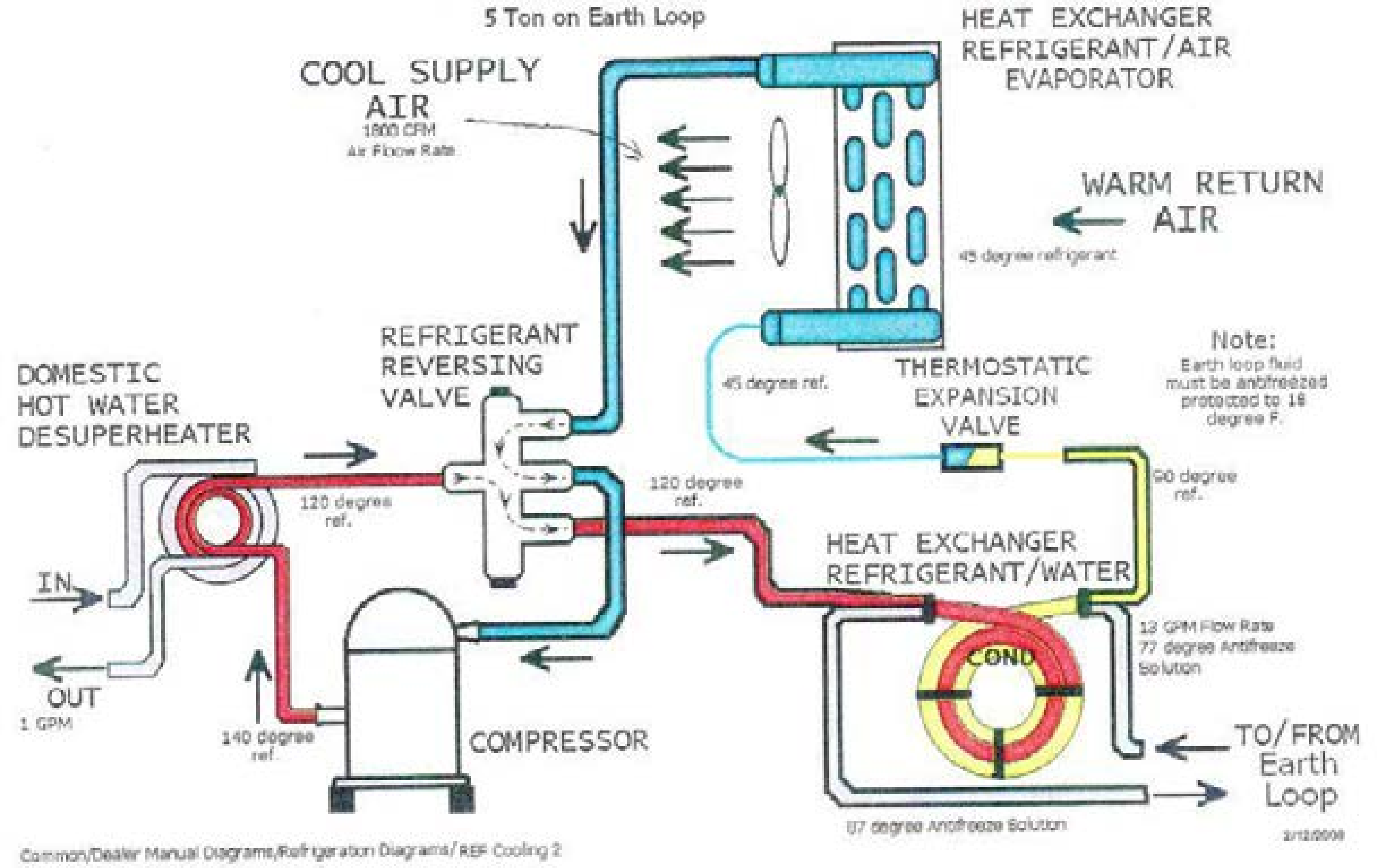
Zeroth Law of Thermodynamics



Typical Forced Air GSHP System

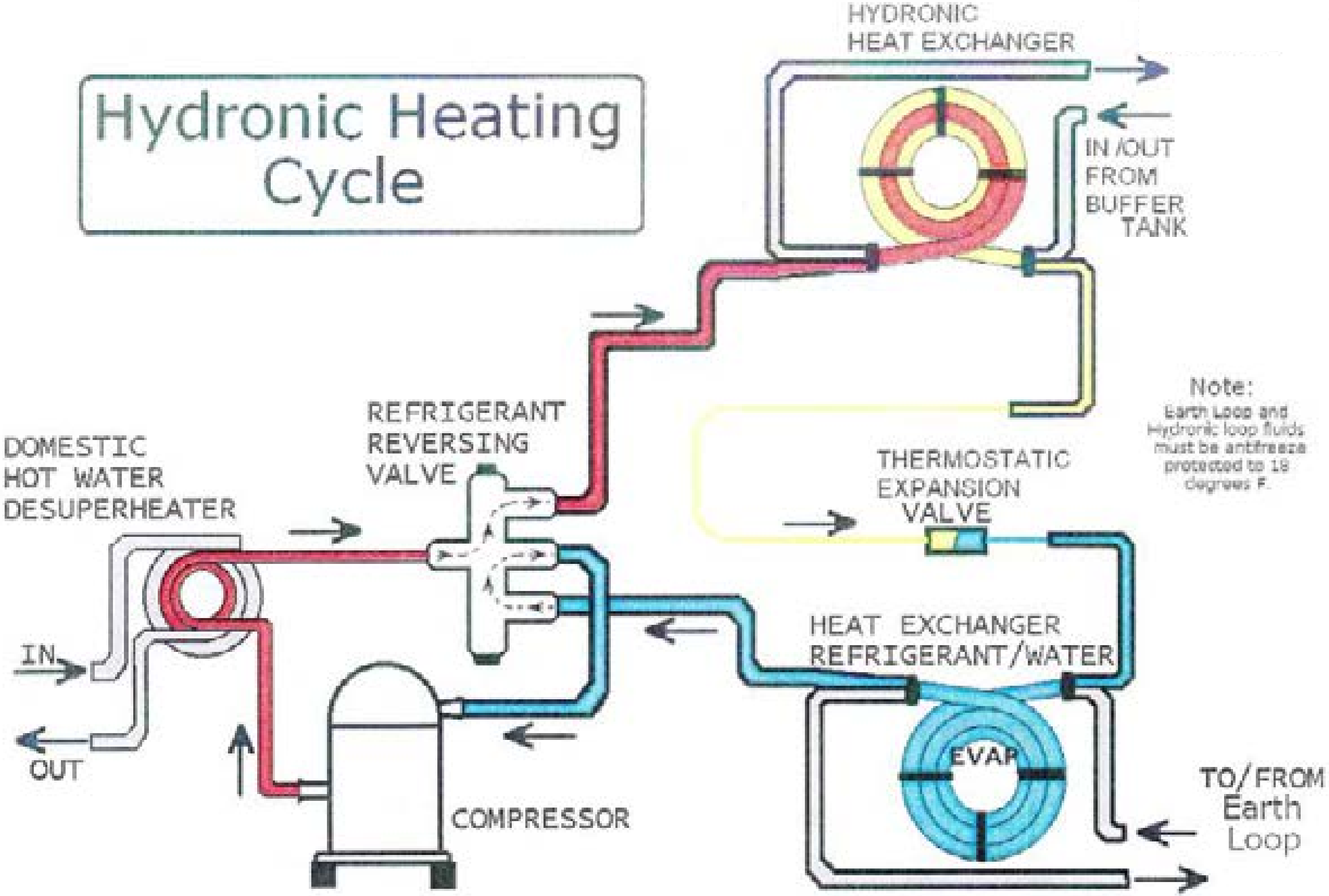


Forced Air GSHP Heating Cycle

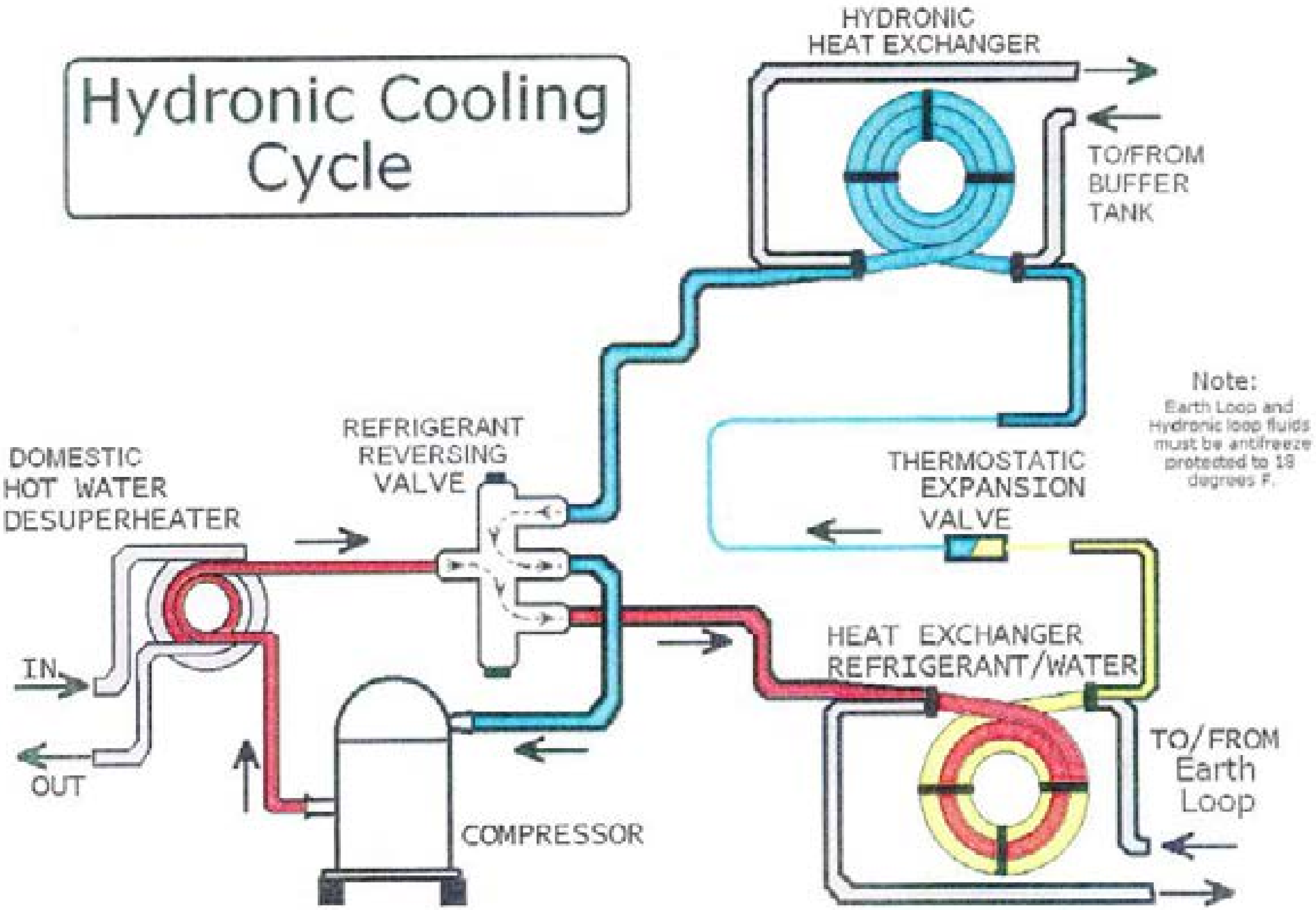


Forced Air GSHP Cooling Cycle

Hydronic Heating Cycle



Hydronic Cooling Cycle



Note:
Earth Loop and Hydronic loop fluids must be antifreeze protected to 18 degrees F.

QUESTIONS?

3. GSHP System Design

There are many variables to consider in GSHP system design.

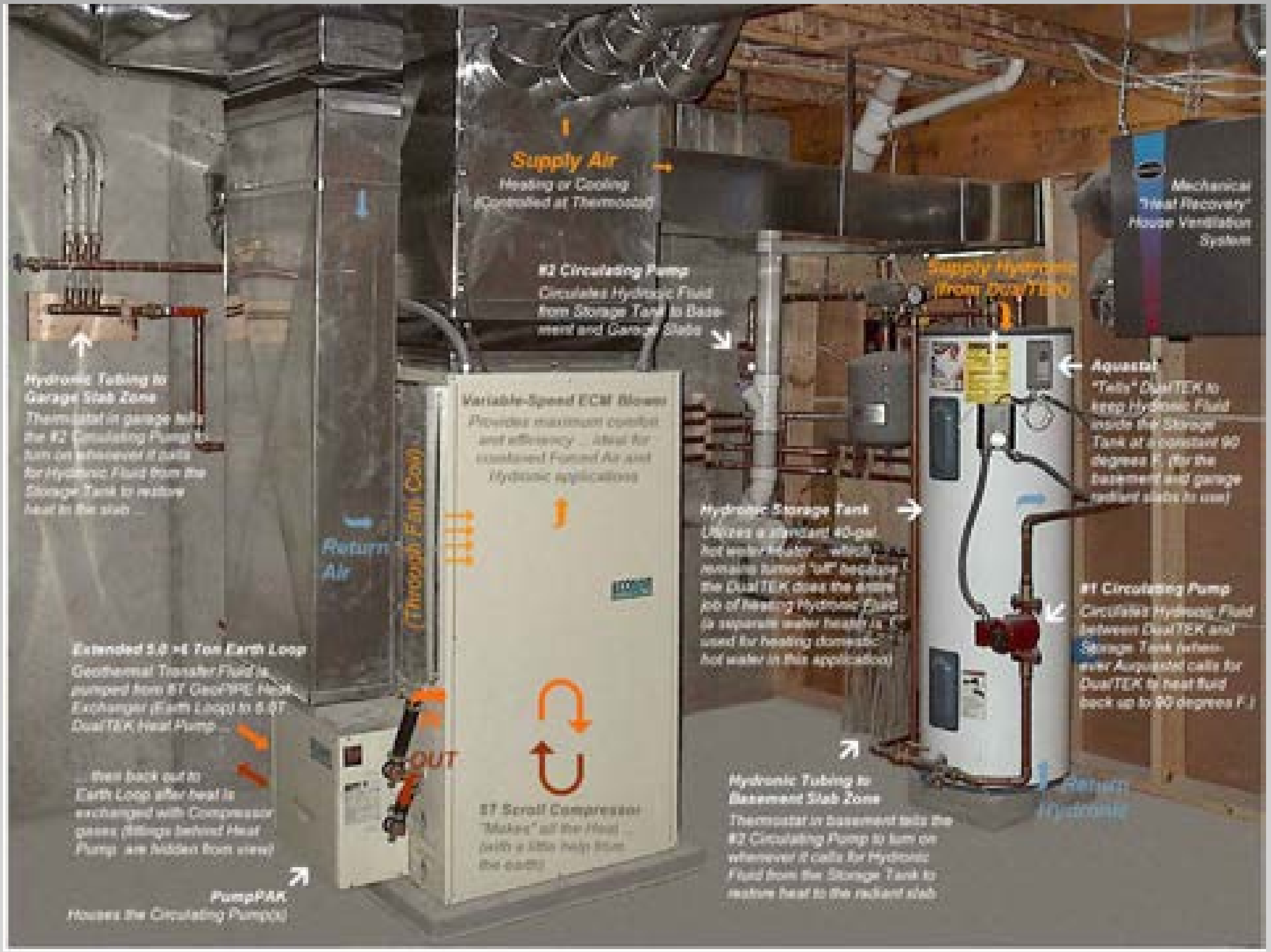
Supply Side (GSHP)

- Ground Heat Exchanger (GHEX)
- Ground Source Heat Pump (GSHP or GHP)
- Loop Pump or Flow Center
- Some Peripheral and Auxiliary Components (incl. Controls)

Delivery Side (HVAC)

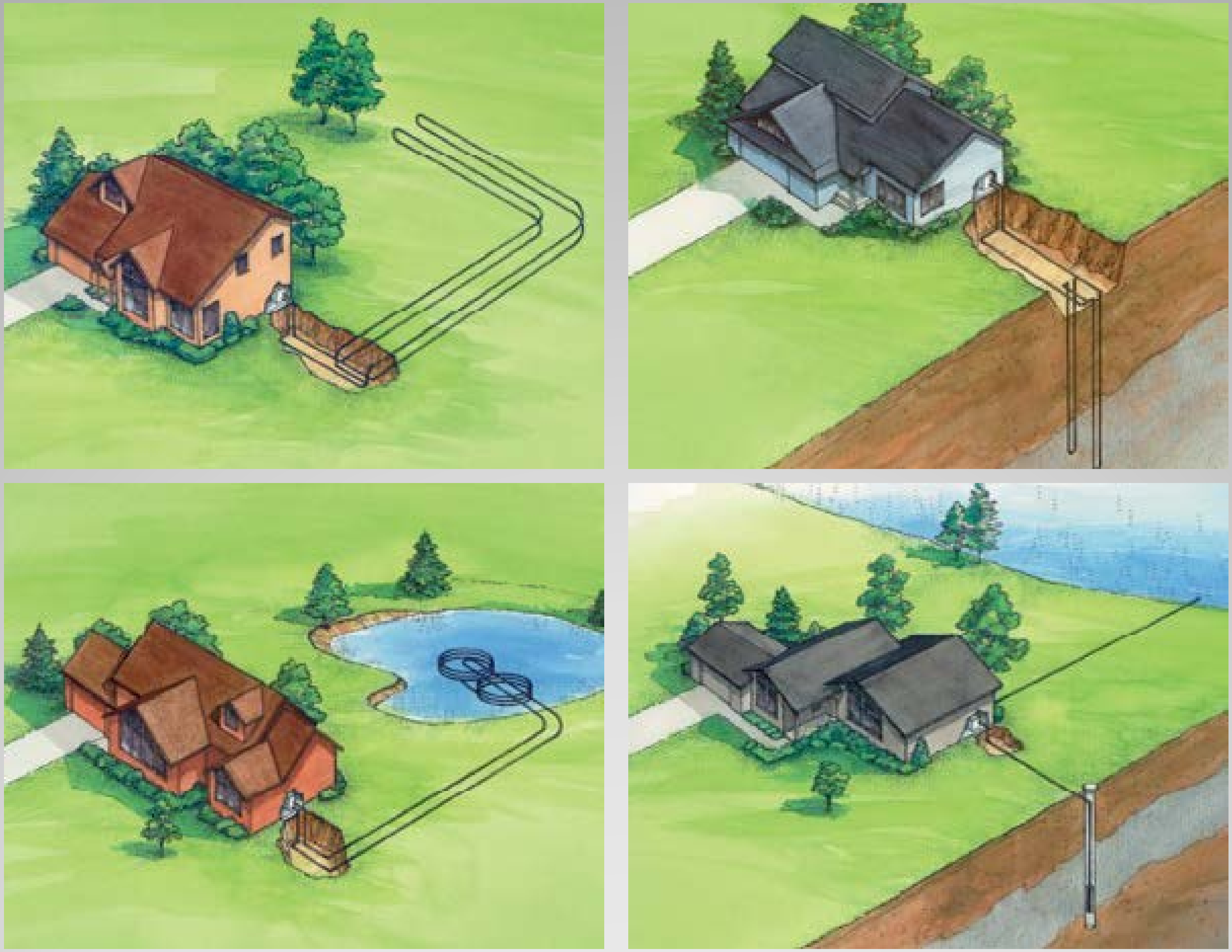
- Duct System (incl. Air Exchanger)
- Radiant Floor Tubing, Manifolds, Zone Pumps and Controls
- Radiant Baseboards, Panels, Radiators
- Plumbing/Piping Delivery Systems

The "geothermal system" is generally assigned to the "supply" side of heating/cooling functions.



Many GSHP/HVAC Considerations

(Owner must become "educated" & involved!)



Many GHEX/Earth Loop Options

(Who decides?... Who designs?)

Design Procedure

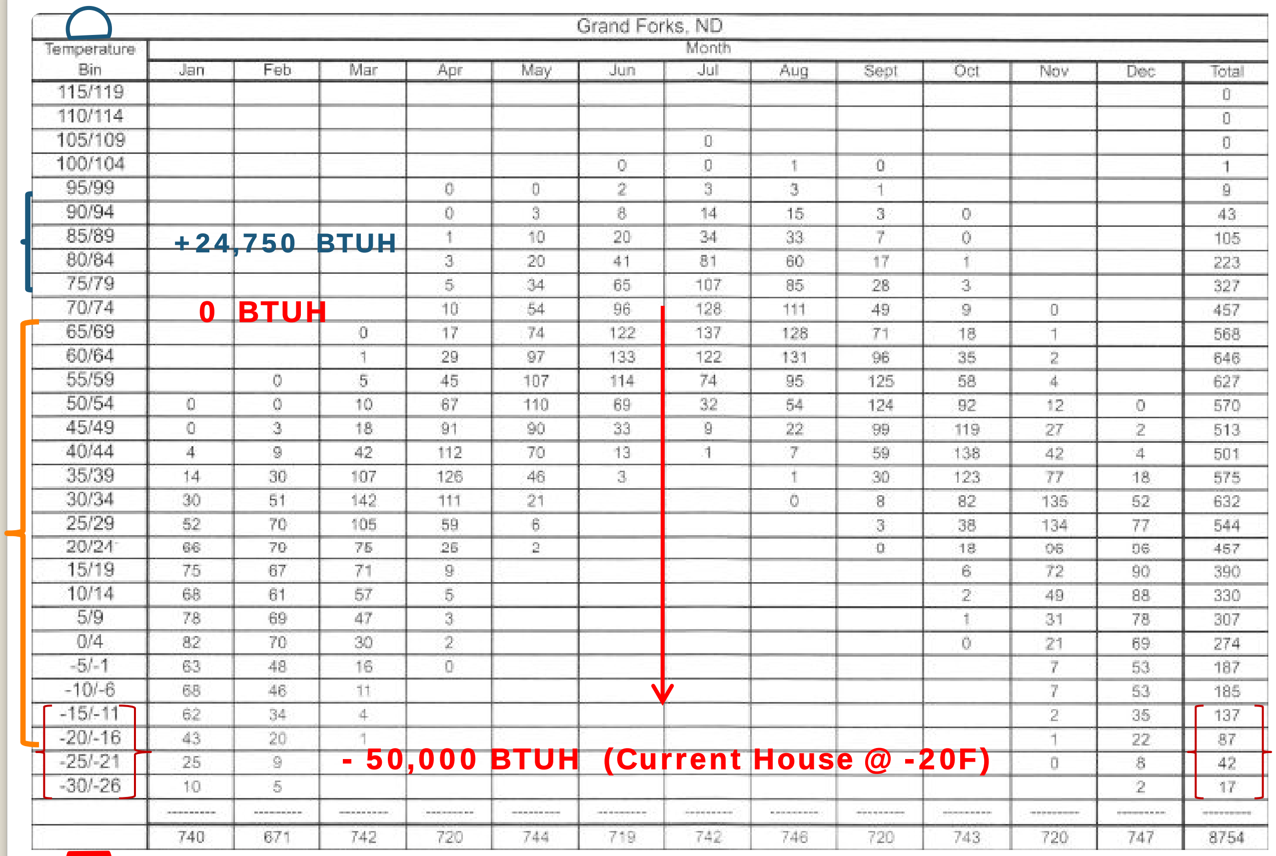
- Estimate Heating/Cooling loads (BTUH)
- Determine proper heat pump size(s)
- Select indoor air/water distribution system(s)
- Estimate the building's energy requirement
- Estimate the ground heat exchanger loads
  --Annual load
  --Design month load

DULUTH HOUSE: New Construction

- DULUTH INTL AP (Bin Weather Data)
- 50,000 BTUH Heat Loss (@ -20°F OAT)
- 24,750 BTUH Heat Gain (@ +84°F OAT)

- 5 Ton 3HT/2CL Forced Air Heat Pump **[<u>NOTE</u>: 1 Ton = 12,000 BTUH]**
- Compare to LP or NG Furnace w/AC

SIMPLE FORCED AIR EXAMPLE: 2,500 to 3,000 ft^2 House (Typical)



Grand Forks, ND

Temperature Bin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
115/119													0
110/114													0
105/109							0						0
100/104						0	0	1	0				1
95/99				0	0	2	3	3	1				9
90/94				0	3	8	14	15	3	0			43
85/89				1	10	20	34	33	7	0			105
80/84				3	20	41	81	60	17	1			223
75/79				5	34	65	107	85	28	3			327
70/74				10	54	96	128	111	49	9	0		457
65/69			0	17	74	122	137	128	71	18	1		568
60/64			1	29	97	133	122	131	96	35	2		646
55/59		0	5	45	107	114	74	95	125	58	4		627
50/54	0	0	10	67	110	69	32	54	124	92	12	0	570
45/49	0	3	18	91	90	33	9	22	99	119	27	2	513
40/44	4	9	42	112	70	13	1	7	59	138	42	4	501
35/39	14	30	107	126	46	3		1	30	123	77	18	575
30/34	30	51	142	111	21			0	8	82	135	52	632
25/29	52	70	105	59	6				3	38	134	77	544
20/24	66	70	75	26	2				0	18	06	06	457
15/19	75	67	71	9						6	72	90	390
10/14	68	61	57	5						2	49	88	330
5/9	78	69	47	3						1	31	78	307
0/4	82	70	30	2						0	21	69	274
-5/-1	63	48	16	0							7	53	187
-10/-6	68	46	11								7	53	185
-15/-11	62	34	4								2	35	137
-20/-16	43	20	1								1	22	87
-25/-21	25	9									0	8	42
-30/-26	10	5										2	17
	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------
	740	671	742	720	744	719	742	746	720	743	720	747	8754

+24,750 BTUH

0 BTUH

- 50,000 BTUH (Current House @ -20F)

Figure 3.6 Weather Bin Data for Grand Forks, ND

PEAK HEATING LOAD
per "DESIGN DAY"

Design to the most "reasonable" lowest outdoor temperature.

FOR EXAMPLE:
Duluth INT ≈ -20°F

THAT MEANS:

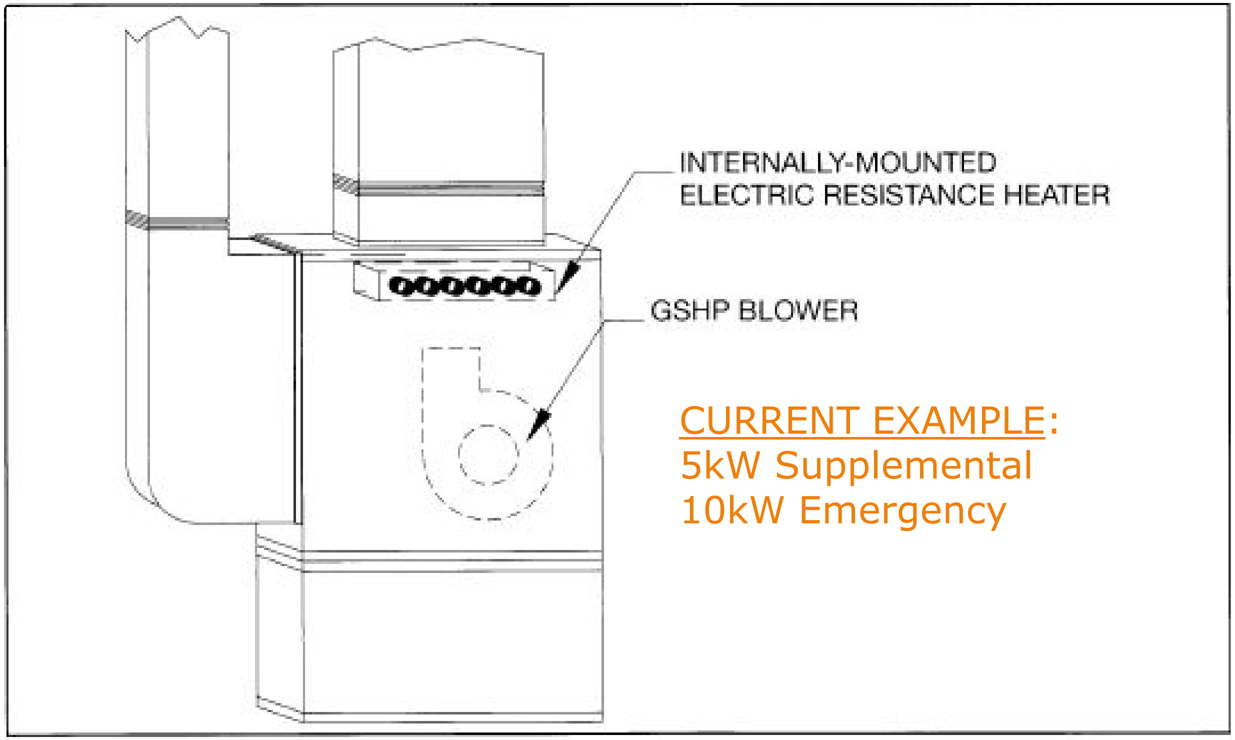
If the indoor temperature is kept at 70°F...

That is a **difference** of **90°F** between indoor and outdoor temperatures.

Simple Rule #1: *As it gets colder, the rate of structural heat loss increases.*

Auxiliary Electric Resistant Heat… Supplemental/Emergency Heat "Option"

1kW = 3,414 Btu



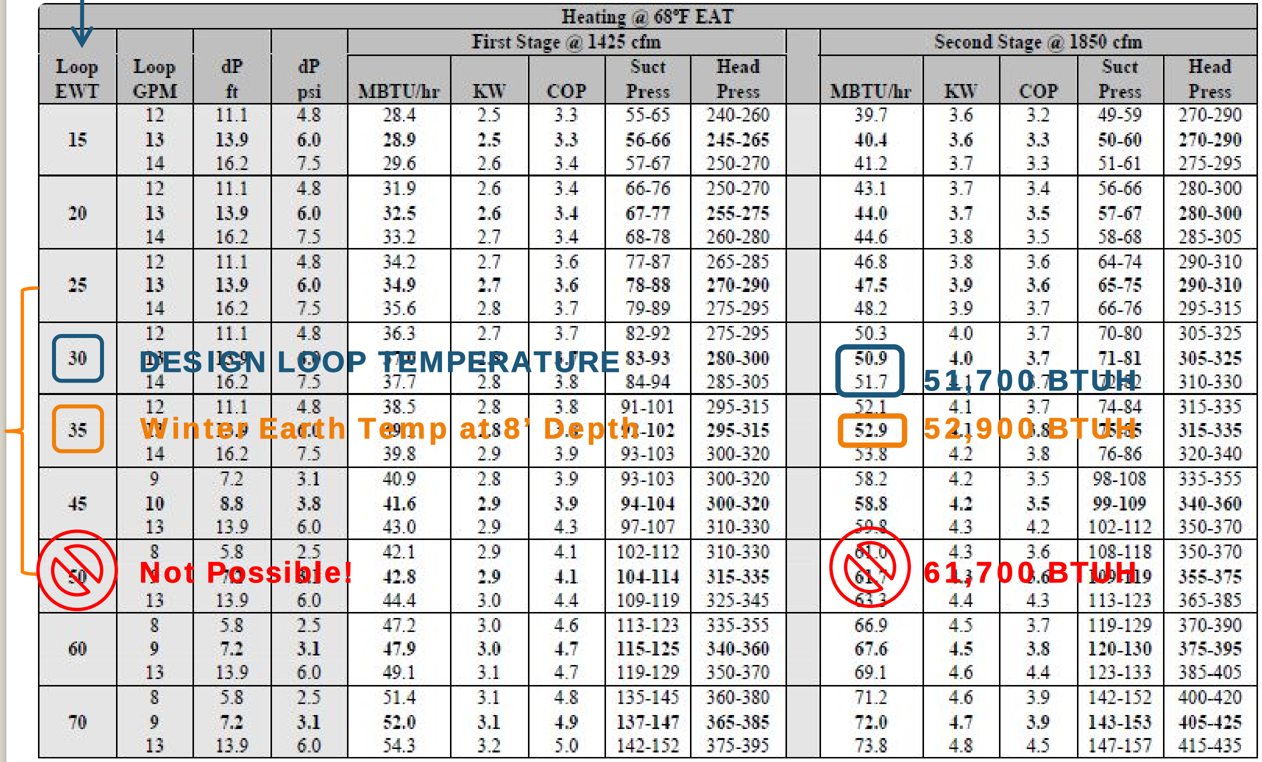
CURRENT EXAMPLE:
5kW Supplemental
10kW Emergency

PROPER USE:

- Brief intermittent "heat boost" for extreme cold periods (below balance point)
- Occasionally necessary GSHP/GHEX system sizing scale-back (site limitations)
- Availability of optional "emergency" heat
- Make up for undersized or inadequate GSHP installation—after the fact!

LOOP
TEMP.

[Current 5 Ton 3HT / 2CL Forced Air GSHP] GV / GH 580 / 581



Heating @ 68°F EAT													
				First Stage @ 1425 cfm					Second Stage @ 1850 cfm				
Loop EWT	Loop GPM	dP ft	dP psi	MBTU/hr	KW	COP	Suct Press	Head Press	MBTU/hr	KW	COP	Suct Press	Head Press
15	12	11.1	4.8	28.4	2.5	3.3	55-65	240-260	39.7	3.6	3.2	49-59	270-290
	13	13.9	6.0	28.9	2.5	3.3	56-66	245-265	40.4	3.6	3.3	50-60	270-290
	14	16.2	7.5	29.6	2.6	3.4	57-67	250-270	41.2	3.7	3.3	51-61	275-295
20	12	11.1	4.8	31.9	2.6	3.4	66-76	250-270	43.1	3.7	3.4	56-66	280-300
	13	13.9	6.0	32.5	2.6	3.4	67-77	255-275	44.0	3.7	3.5	57-67	280-300
	14	16.2	7.5	33.2	2.7	3.4	68-78	260-280	44.6	3.8	3.5	58-68	285-305
25	12	11.1	4.8	34.2	2.7	3.6	77-87	265-285	46.8	3.8	3.6	64-74	290-310
	13	13.9	6.0	34.9	2.7	3.6	78-88	270-290	47.5	3.9	3.6	65-75	290-310
	14	16.2	7.5	35.6	2.8	3.7	79-89	275-295	48.2	3.9	3.7	66-76	295-315
30	12	11.1	4.8	36.3	2.7	3.7	82-92	275-295	50.3	4.0	3.7	70-80	305-325
	13	13.9	6.0	[illegible]	[illegible]	3.7	83-93	280-300	50.9	4.0	3.7	71-81	305-325
	14	16.2	7.5	37.7	2.8	3.8	84-94	285-305	51.7	4.1	3.7	72-82	310-330
35	12	11.1	4.8	38.5	2.8	3.8	91-101	295-315	52.1	4.1	3.7	74-84	315-335
	13	13.9	6.0	39.1	2.8	[illegible]	[illegible]	295-315	52.9	4.1	3.8	75-85	315-335
	14	16.2	7.5	39.8	2.9	3.9	93-103	300-320	53.8	4.2	3.8	76-86	320-340
45	9	7.2	3.1	40.9	2.8	3.9	93-103	300-320	58.2	4.2	3.5	98-108	335-355
	10	8.8	3.8	41.6	2.9	3.9	94-104	300-320	58.8	4.2	3.5	99-109	340-360
	13	13.9	6.0	43.0	2.9	4.3	97-107	310-330	59.8	4.3	4.2	102-112	350-370
50	8	5.8	2.5	42.1	2.9	4.1	102-112	310-330	61.0	4.3	3.6	108-118	350-370
	9	7.2	3.1	42.8	2.9	4.1	104-114	315-335	61.7	4.3	3.6	109-119	355-375
	13	13.9	6.0	44.4	3.0	4.4	109-119	325-345	63.3	4.4	4.3	113-123	365-385
60	8	5.8	2.5	47.2	3.0	4.6	113-123	335-355	66.9	4.5	3.7	119-129	370-390
	9	7.2	3.1	47.9	3.0	4.7	115-125	340-360	67.6	4.5	3.8	120-130	375-395
	13	13.9	6.0	49.1	3.1	4.7	119-129	350-370	69.1	4.6	4.4	123-133	385-405
70	8	5.8	2.5	51.4	3.1	4.8	135-145	360-380	71.2	4.6	3.9	142-152	400-420
	9	7.2	3.1	52.0	3.1	4.9	137-147	365-385	72.0	4.7	3.9	143-153	405-425
	13	13.9	6.0	54.3	3.2	5.0	142-152	375-395	73.8	4.8	4.5	147-157	415-435

DESIGN LOOP TEMPERATURE

51,700 BTUH

Winter Earth Temp at 8' Depth

52,900 BTUH

Not Possible!

61,700 BTUH

30°F EWT suggested for 5T Horz. Earth Loop Designed to 8' Depth

PROPER GSHP SIZING
per "PEAK LOAD"

Design to the most reasonable minimum loop temperature.

FOR EXAMPLE:
NE Minnesota ≈ 30°F
NW Wisconsin ≈ 30°F

RESULT:

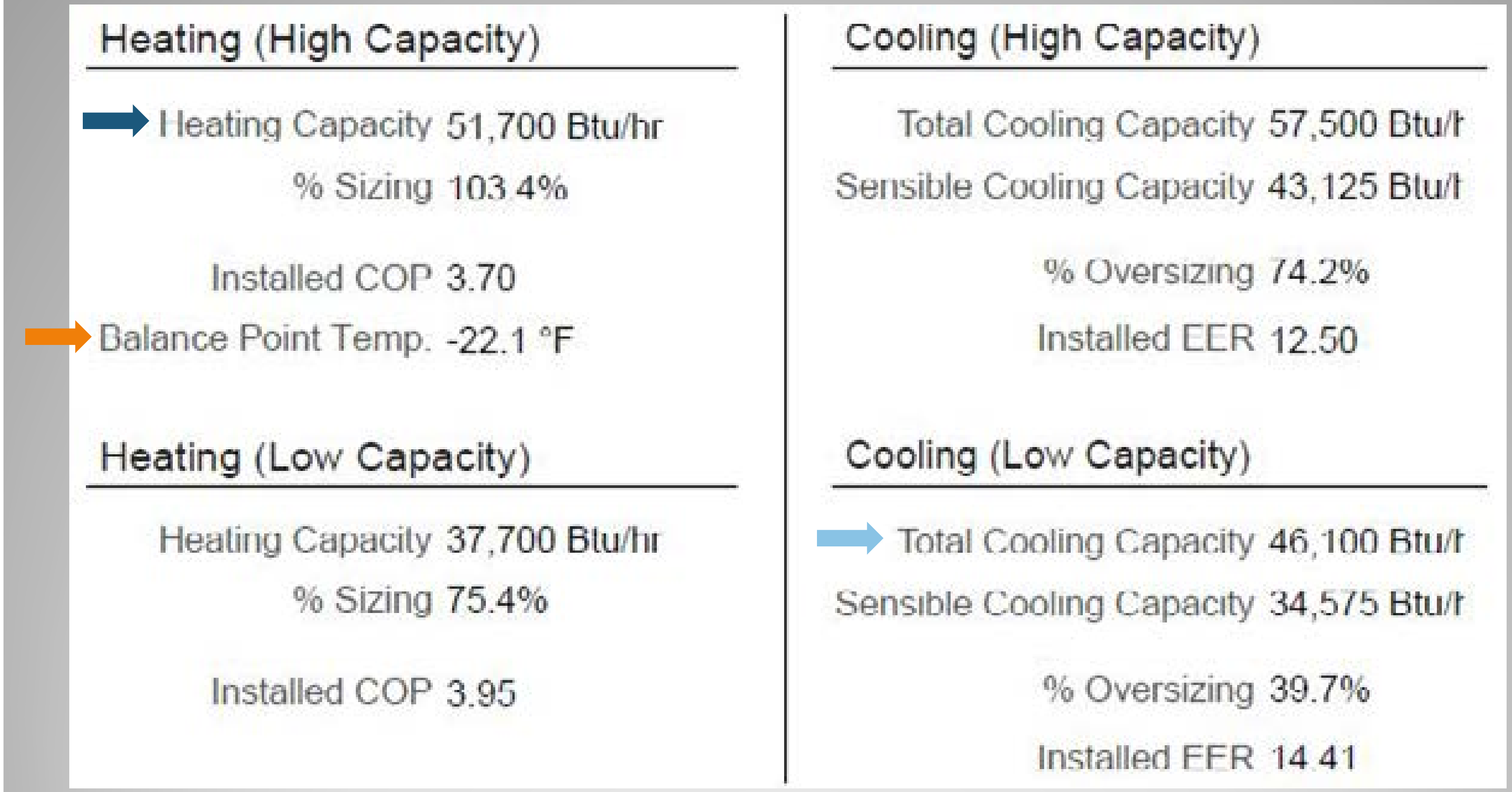
Reduces GHEX Installation Cost!

Remember Goal—
maximize benefits…
while *minimizing* cost!

Simple Rule #2: *Lower loop temp. = less GSHP heat output…but also less loop cost!*

Concentration (by Volume)	Propylene Glycol	Methanol	Ethanol
	Freeze Point (˚F)		
5.0%	29.3	26.2	29.5
7.5%	27.7	23.0	28.1
10.0%	26.1	19.7	26.4
12.5%	24.4	16.2	24.6
15.0%	22.5	12.6	22.6
17.5%	20.5	8.8	20.4
20.0%	18.4	4.9	18.1
22.5%	16.1	--	15.6
25.0%	13.8	--	12.9
27.5%	11.3	--	10.0
30.0%	8.8	--	7.0

Antifreeze protection is required for lower loop temperatures (i.e., <u>Leaving</u> Water Temperature).



Heating (High Capacity)

Heating Capacity	51,700 Btu/hr
% Sizing	103.4%
Installed COP	3.70
Balance Point Temp.	-22.1 °F

Heating (Low Capacity)

Heating Capacity	37,700 Btu/hr
% Sizing	75.4%
Installed COP	3.95

Cooling (High Capacity)

Total Cooling Capacity	57,500 Btu/h
Sensible Cooling Capacity	43,125 Btu/h
% Oversizing	74.2%
Installed EER	12.50

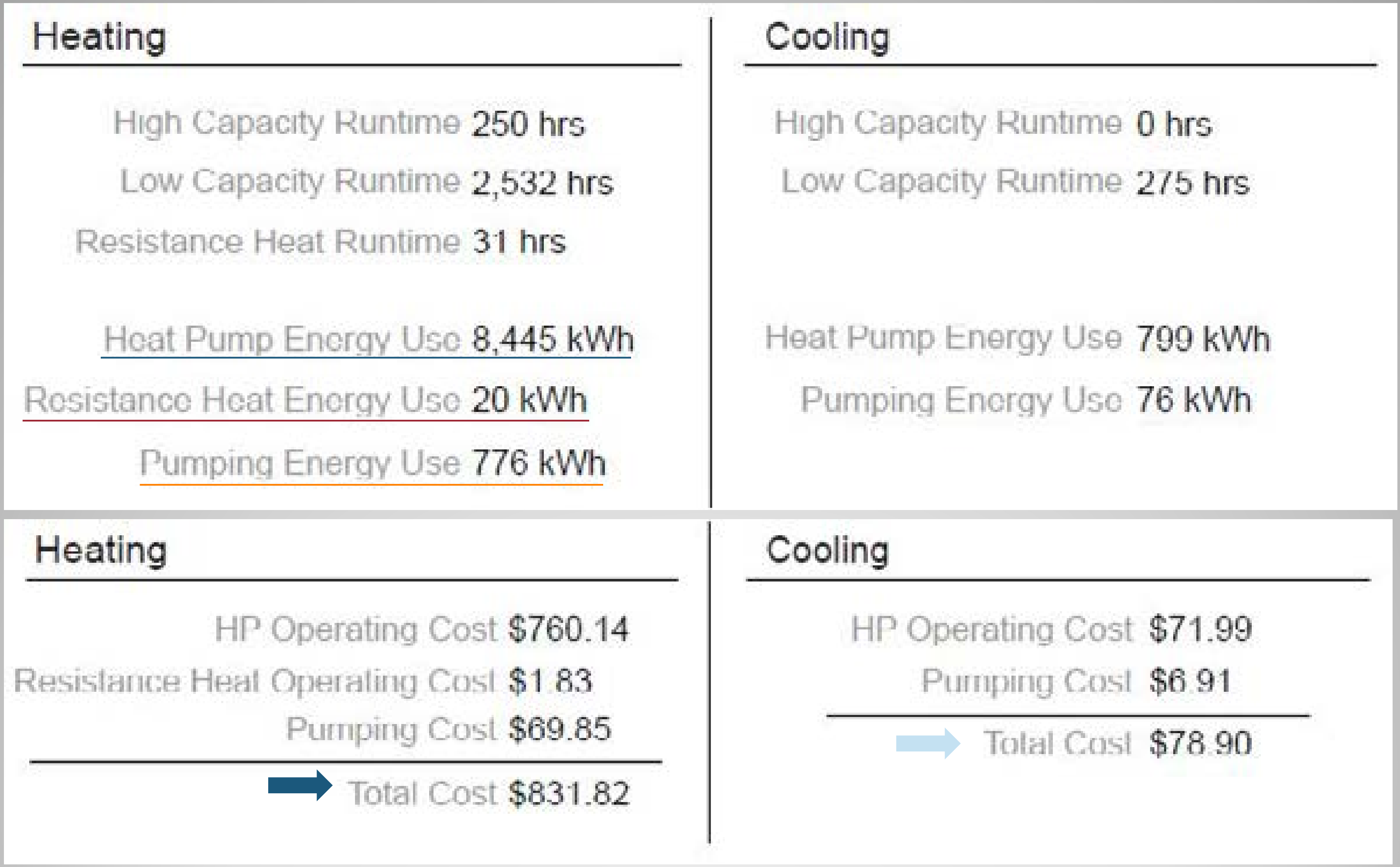
Cooling (Low Capacity)

Total Cooling Capacity	46,100 Btu/h
Sensible Cooling Capacity	34,575 Btu/h
% Oversizing	39.7%
Installed EER	14.41

51,700 BTUH GSHP CAP @ 30F EWT

50,000 BTUH Heating Load @ -20°F

5T GSHP Runtime & Operating Cost



Heating

High Capacity Runtime	250 hrs
Low Capacity Runtime	2,532 hrs
Resistance Heat Runtime	31 hrs
Heat Pump Energy Use	8,445 kWh
Resistance Heat Energy Use	20 kWh
Pumping Energy Use	776 kWh

Cooling

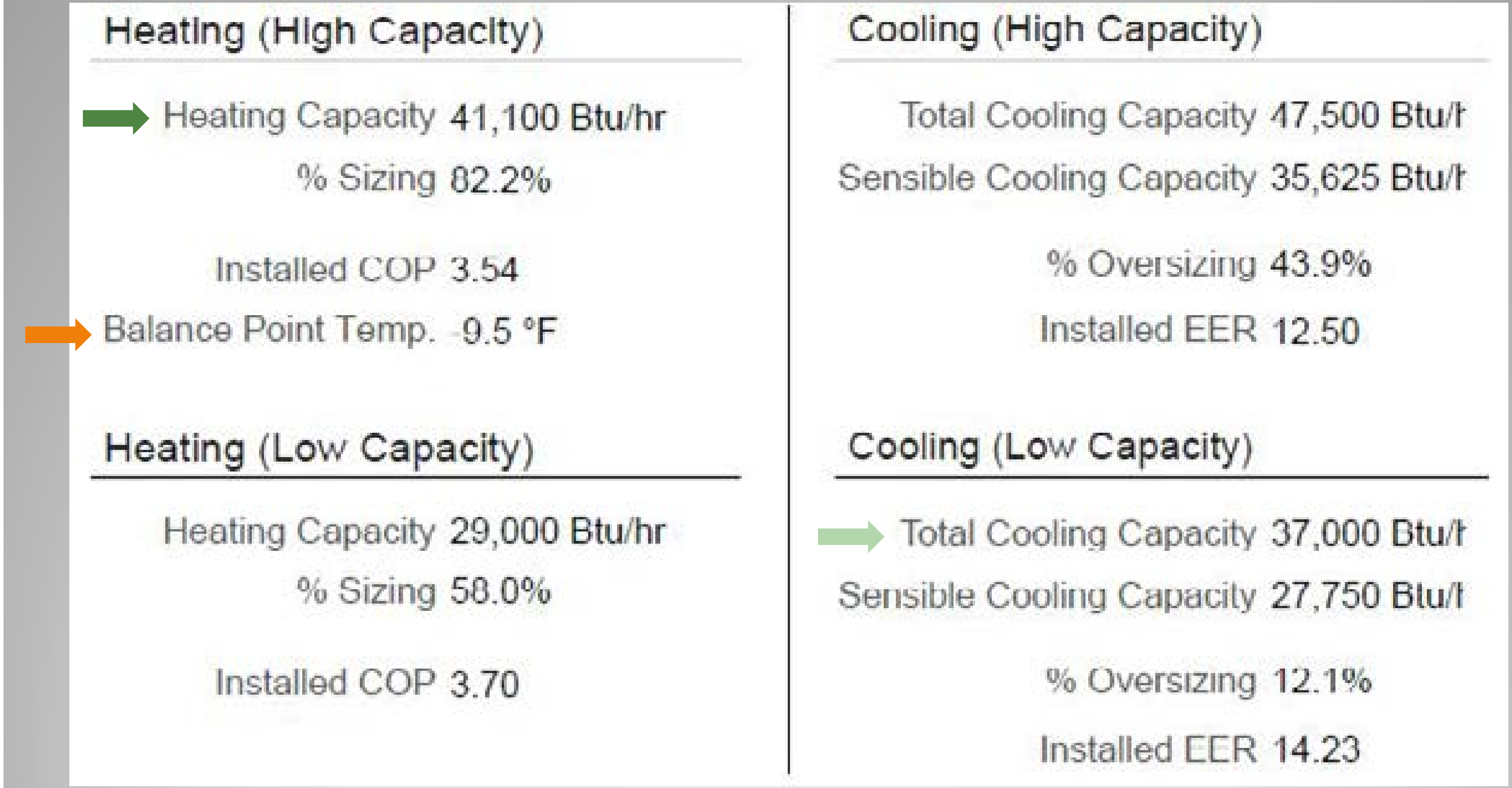
High Capacity Runtime	0 hrs
Low Capacity Runtime	275 hrs
Heat Pump Energy Use	799 kWh
Pumping Energy Use	76 kWh

Heating

HP Operating Cost	$760.14
Resistance Heat Operating Cost	$1.83
Pumping Cost	$69.85
Total Cost	$831.82

Cooling

HP Operating Cost	$71.99
Pumping Cost	$6.91
Total Cost	$78.90



Heating (High Capacity)

Heating Capacity	41,100 Btu/hr
% Sizing	82.2%
Installed COP	3.54
Balance Point Temp.	-9.5 °F

Heating (Low Capacity)

Heating Capacity	29,000 Btu/hr
% Sizing	58.0%
Installed COP	3.70

Cooling (High Capacity)

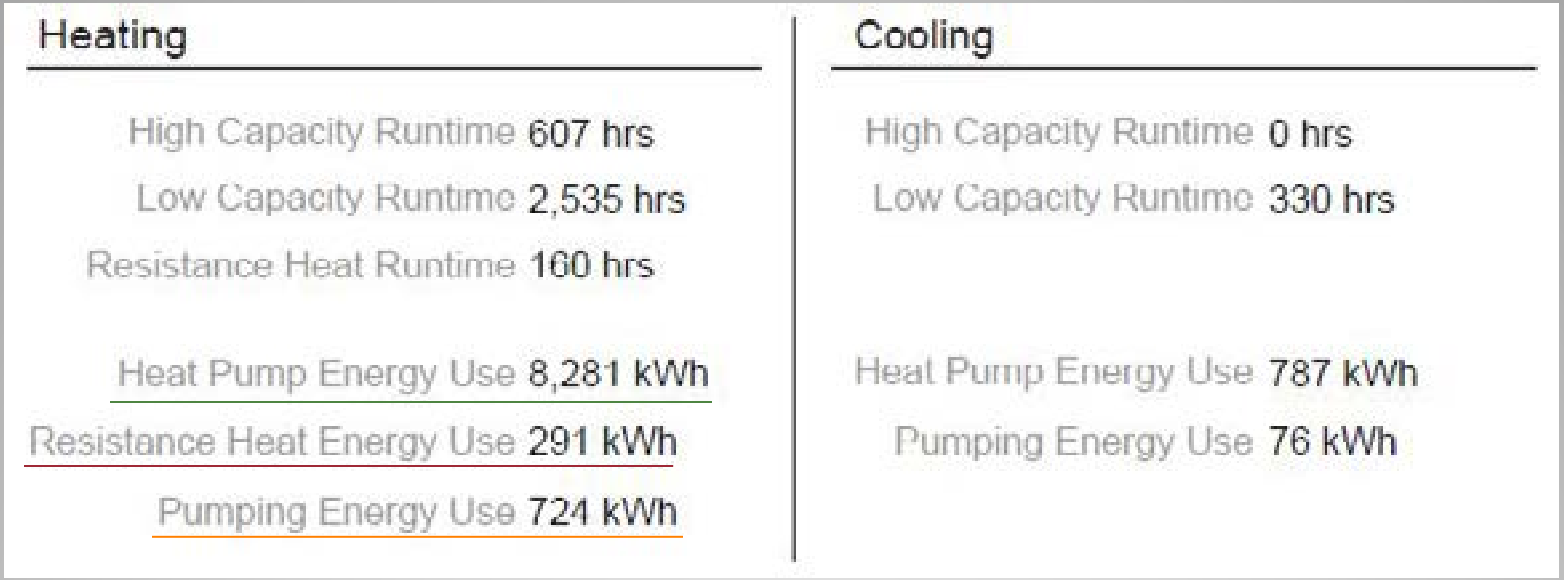
Total Cooling Capacity	47,500 Btu/h
Sensible Cooling Capacity	35,625 Btu/h
% Oversizing	43.9%
Installed EER	12.50

Cooling (Low Capacity)

Total Cooling Capacity	37,000 Btu/h
Sensible Cooling Capacity	27,750 Btu/h
% Oversizing	12.1%
Installed EER	14.23

41,100 BTUH GSHP CAP @ 30F EWT

50,000 BTUH Heating Load @ -20°F



Heating

High Capacity Runtime 607 hrs
Low Capacity Runtime 2,535 hrs
Resistance Heat Runtime 160 hrs

Heat Pump Energy Use 8,281 kWh
Resistance Heat Energy Use 291 kWh
Pumping Energy Use 724 kWh

Cooling

High Capacity Runtime 0 hrs
Low Capacity Runtime 330 hrs

Heat Pump Energy Use 787 kWh
Pumping Energy Use 76 kWh

Heating

HP Operating Cost $745.30
Resistance Heat Operating Cost $26.21
Pumping Cost $65.16

Total Cost $836.67

Cooling

HP Operating Cost $70.83
Pumping Cost $6.86

Total Cost $77.69

4.0<5T GSHP Runtime & Operating Cost

51,700 BTUH GSHP CAP
$831.82 Annual Heating Cost

41,100 BTUH GSHP CAP
$836.67 Annual Heating Cost

System Type	Heating	Cooling	Total	vs. GSHP
Ground Source Heat Pump (GSHP)	$836.67	$77.69	$914.36	—
RH	$3,044.93	$70.14	$3,115.07	$2,200.71
ASHP	$1,732.06	$70.14	$1,802.20	$887.84
Nat Gas	$1,807.48	$70.14	$1,877.62	$963.26
Propane	$3,493.93	$70.14	$3,564.07	$2,649.71
Fuel Oil	$3,669.95	$70.14	$3,740.09	$2,825.73

Similar Result?...What’s the Hitch?

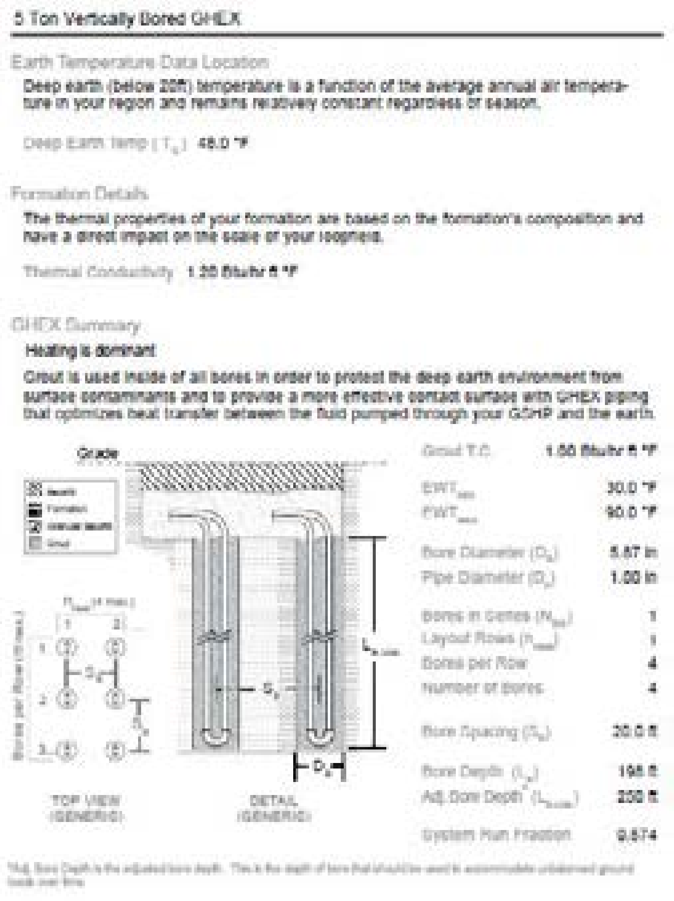
5,068 ft. Total Pipe

4,796 ft. Total Pipe

Saves Only 272 ft. of Total Pipe

GHEX Sizing (i.e., cost)…about the same!

4 X 250 ft. Total Bore



5 Ton Vertically Bored GHEX

Earth Temperature Data Location

Deep earth (below 20ft) temperature is a function of the average annual air temperature in your region and remains relatively constant regardless of season.

Deep Earth Temp (T_g) 48.0 °F

Formation Details

The thermal properties of your formation are based on the formation's composition and have a direct impact on the scale of your loopfield.

Thermal Conductivity 1.20 Btu/hr ft °F

GHEX Summary

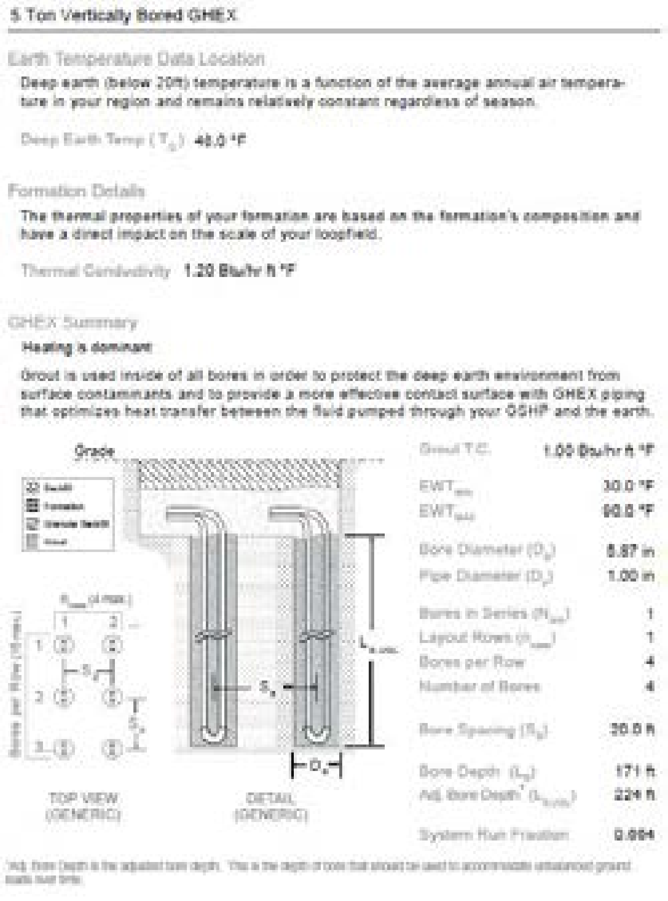
Heating is dominant

Grout is used inside of all bores in order to protect the deep earth environment from surface contaminants and to provide a more effective contact surface with GHEX piping that optimizes heat transfer between the fluid pumped through your GSHP and the earth.

Grout T.C.	1.00 Btu/hr ft °F
EWT_{min}	30.0 °F
EWT_{max}	90.0 °F
Bore Diameter (D_b)	5.87 in
Pipe Diameter (D_p)	1.00 in
Bores in Series (N_{ser})	1
Layout Rows (n_{rows})	1
Bores per Row	4
Number of Bores	4
Bore Spacing (S_b)	20.0 ft
Bore Depth (L_b)	196 ft
Adj. Bore Depth* ($L_{b,adj}$)	250 ft
System Run Fraction	0.574

*Adj. Bore Depth is the adjusted bore depth. This is the depth of bore that should be used to accommodate unbalanced ground loads over time.

4 X 224 ft. Total Bore



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Bore Diameter (D_b)	5.87 in
Pipe Diameter (D_p)	1.00 in
Bores in Series (N_{ser})	1
Layout Rows (n_{rows})	1
Bores per Row	4
Number of Bores	4
Bore Spacing (S_b)	20.0 ft
Bore Depth (L_b)	171 ft
Adj. Bore Depth* ($L_{b,adj}$)	224 ft
System Run Fraction	0.664

*Adj. Bore Depth is the adjusted bore depth. This is the depth of bore that should be used to accommodate unbalanced ground loads over time.

Saves 26 ft. Off Each Bore Hole

(Slightly More Savings on Drilling)

- Cooling-Dominant Derived Rule: *Do not size GSHP heating capacity more than 25% above the cooling load (impractical?)*

- Manufacturer-Derived Rule: *Do not size GSHP to less than 85% of the peak heating load (roughly 1 Ton undersizing)*

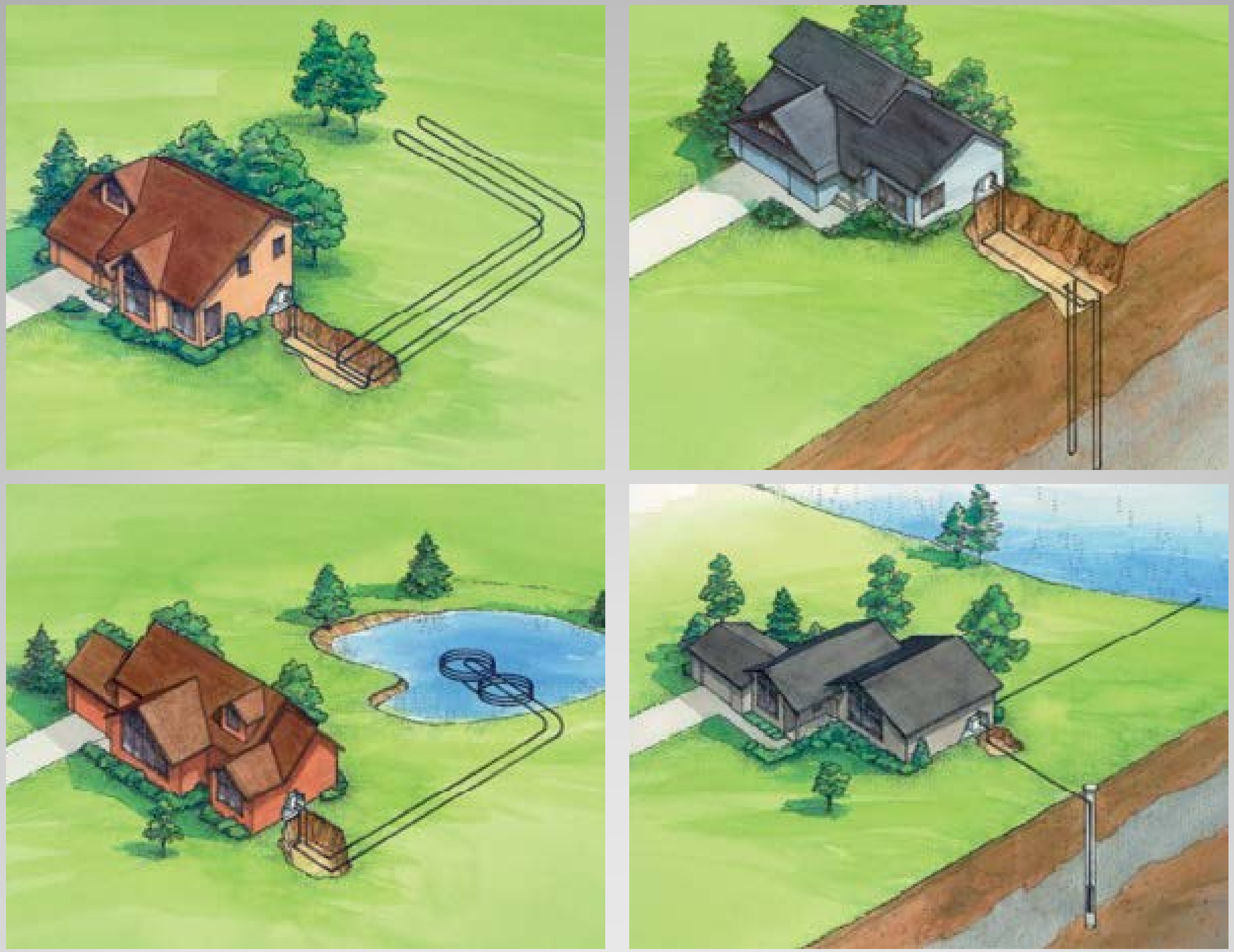
- Cold Climate Sizing Trend: *Size to perform 96-100% of all the heating (but consider sizing scale-back for honest "hardships")*

GSHP Sizing Rules of Thumb

QUESTIONS?

4. Earth Loop Considerations are Site Specific

Is there a single “best way” to do it?...There are *many* options!



Common GHEX/Loop Options

Common GHEX/Loop Options

GHEX Options by General Descending Cost:

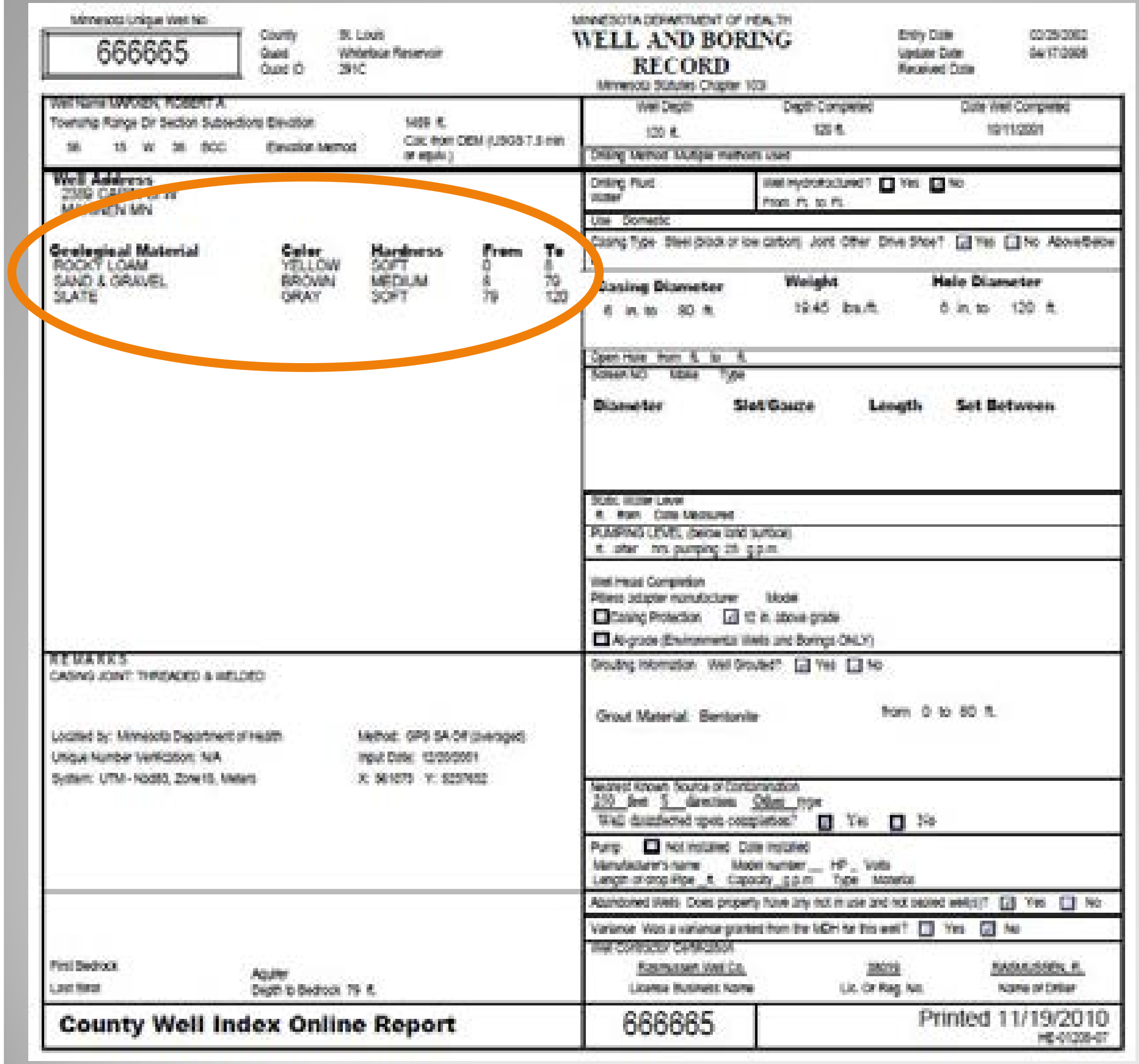
- Vertically Bored in Rock
- Vertically Bored “Standing Column” (Rock)
- Vertically Bored in Deep Soil/Overburden
- Horizontally Drilled
- Horizontally Trenched or Excavated
- Lake Loop (Permit?)
- Pond Loop (Existing Pond)
- Open Loop / Pump & Dump

Wetlands

Wetland concerns must be evaluated on every site… *prior* to breaking ground. It may not be completely evident that an area is actually classified as type of wetland until inspected by the proper authority.

Required Sequencing:

- AVOID
- MINIMIZE
- MITIGATE



Minnesota Unique Well No.
666665

County St. Louis
Quad Whiteface Reservoir
Quad ID 39C

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD
Minnesota Statutes Chapter 103I

Entry Date 02/28/2002
Update Date 04/17/2008
Received Date

Well Name MAKINEN, ROBERT A.
Township Range Dir Section Subsections Elevation 1458 ft.
56 15 W 36 BCC
Elevation Method Cal. from DEM (USGS 7.5 min or equiv.)

Well Depth 120 ft.
Depth Completed 120 ft.
Date Well Completed 10/11/2001

Drilling Method Multiple methods used
Drilling Fluid Water
Well Hydrofractured? ☐ Yes ☒ No
From ft. to ft.
Use Domestic

Well Address

Geological Material	**Color**	**Hardness**	**From**	**To**
ROCKY LOAM	YELLOW	SOFT	0	6
SAND & GRAVEL	BROWN	MEDIUM	6	79
SLATE	GRAY	SOFT	79	120

Casing Diameter 6 in. to 80 ft.
Weight 19.45 lbs./ft.
Hole Diameter 6 in. to 120 ft.

Open Hole from ft. to ft.

Diameter **Slot/Gauze** **Length** **Set Between**

Static Water Level

Well Head Completion

Grouting Information Well Grouted? ☑ Yes ☐ No
Grout Material: Bentonite from 0 to 80 ft.

REMARKS
CASING JOINT: THREADED & WELDED

Located by: Minnesota Department of Health
Method: GPS SA Off (averaged)
Unique Number Verification: N/A
Input Date: 12/20/2001
System: UTM - Nad83, Zone15, Meters
X: 561073 Y: 5237602

First Bedrock
Aquifer
Last Strat
Depth to Bedrock 79 ft.

Variance Was a variance granted from the MDH for this well? ☐ Yes ☑ No

Well Contractor Certification
Rasmussen Well Co.
License Business Name

County Well Index Online Report
666665
Printed 11/19/2010

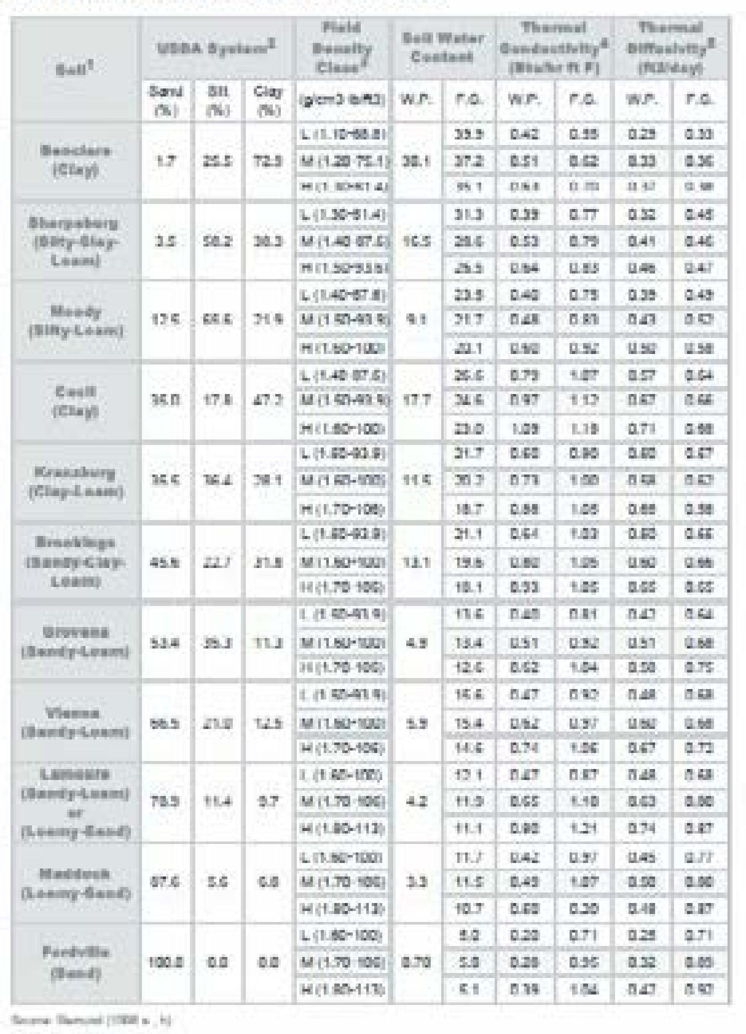
Well Logs

Well logs can provide excellent information about local geological formations and soil types.

MN County Well Index:

http://www.health.state.mn.us/divs/eh/cwi/

Site test boring data can also be very useful!



Thermal Properties for Various Soils

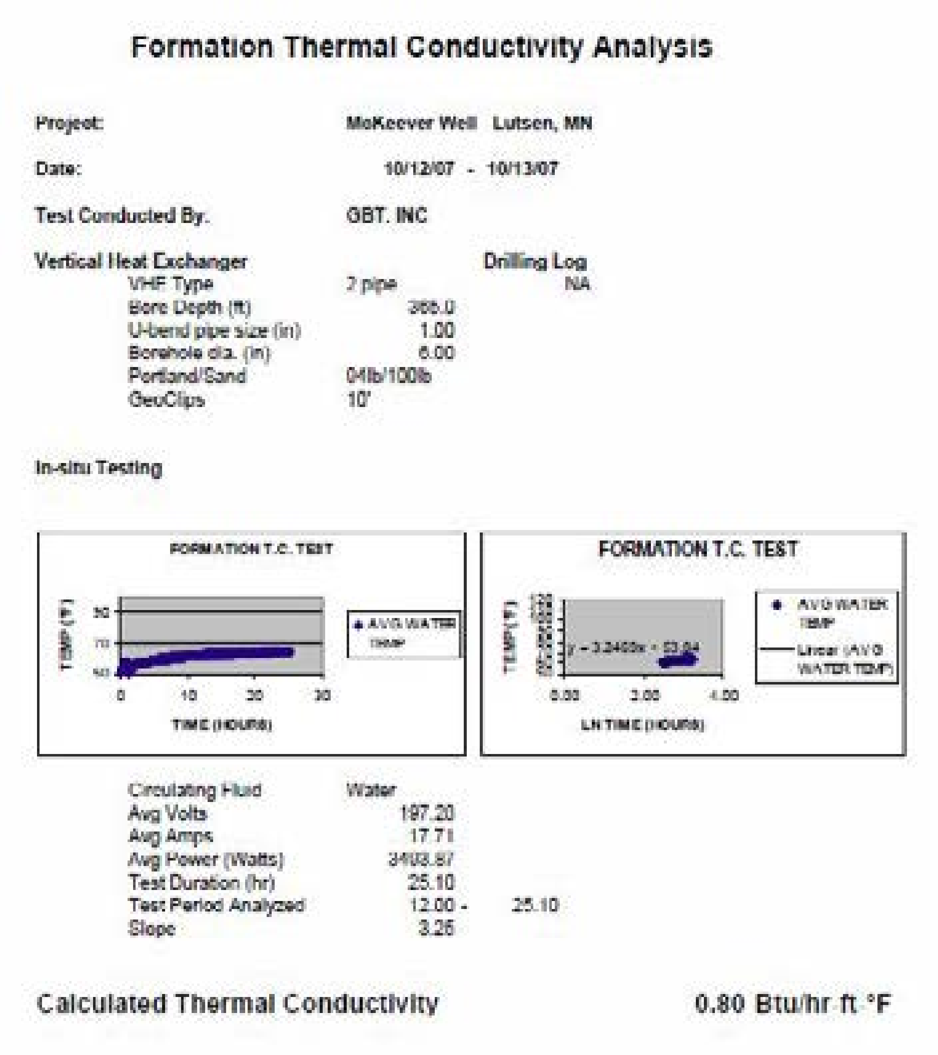
Soil[1]	USDA System[2]			Field Density Class[3]	Soil Water Content		Thermal Conductivity[4] (Btu/hr ft F)		Thermal Diffusivity[5] (ft2/day)	
	Sand (%)	Silt (%)	Clay (%)	(g/cm3 lb/ft3)	W.P.	F.C.	W.P.	F.C.	W.P.	F.C.
Benclare (Clay)	1.7	25.5	72.8	L (1.10-68.8)	30.1	33.9	0.42	0.55	0.29	0.33
				M (1.20 75.1)		37.2	0.51	0.62	0.33	0.36
				H (1.30-81.4)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sharpsburg (Silty-Clay-Loam)	3.5	58.2	38.3	L (1.30-81.4)	16.5	31.3	0.39	0.77	0.32	0.45
				M (1.40 87.6)		28.6	0.53	0.79	0.41	0.46
				H (1.50-93.6)		25.5	0.64	0.83	0.46	0.47
Moody (Silty-Loam)	17.5	60.6	21.9	L (1.40-87.6)	9.1	23.5	0.40	0.75	0.39	0.49
				M (1.50-93.6)		21.7	0.48	0.83	0.43	0.52
				H (1.60-100)		20.1	0.60	0.92	0.52	0.58
Cecil (Clay)	35.0	17.8	47.2	L (1.40 87.6)	17.7	26.6	0.79	1.07	0.57	0.64
				M (1.50-93.6)		24.6	0.97	1.12	0.67	0.66
				H (1.60-100)		23.0	1.09	1.18	0.71	0.68
Kranzburg (Clay-Loam)	35.5	36.4	28.1	L (1.50-93.6)	11.5	21.7	0.60	0.90	0.50	0.67
				M (1.60-100)		20.7	0.73	1.00	0.58	0.62
				H (1.70-106)		18.7	0.88	1.05	0.68	0.58
Brookings (Sandy-Clay-Loam)	45.5	22.7	31.8	L (1.50-93.6)	13.1	21.1	0.64	1.03	0.60	0.66
				M (1.60-100)		19.6	0.80	1.05	0.62	0.66
				H (1.70-106)		18.1	0.93	1.05	0.65	0.65
Grovena (Sandy-Loam)	53.4	35.3	11.3	L (1.50-93.6)	4.9	13.6	0.40	0.81	0.47	0.64
				M (1.60-100)		13.4	0.51	0.92	0.51	0.68
				H (1.70-106)		12.6	0.62	1.04	0.58	0.75
Vienna (Sandy-Loam)	66.5	21.0	12.5	L (1.50-93.6)	5.9	15.6	0.47	0.92	0.48	0.68
				M (1.60-100)		15.4	0.62	0.97	0.60	0.68
				H (1.70-106)		14.6	0.74	1.06	0.67	0.72
Lamoure (Sandy-Loam) or (Loamy-Sand)	78.9	11.4	9.7	L (1.60-100)	4.2	12.1	0.47	0.87	0.48	0.68
				M (1.70-106)		11.9	0.65	1.10	0.63	0.80
				H (1.80-113)		11.1	0.80	1.21	0.74	0.87
Maddock (Loamy-Sand)	87.6	5.6	6.8	L (1.60-100)	3.3	11.7	0.42	0.97	0.45	0.77
				M (1.70-106)		11.5	0.49	1.07	0.50	0.80
				H (1.80-113)		10.7	0.60	[illegible]	0.48	0.87
Fordville (Sand)	100.0	0.0	0.0	L (1.60-100)	0.70	5.0	0.20	0.71	0.28	0.71
				M (1.70-106)		5.8	0.28	0.95	0.32	0.85
				H (1.80-113)		5.1	0.39	1.04	0.47	0.92

Source: [illegible]

Soil Properties & Composition

Site soil samples can be cross referenced with a soil thermal properties table for more exacting ranges of conductivity.

Bore hole cutting samples can also be collected and analyzed for composition and thermal properties.



Formation Thermal Conductivity Analysis

Project:	McKeever Well Lutsen, MN	
Date:	10/12/07 - 10/13/07	
Test Conducted By.	GBT. INC	

Vertical Heat Exchanger

		Drilling Log
VHF Type	2 pipe	NA
Bore Depth (ft)	365.0	
U-bend pipe size (in)	1.00	
Borehole dia. (in)	6.00	
Portland/Sand	0lb/100lb	
GeoClips	10'	

In-situ Testing

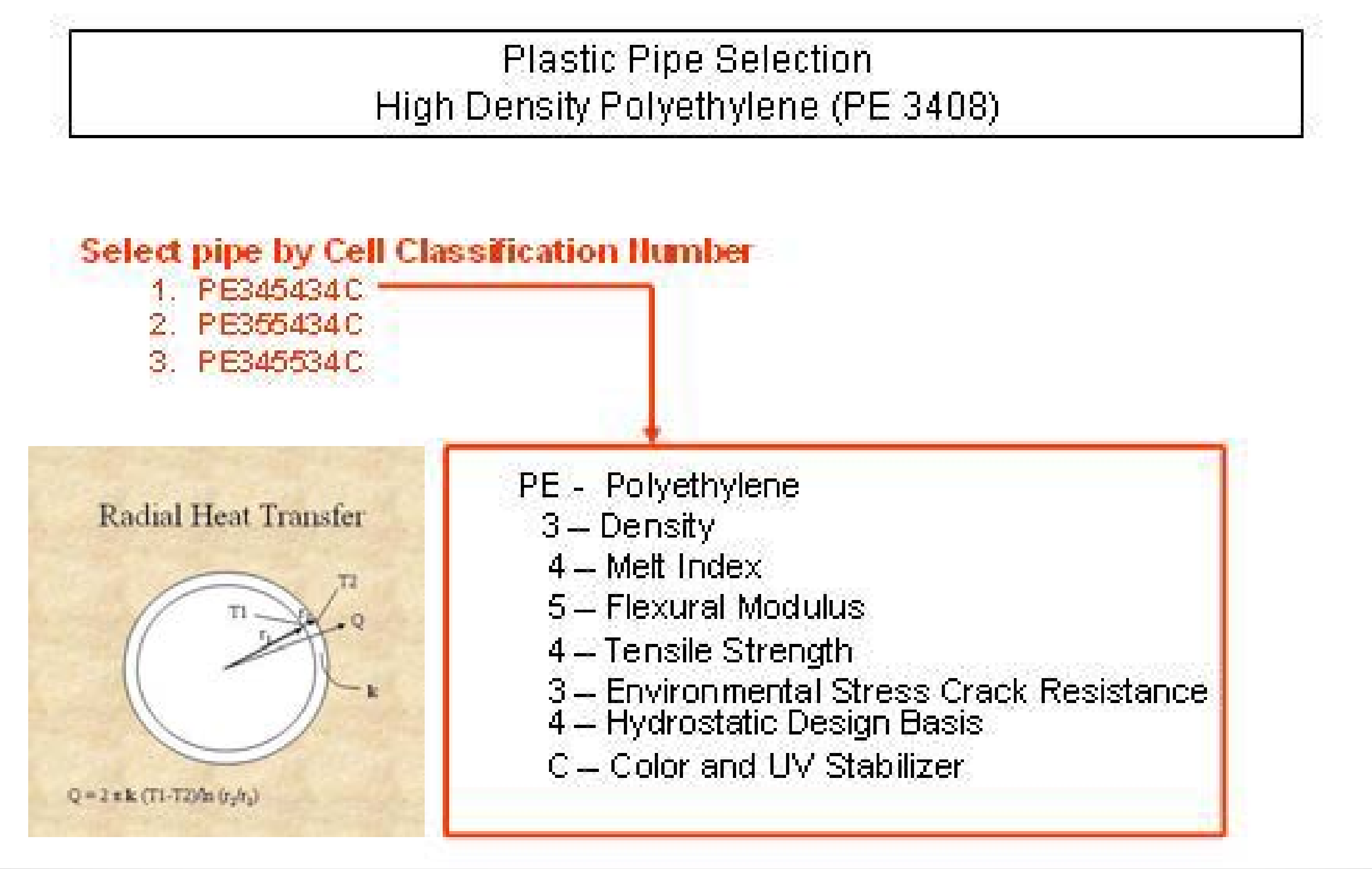
Circulating Fluid	Water	
Avg Volts	197.20	
Avg Amps	17.71	
Avg Power (Watts)	3493.87	
Test Duration (hr)	25.10	
Test Period Analyzed	12.00 -	25.10
Slope	3.26	

Calculated Thermal Conductivity 0.80 Btu/hr ft °F

Conductivity Testing

An *in situ* (on site) thermal conductivity test is the most effective way to determine the thermal properties of soil and rock across a specific formation.

It can be well worth the expense on larger boring projects where margins in cost are critical. It must be done at the <u>design</u> stage!



Plastic Pipe Selection
High Density Polyethylene (PE 3408)

Select pipe by Cell Classification Number

1. PE345434C
2. PE355434C
3. PE345534C

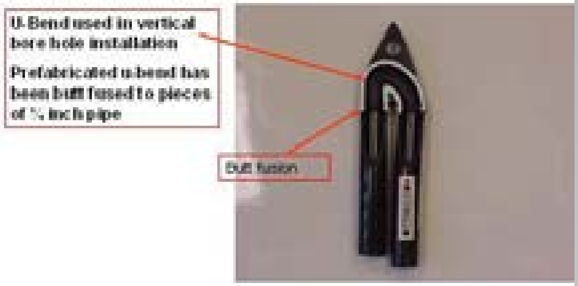
PE - Polyethylene
3 – Density
4 – Melt Index
5 – Flexural Modulus
4 – Tensile Strength
3 – Environmental Stress Crack Resistance
4 – Hydrostatic Design Basis
C – Color and UV Stabilizer

High Density Polyethylene (HDPE) has become widely established as the pipe of choice across the GSHP industry. It possesses the best characteristics of durability and conductivity…*combined.*

HDPE Pipe Joining Requires Heat Fusion

Butt and Saddle Heat Fusion

Pre-Fabricated U-Bend


U-Bend used in vertical bore hole installation

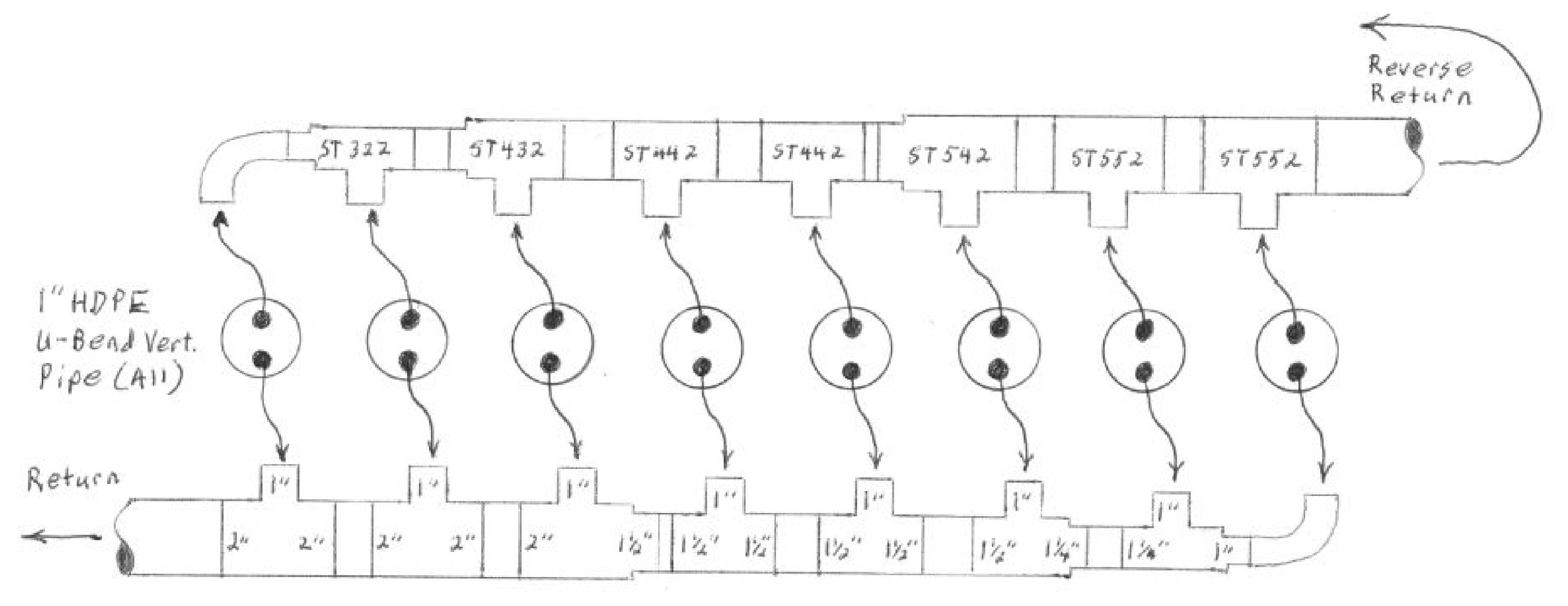
Prefabricated u-bend has been butt fused to pieces of ¾ inch pipe

Electro Fusion

Socket Fusion Joint

HDPE Pipe Joining Requires Heat Fusion

The Mother of All Fusion Rigs!



Header Configuration for 8T Vertical GHEX

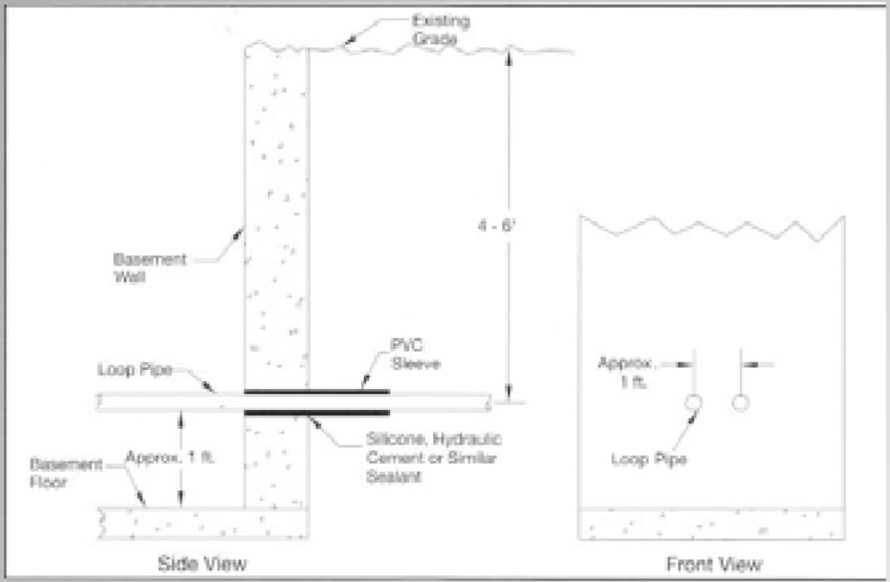
Loop flow is balanced using a "Step-down" Reducing Reverse Return design—system air purging and flushing is achieved by "choking" flow progressively along header as fluid is channeled through loops and available flow decreases.

IGSHPA STANDARD 3A.11 (1996)

All pipes passing through walls will be **sleeved** and **sealed** with non-hardening caulking material [emphasis added].

SCH40 PVC Pipe Sleeves (Typical)…

High thermal resistance (insulating value), rigidity, and excellent adherence to sealing caulks, foams, and hydraulic cements.



Wall and Slab Penetrations

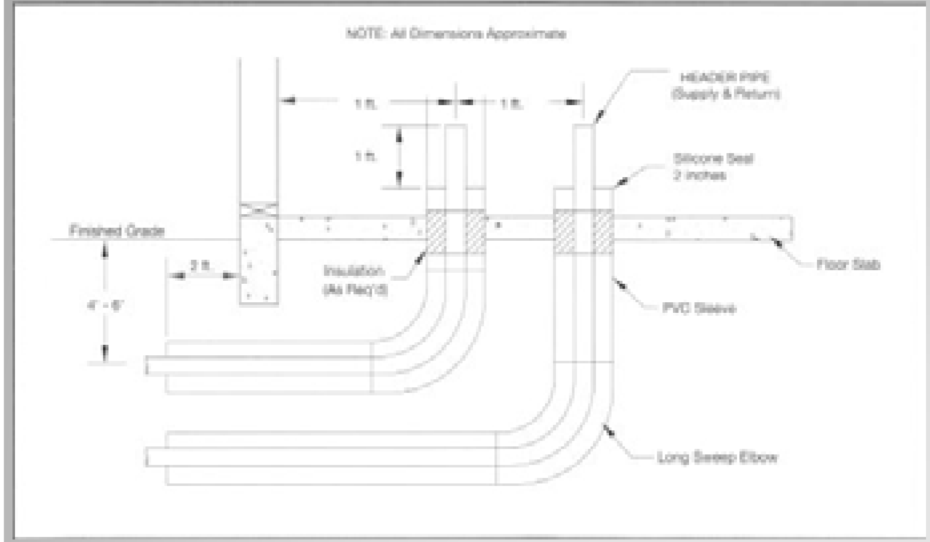
Should be completed <u>before</u> pouring!

IGSHPA STANDARD 3A.11 (1996)

All pipes passing through walls will be **sleeved** and **sealed** with non-hardening caulking material [emphasis added].

Long Sweep Elbows for Pipe Bends!…

Proper pipe sleeve sizing and configuration will make it a lot easier to place geothermal HDPE supply/return header pipes later.



Wall and Slab Penetrations

Should be completed before pouring!

Closed-Loop Vertically Bored GHEX

Nominal *versus* Design Pipe Length

REMEMBER: Maximum Performance Benefit…at Minimum Installation Cost

Nominal (Fixed) Length

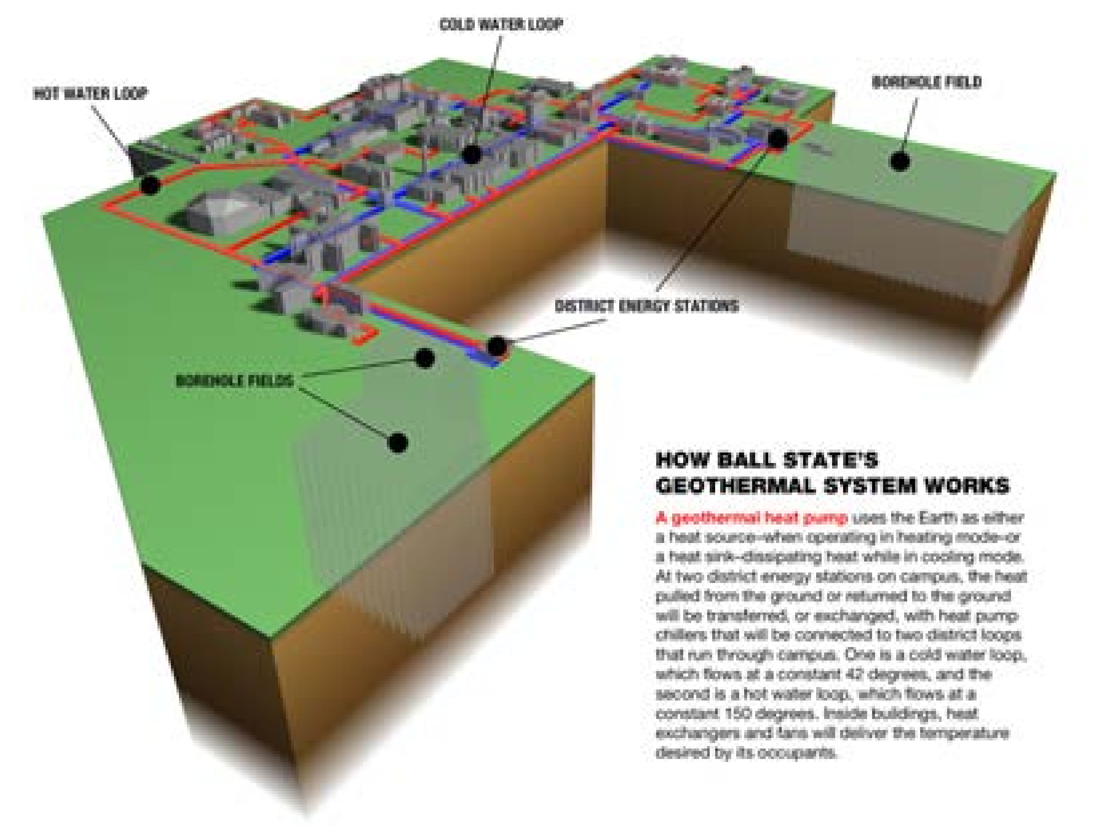
- Generally acceptable for smaller (1 to 16 Ton) GSHP systems where designer is very familiar with local site geology and climate.
- Design/performance enhancements can be made by increasing spacing, pitch, depth, moisture, loops, etc.

Design Loop Length

- Generally required for larger GSHP systems, where loads must be more precisely met in order to eliminate unnecessary redundancy or oversizing expense.
- Soil sampling and analysis or *in situ* conductivity testing is usually specified.

With 4,100 vertical bore holes at 400 ft. deep each, Ball State University will soon have the largest ground source heat pump system in the country.

More Facts: http://cms.bsu.edu/About/Geothermal.aspx



HOW BALL STATE'S GEOTHERMAL SYSTEM WORKS

A geothermal heat pump uses the Earth as either a heat source–when operating in heating mode–or a heat sink–dissipating heat while in cooling mode. At two district energy stations on campus, the heat pulled from the ground or returned to the ground will be transferred, or exchanged, with heat pump chillers that will be connected to two district loops that run through campus. One is a cold water loop, which flows at a constant 42 degrees, and the second is a hot water loop, which flows at a constant 150 degrees. Inside buildings, heat exchangers and fans will deliver the temperature desired by its occupants.

More than 40 buildings on the 660-acre Ball State University campus will be converted to geothermal heating and cooling. It is slated for completion in 2013.

More Facts: http://cms.bsu.edu/About/Geothermal.aspx

1 ¼“ U-Bend pipe being reeled directly into 320’ vertical hole

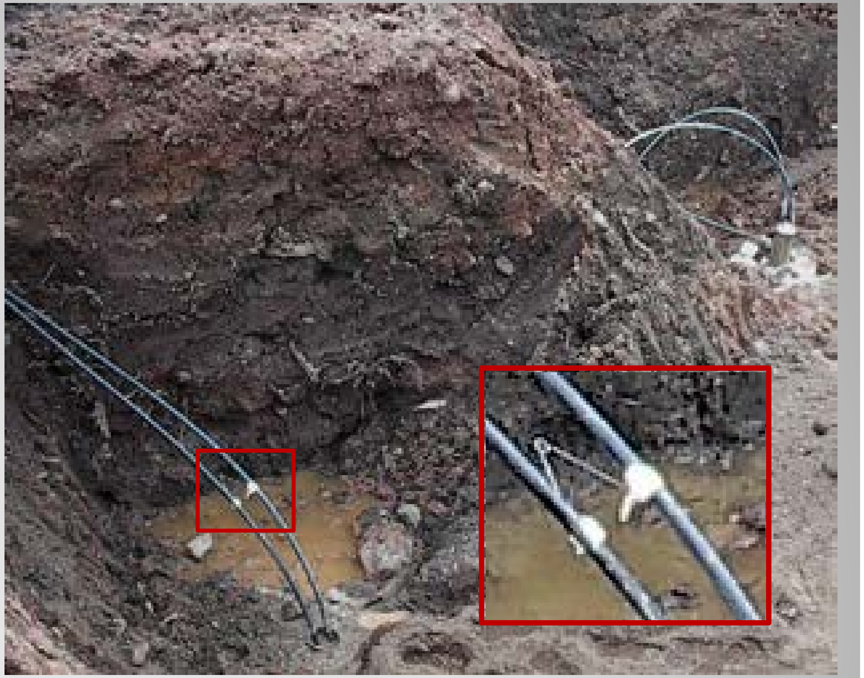
Spreader clips being clamped to U-bend & tremie pipe assy.

Closed-Loop Vertically Bored GHEX

Even a rock bored system can pay off…

After grouting, U-bend pipes are pressure tested and header trench is excavated…

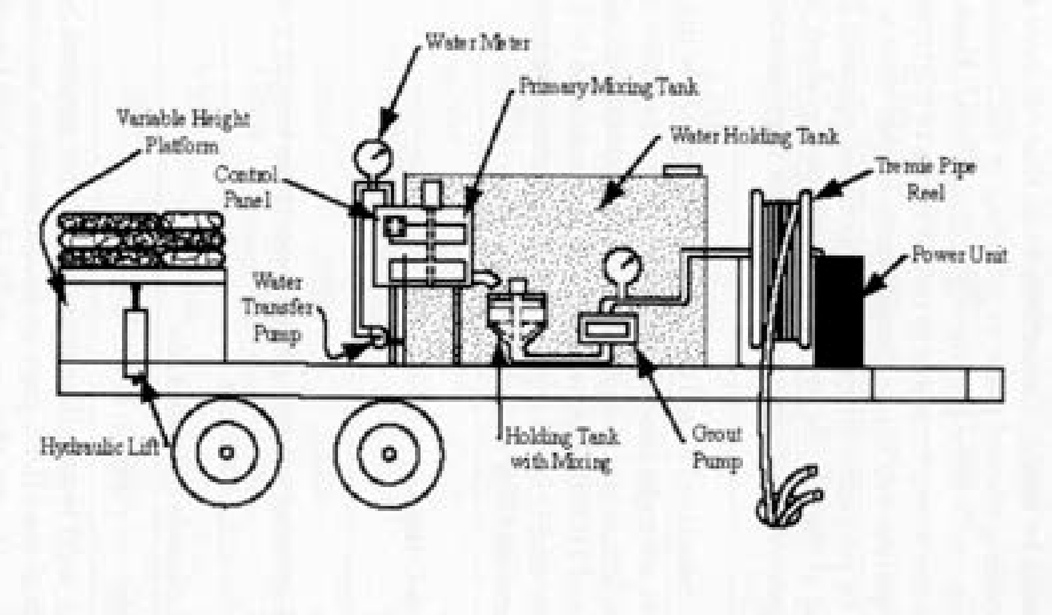
Casings are cut & removed from trench (orphan spreader clip visible in exploded view).



Closed-Loop Vertically Bored GHEX

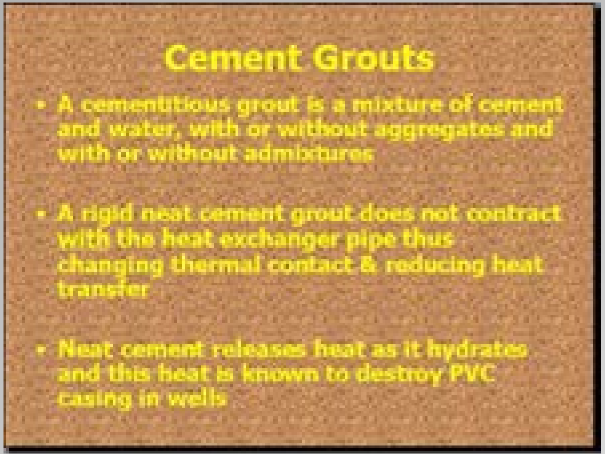
…but metal casings required down to rock!

Pressure tremie grouting is required for each bore hole using appropriate grout mixing and pump equipment.



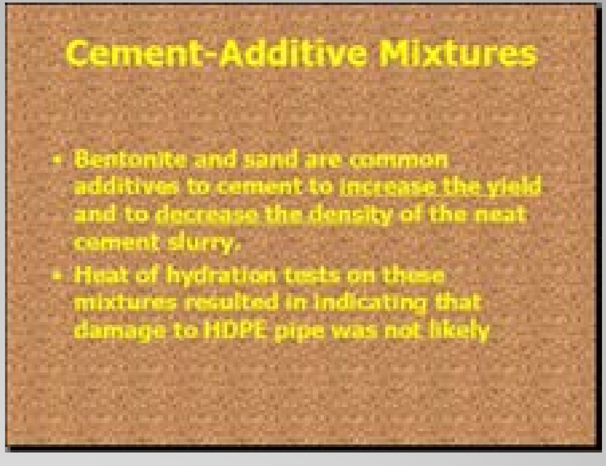
Cross section of cement grouted U-Bend bore without spreader clips.

Proper grouting provides sanitary protection of water supply, preserves hydraulic characteristics of artesian formations…*and improves heat transfer!*



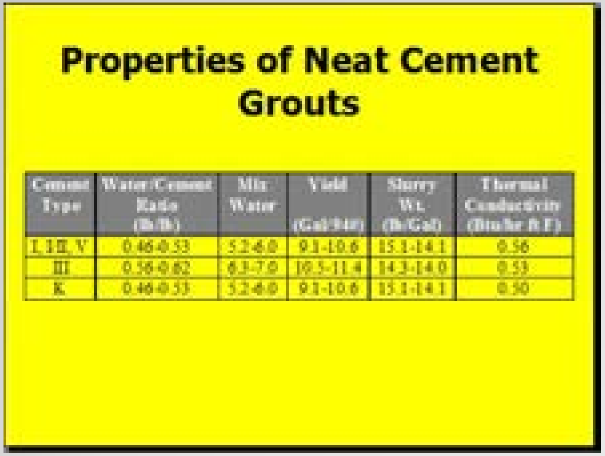
Cement Grouts

- A cementitious grout is a mixture of cement and water, with or without aggregates and with or without admixtures
- A rigid neat cement grout does not contract with the heat exchanger pipe thus changing thermal contact & reducing heat transfer
- Neat cement releases heat as it hydrates and this heat is known to destroy PVC casing in wells



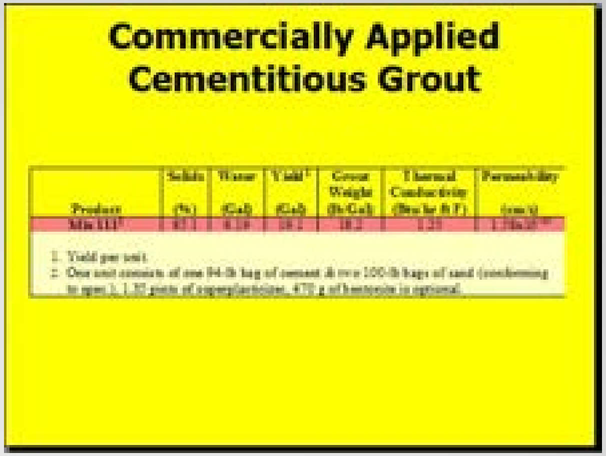
Cement-Additive Mixtures

- Bentonite and sand are common additives to cement to increase the yield and to decrease the density of the neat cement slurry.
- Heat of hydration tests on these mixtures resulted in indicating that damage to HDPE pipe was not likely



Properties of Neat Cement Grouts

Cement Type	Water/Cement Ratio (lb/lb)	Mix Water	Yield (Gal/94#)	Slurry Wt. (lb/Gal)	Thermal Conductivity (Btu/hr ft F)
I, II, V	0.46-0.53	5.2-6.0	9.1-10.6	15.1-14.1	0.56
III	0.56-0.62	6.3-7.0	10.5-11.4	14.3-14.0	0.53
K	0.46-0.53	5.2-6.0	9.1-10.6	15.1-14.1	0.50

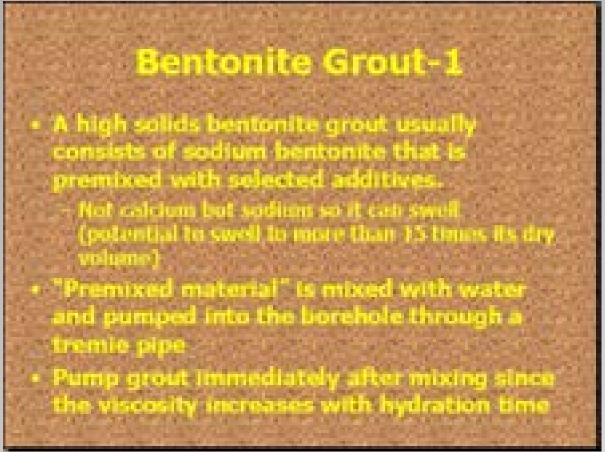


Commercially Applied Cementitious Grout

Product	Solids (%)	Water (Gal)	Yield[1] (Gal)	Grout Weight (lb/Gal)	Thermal Conductivity (Btu/hr ft F)	Permeability (cm/s)
Mix 111[2]	87.1	6.19	16.1	18.2	1.23	[illegible]

1. Yield per unit.
2. One unit consists of one 94-lb bag of cement & two 100-lb bags of sand (conforming to spec.), 1.35 pints of superplasticizer, 470 g of bentonite is optional.

In rock formations neat cement is mixed with fine sand or other additive to enhance grout.

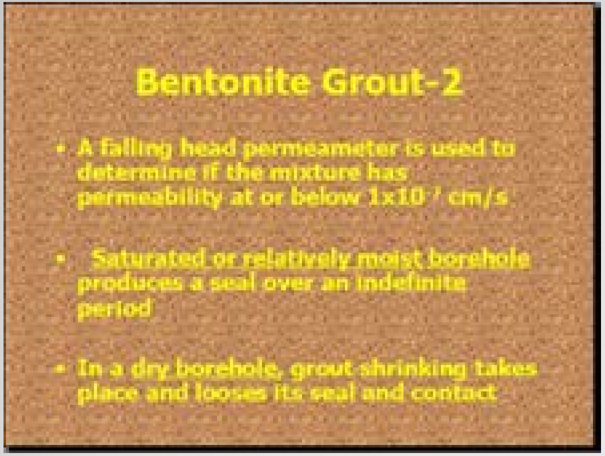


Bentonite Grout-1

- A high solids bentonite grout usually consists of sodium bentonite that is premixed with selected additives.
  - Not calcium but sodium so it can swell (potential to swell to more than 15 times its dry volume)
- "Premixed material" is mixed with water and pumped into the borehole through a tremie pipe
- Pump grout immediately after mixing since the viscosity increases with hydration time

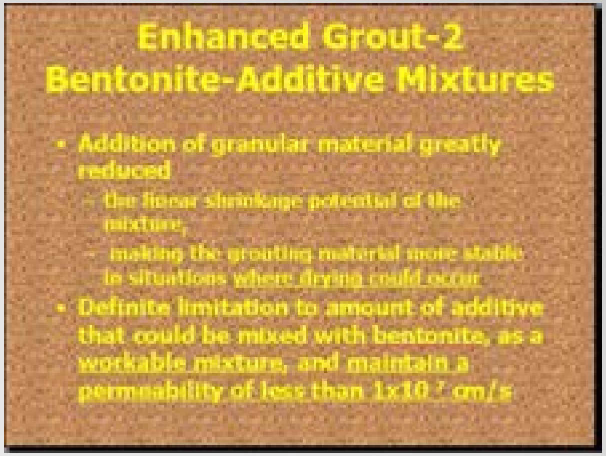
Enhanced Grout-1
Bentonite-Additive Mixtures

- Most success in increasing thermal conductivity was found when utilizing fine sands:
  - Common limestone
  - Masonry
  - Quartzite (silica sands and quartzite produce approximately the same effect)



Bentonite Grout-2

- A falling head permeameter is used to determine if the mixture has permeability at or below $1x10^{-7}$ cm/s
- Saturated or relatively moist borehole produces a seal over an indefinite period
- In a dry borehole, grout shrinking takes place and looses its seal and contact



Enhanced Grout-2
Bentonite-Additive Mixtures

- Addition of granular material greatly reduced
  - the linear shrinkage potential of the mixture,
  - making the grouting material more stable in situations where drying could occur
- Definite limitation to amount of additive that could be mixed with bentonite, as a workable mixture, and maintain a permeability of less than $1x10^{-7}$ cm/s

In soil formations use a high-solids "Western" Bentonite mixture—NOT Mud Drilling Grout.

Optional Configurations for 3 Ton Vertically Bored Closed-Loop GHEX

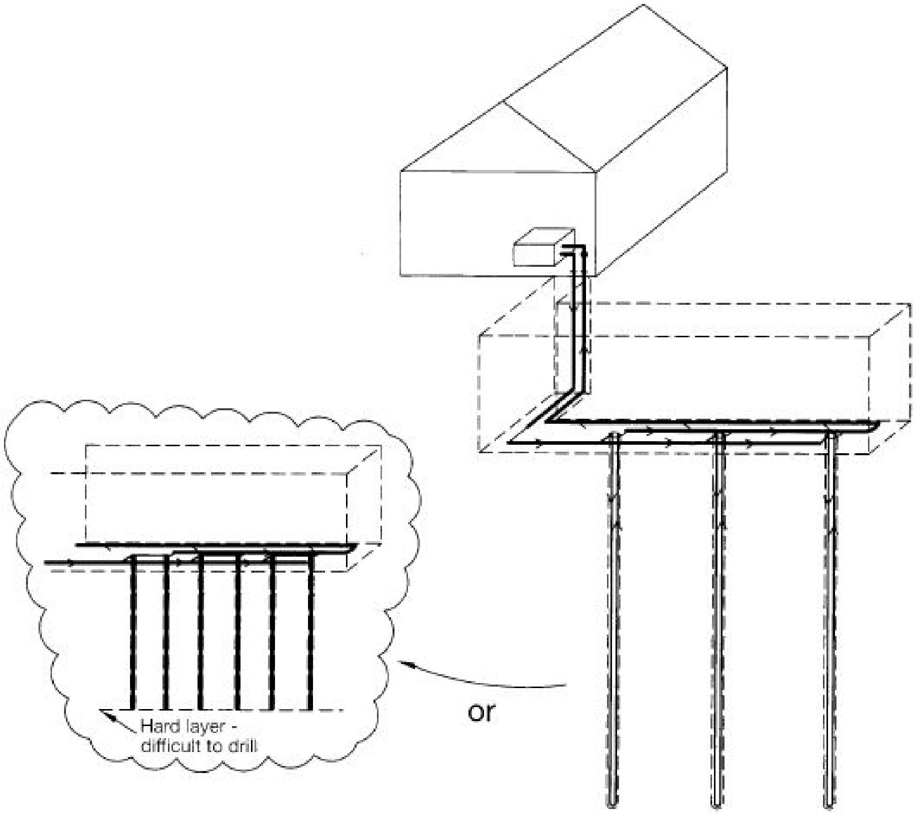


Figure 5.1. Vertically-bored "3-ton" Closed-Loop GHEX.

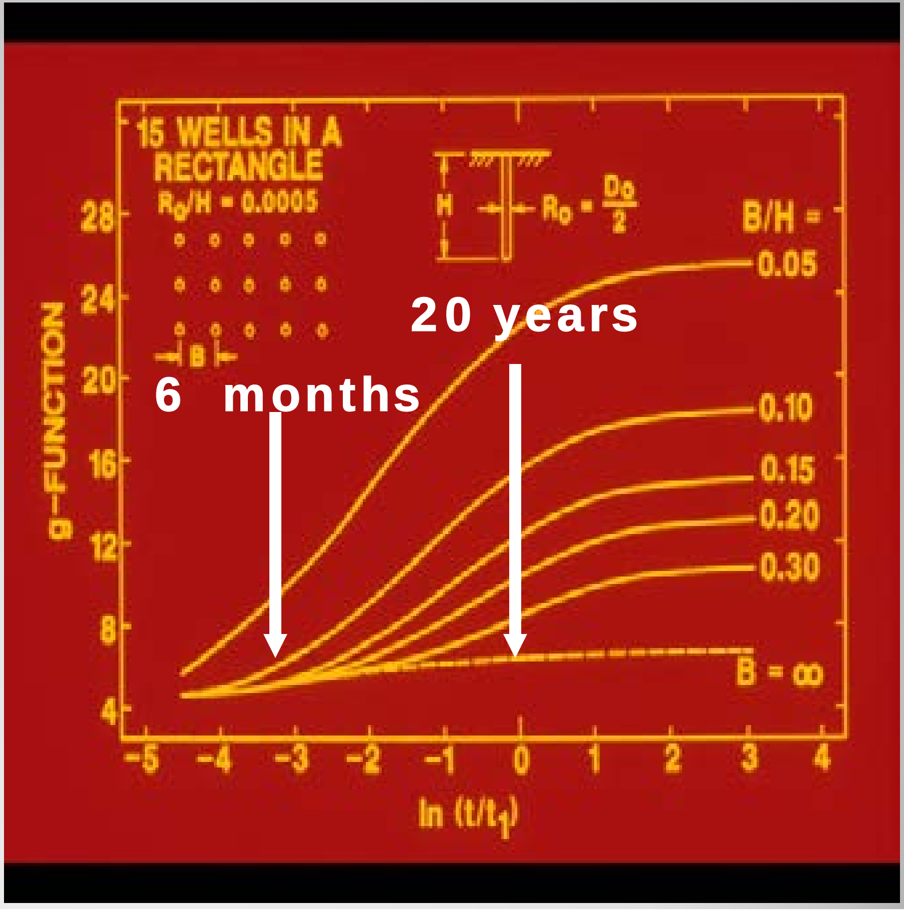
- One loop circuit per Ton of nominal GSHP capacity (this will vary by design!)
- 200' X ¾" U-Bend HDPE pipe/bore hole
- Thermally enhanced high-solids Western Bentonite or Portland Cement Grout
- You must use Propylene Glycol in MN
- In MN…bore holes must be fully cased in any unconsolidated overburden over drilled rock!

Long Term Thermal Effects of GHEX on Deep Soil & Rock Formations

- B = bore hole spacing
- H = bore hole depth
- g = temp resistance
- t_1 = time constant

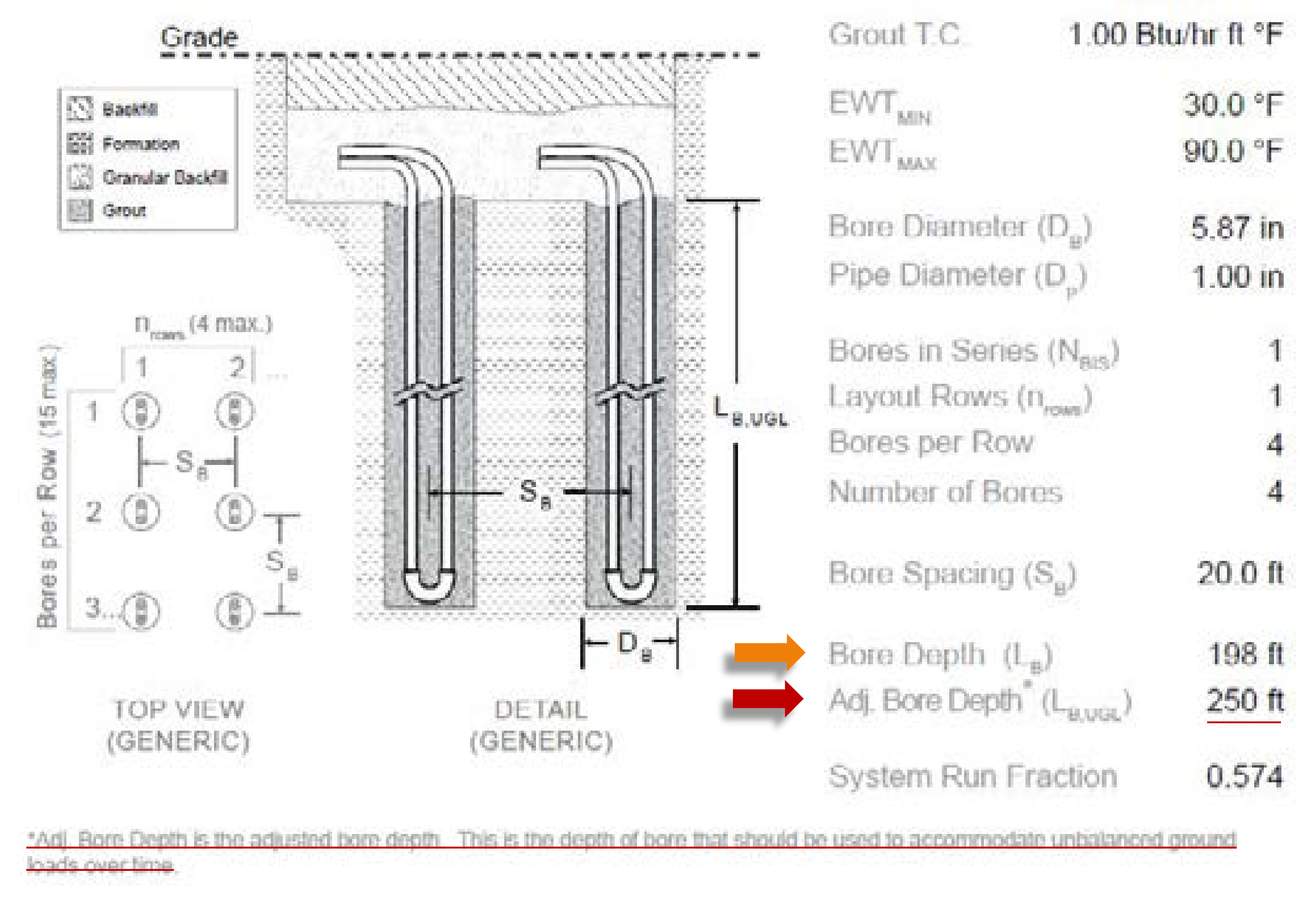
  = $H^2/9a$
- a = diffusivity

  = k / (r c)
- a = 0.6 ft^2/day
- H = 200 ft



20 years

6 months



Grout T.C.	1.00 Btu/hr ft °F
EWT_{MIN}	30.0 °F
EWT_{MAX}	90.0 °F
Bore Diameter (D_B)	5.87 in
Pipe Diameter (D_P)	1.00 in
Bores in Series (N_{BIS})	1
Layout Rows (n_{rows})	1
Bores per Row	4
Number of Bores	4
Bore Spacing (S_B)	20.0 ft
Bore Depth (L_B)	198 ft
Adj. Bore Depth* ($L_{B,UGL}$)	250 ft
System Run Fraction	0.574

*Adj. Bore Depth is the adjusted bore depth. This is the depth of bore that should be used to accommodate unbalanced ground loads over time.

Adjusted Bore Length for Current 5T System

(Also applies to Horizontally Drilled GHEX Designs!)

ADVANTAGES:

- Requires least amount of site surface area
- Minimal excavation required (header only)
- Versatility in pipe configuration & placement (may utilize small yards, parking lots, etc.)
- Higher, more stable deep earth temperatures (Duluth Complex 46°F to 48°F)

Vertically Bored GHEX

DISADVANTAGES:

- Cost is generally higher compared to other GHEX loop options
- Might require adding expensive steel casings in unconsolidated overburden when boring into rock formations (must use in Minnesota!)
- Propylene Glycol is usually specified instead of better performing Methanol (Minnesota!)
- Drilling equipment access can be limited
- Drilling fluid & cuttings can make a huge mess
- There is often more science involved in grouting than drilling—local contractors may be limited

Vertically Bored GHEX

HDD Machine Drilling
150 Ton GHEX for a
Minnesota School

Horizontal Directional Drilling

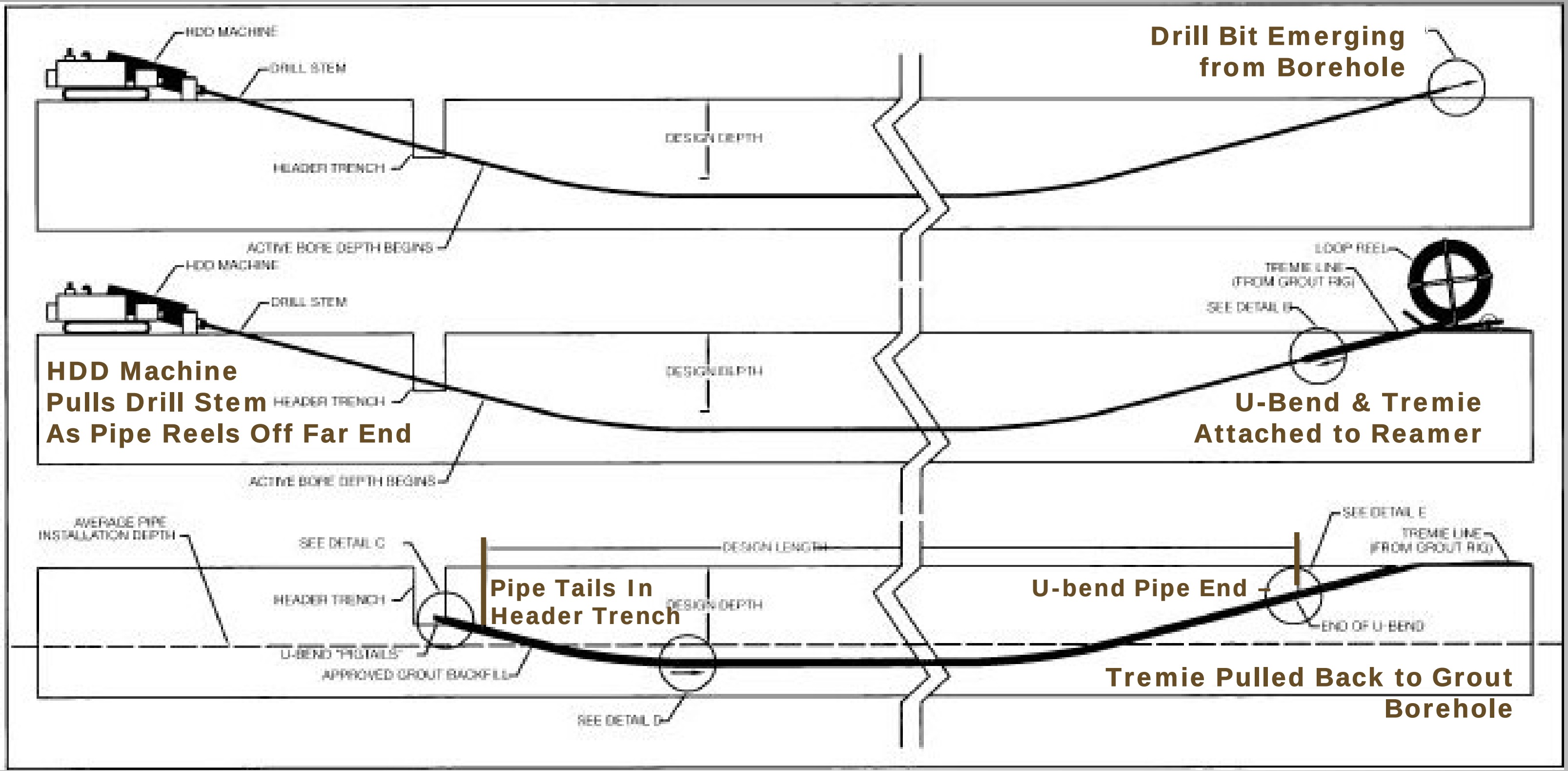


Figure 7.11a. Horizontally-Bored Loop Installation Process

Drill Bit Emerging from Borehole

HDD Machine Pulls Drill Stem As Pipe Reels Off Far End

U-Bend & Tremie Attached to Reamer

Pipe Tails In Header Trench

U-bend Pipe End

Tremie Pulled Back to Grout Borehole

Horizontal Directional Drilling

Drill Bit Emerging
from Borehole

U-bend & Tremie
Attached to Reamer

Header Pipe
Attached to Reamer

U-bend Being
Pulled from Reel

Horizontal Directional Drilling

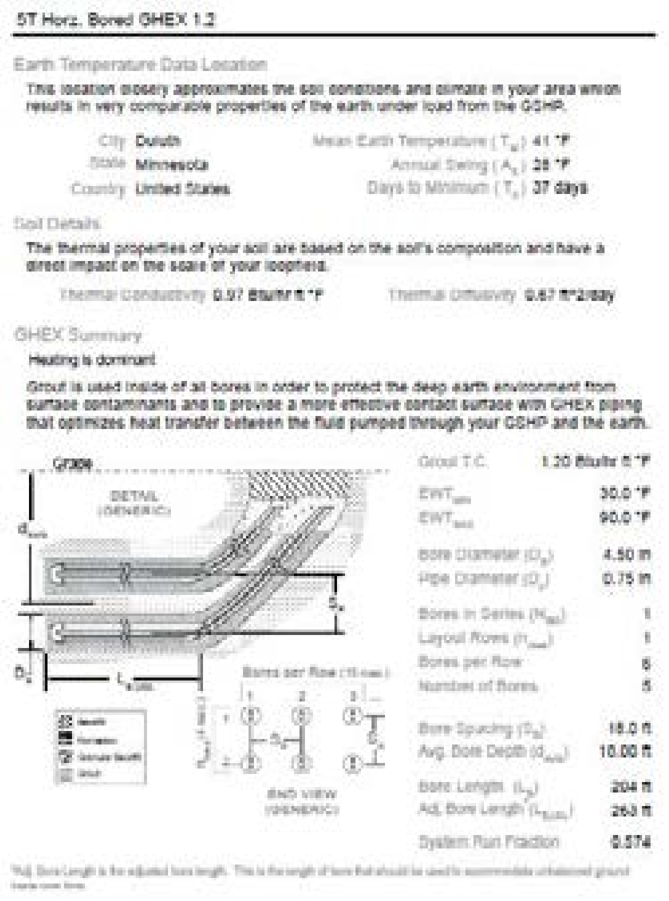
Pulled Pipe Tails
Ready for Header
Excavation

Horizontal Directional Drilling

Header Excavation
Reveals "Fanned"
Loop Configuration

Horizontal Directional Drilling

Good Grout Conductivity = 1.2
5 X <u>263</u> ft. Horz. Bore Length



5T Horz. Bored GHEX 1.2

Earth Temperature Data Location

This location closely approximates the soil conditions and climate in your area which results in very comparable properties of the earth under load from the GSHP.

City	Duluth	Mean Earth Temperature (T_M)	41 °F
State	Minnesota	Annual Swing (A_S)	28 °F
Country	United States	Days to Minimum (T_0)	37 days

Soil Details

The thermal properties of your soil are based on the soil's composition and have a direct impact on the scale of your loopfield.

Thermal Conductivity 0.97 Btu/hr ft °F　Thermal Diffusivity 0.67 ft^2/day

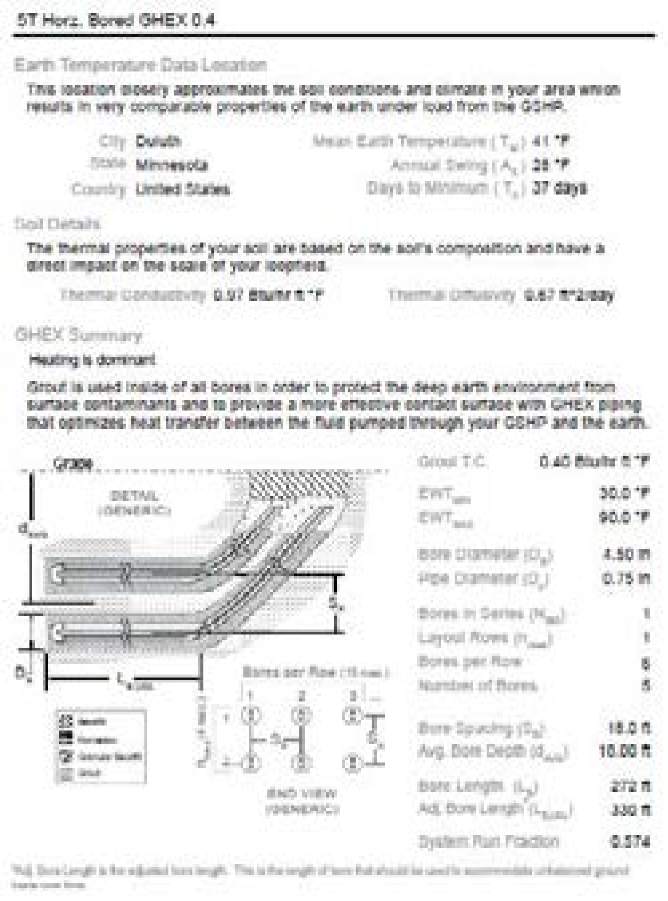
GHEX Summary

Heating is dominant

Grout is used inside of all bores in order to protect the deep earth environment from surface contaminants and to provide a more effective contact surface with GHEX piping that optimizes heat transfer between the fluid pumped through your GSHP and the earth.

Grout T.C.	1.20 Btu/hr ft °F
EWT_{min}	30.0 °F
EWT_{max}	90.0 °F
Bore Diameter (D_B)	4.50 in
Pipe Diameter (D_P)	0.75 in
Bores in Series (N_{BS})	1
Layout Rows (n_{row})	1
Bores per Row	5
Number of Bores	5
Bore Spacing (S_B)	18.0 ft
Avg. Bore Depth (d_{avg})	10.00 ft
Bore Length (L_B)	204 ft
Adj. Bore Length ($L_{B,adj}$)	263 ft
System Run Fraction	0.574

Poor Grout Conductivity = 0.4
5 X <u>330</u> ft. Horz. Bore Length



5T Horz. Bored GHEX 0.4

Earth Temperature Data Location

This location closely approximates the soil conditions and climate in your area which results in very comparable properties of the earth under load from the GSHP.

City	Duluth	Mean Earth Temperature (T_M)	41 °F
State	Minnesota	Annual Swing (A_S)	28 °F
Country	United States	Days to Minimum (T_0)	37 days

Soil Details

The thermal properties of your soil are based on the soil's composition and have a direct impact on the scale of your loopfield.

Thermal Conductivity 0.97 Btu/hr ft °F　Thermal Diffusivity 0.67 ft^2/day

GHEX Summary

Heating is dominant

Grout is used inside of all bores in order to protect the deep earth environment from surface contaminants and to provide a more effective contact surface with GHEX piping that optimizes heat transfer between the fluid pumped through your GSHP and the earth.

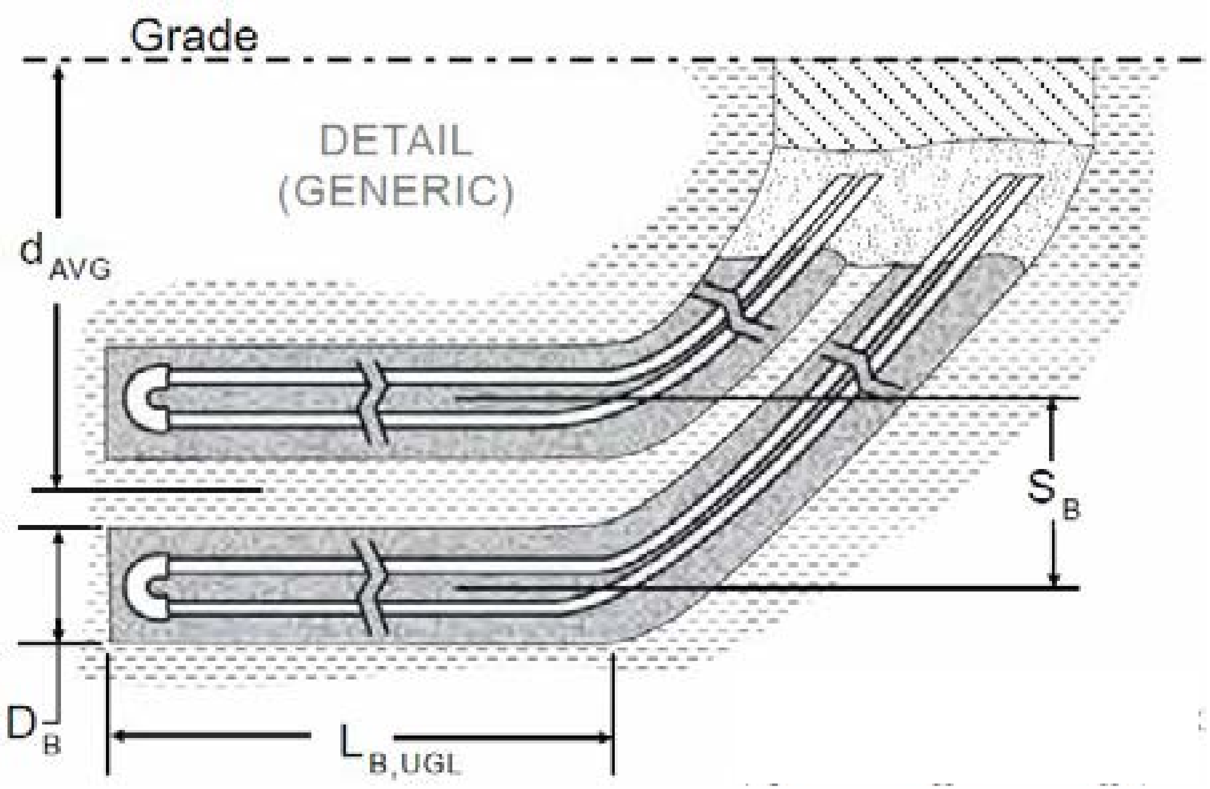
Grout T.C.	0.40 Btu/hr ft °F
EWT_{min}	30.0 °F
EWT_{max}	90.0 °F
Bore Diameter (D_B)	4.50 in
Pipe Diameter (D_P)	0.75 in
Bores in Series (N_{BS})	1
Layout Rows (n_{row})	1
Bores per Row	5
Number of Bores	5
Bore Spacing (S_B)	18.0 ft
Avg. Bore Depth (d_{avg})	10.00 ft
Bore Length (L_B)	272 ft
Adj. Bore Length ($L_{B,adj}$)	330 ft
System Run Fraction	0.574

The Importance of <u>Responsible</u> <u>Grouting</u>

(Big Cost Difference—about 70’ per Bore Length!)

Optimum Grout Conductivity?

- By increasing “design” grout conductivity, required pipe and bore lengths will decrease
- Grout conductivity need not exceed that of the formation (but it is still better to come close)
- Grout (and grout application) costs increase as conductivity and enhancements are increased
- Cheapest grouts start at about 0.40 Btu/hr/ft °F
- It has been effectively demonstrated that Grout Conductivity Benefit per Reduced Bore Length Cost drops off at about an “88” (0.88) grout.



- One loop circuit per Ton of nominal GSHP capacity (will vary by design!)
- 225′ X ¾" U-Bend HDPE pipe/bore hole
- Minimum "average" recommended pipe depth & spacing is 15′
- Thermally enhanced high-solids Western Bentonite Grout is highly advised
- Methanol is presently acceptable; Propylene Glycol may soon be required

HDD loops may be loosely described as "a vertical loop set on its side" (bottom tier limited to 45′ depth)

ADVANTAGES:

- Versatility in pipe configuration & placement: possible beneath buildings, parking lots, play fields, trees & landscaped areas, other obstacles
- Tier-level “layering” is possible (from 45′ depth)
- Minimal disturbance to site—excavation can even be limited to small consolidated area using “fan” configuration and “close header”
- Cost generally lower than vertically bored GHEX (may also be competitive with some horizontally trenched applications—but also consider grout!)

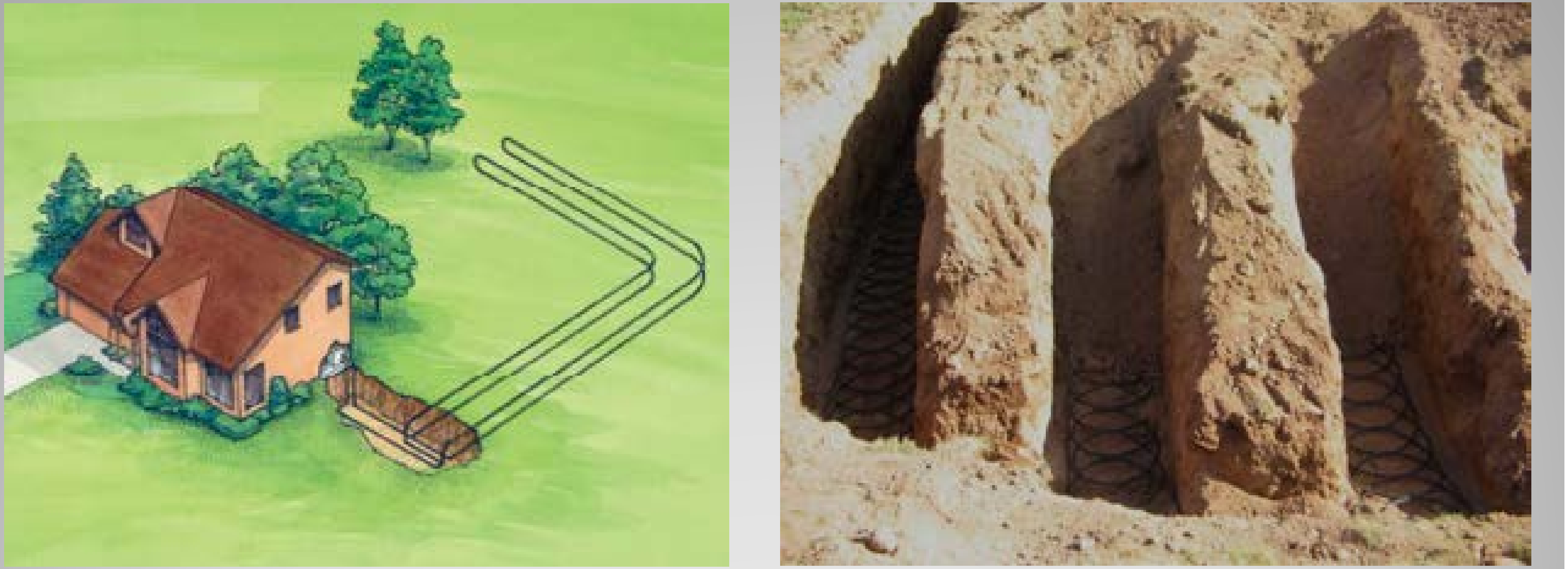
Horizontally Bored GHEX

DISADVANTAGES:

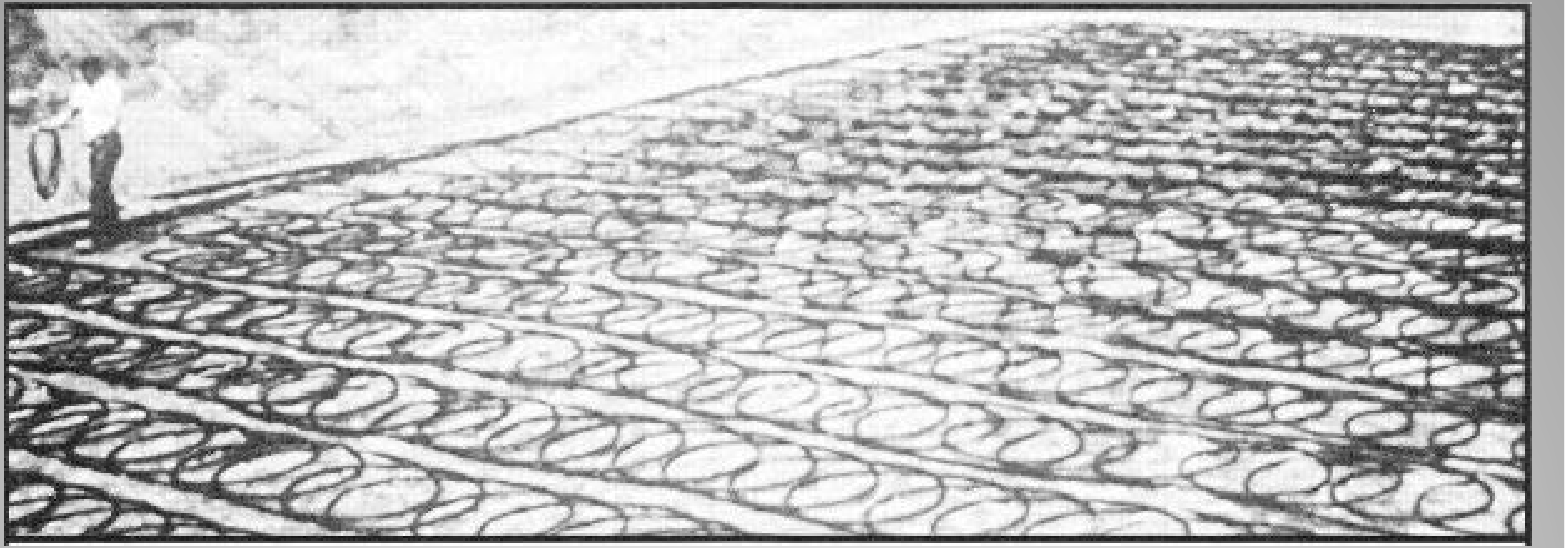
- Limited to unconsolidated (soil) formations
- Required HDD bore lengths and spacing may exceed property dimensions and/or setbacks
- Boulders or other obstructions may hinder boring, damage equipment, or even alter design.
- HDD grouting is currently unregulated and often ignored—or even *purposely* eliminated just to lower cost!
- Coming under closer scrutiny by state health regulators (particularly “slant and plant” drilling)

Horizontally Bored GHEX

QUESTIONS?



Horizontally Trenched (or Excavated) GHEX



What is wrong with *this* picture?

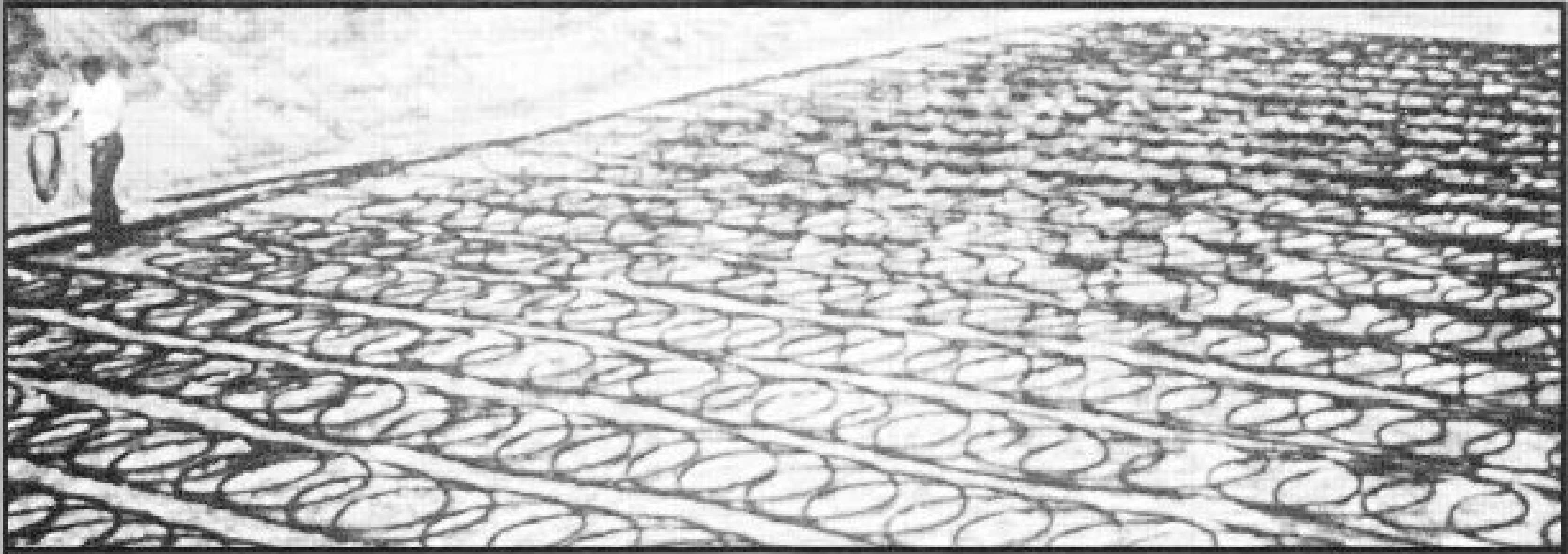


FIGURE 5.2: Horizontal Slinky Applications

SOURCE: *Closed-Loop Geothermal Systems Slinky® Installation Guide*, Rural Electric Research (RER) Project 86-1, IGSHPA 1996.

What is wrong with *this* picture?

Nothing is wrong with this picture!

Selected pipe and trench spacing should not change GSHP <u>design</u> <u>efficiency</u>—*just pipe length, excavation footprint…and <u>cost</u>!*

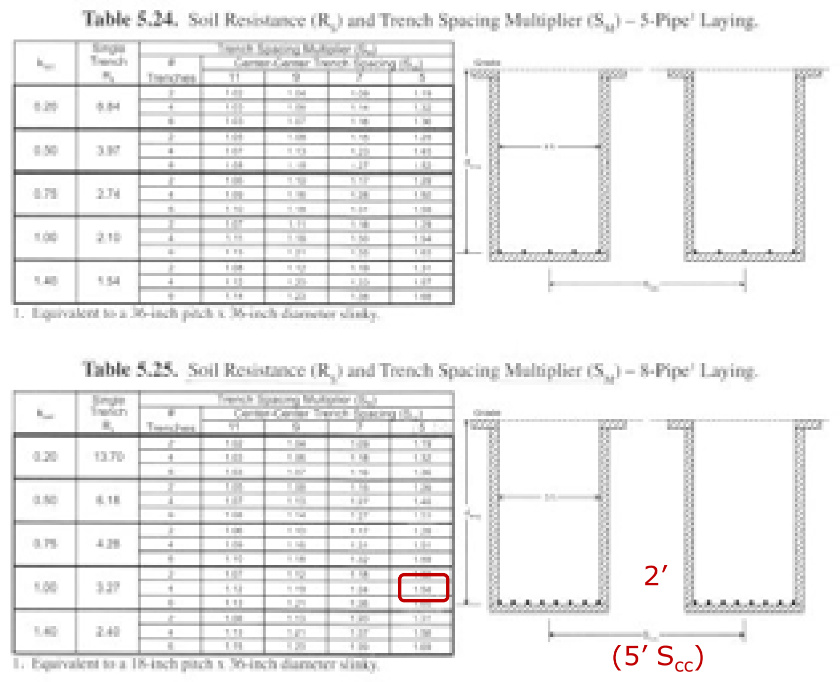
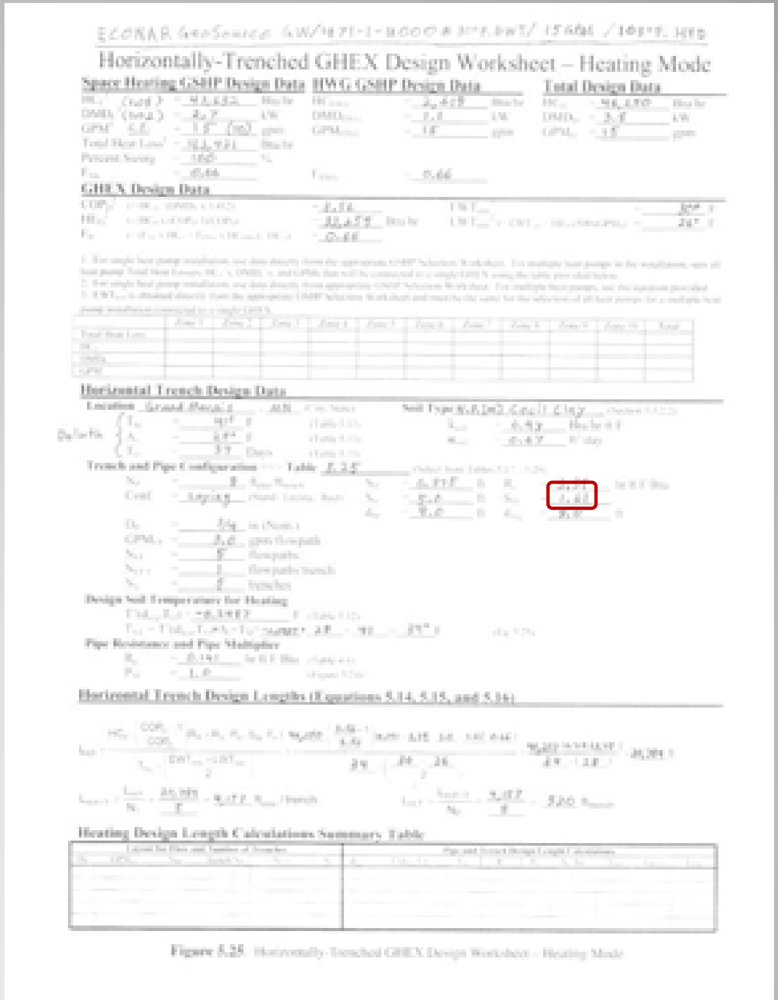


Table 5.24. Soil Resistance (R_s) and Trench Spacing Multiplier (S_M) – 5-Pipe[1] Laying.

1. Equivalent to a 36-inch pitch x 36-inch diameter slinky.

Table 5.25. Soil Resistance (R_s) and Trench Spacing Multiplier (S_M) – 8-Pipe[1] Laying.

1. Equivalent to a 18-inch pitch x 36-inch diameter slinky.



Horizontally-Trenched GHEX Design Worksheet – Heating Mode

Space Heating GSHP Design Data

HWG GSHP Design Data

Total Design Data

GHEX Design Data

Horizontal Trench Design Data

Trench and Pipe Configuration

Design Soil Temperature for Heating

Pipe Resistance and Pipe Multiplier

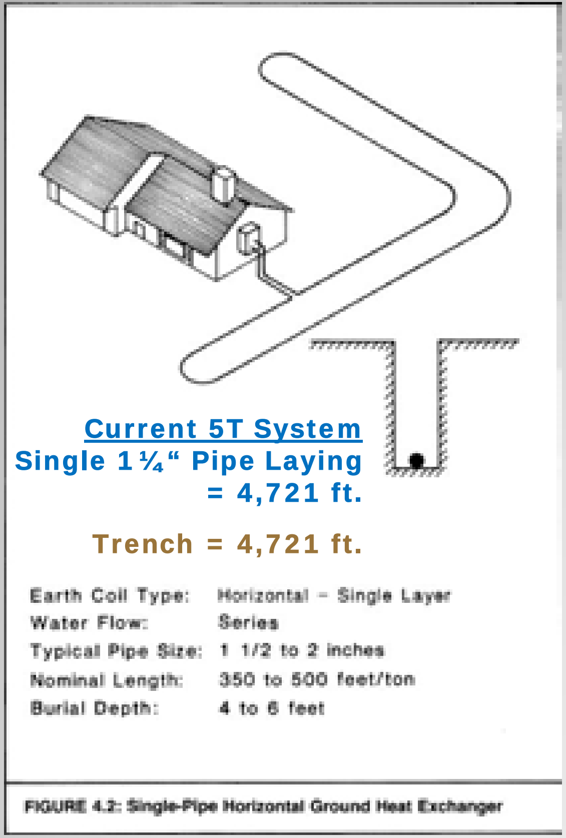
Horizontal Trench Design Lengths (Equations 5.14, 5.15, and 5.16)

Heating Design Length Calculations Summary Table

Figure 5.25 Horizontally-Trenched GHEX Design Worksheet – Heating Mode

Correction Table for Different Trench Spacing

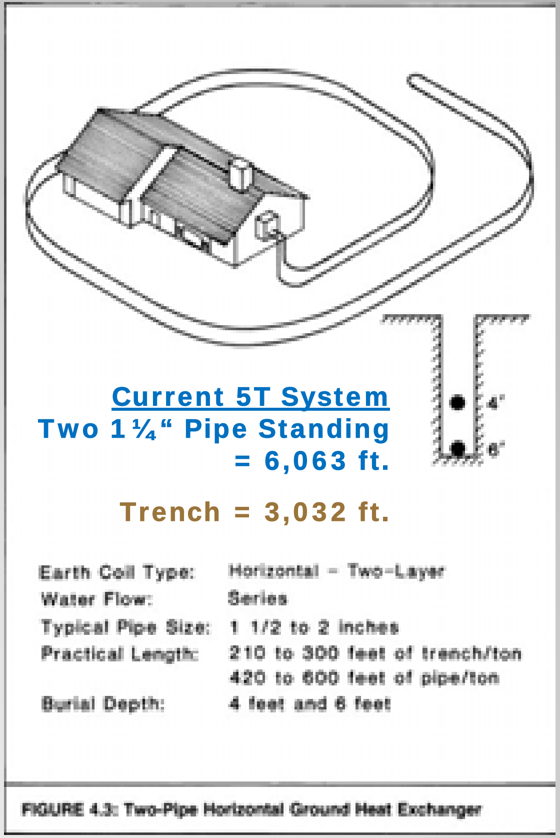
The world's "first" geothermal heat pump system—probably a single pipe in one long trench…



Earth Coil Type:	Horizontal – Single Layer
Water Flow:	Series
Typical Pipe Size:	1 1/2 to 2 inches
Nominal Length:	350 to 500 feet/ton
Burial Depth:	4 to 6 feet

FIGURE 4.2: Single-Pipe Horizontal Ground Heat Exchanger

Eventually modified to conserve space and installation expense…

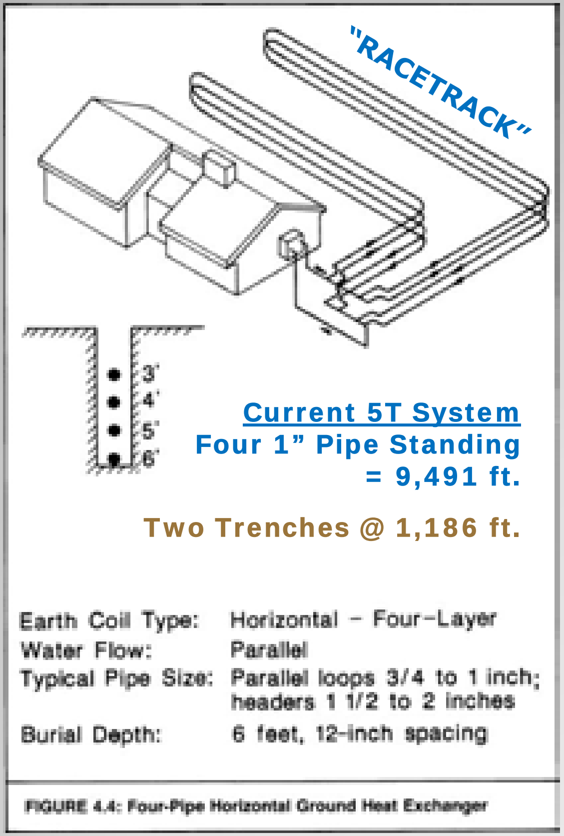


Earth Coil Type:	Horizontal – Two-Layer
Water Flow:	Series
Typical Pipe Size:	1 1/2 to 2 inches
Practical Length:	210 to 300 feet of trench/ton 420 to 600 feet of pipe/ton
Burial Depth:	4 feet and 6 feet

FIGURE 4.3: Two-Pipe Horizontal Ground Heat Exchanger

How did we ever get the "slinky"?

Then advanced to multiple parallel circuits using a single common header…



Current 5T System
Four 1" Pipe Standing
= 9,491 ft.

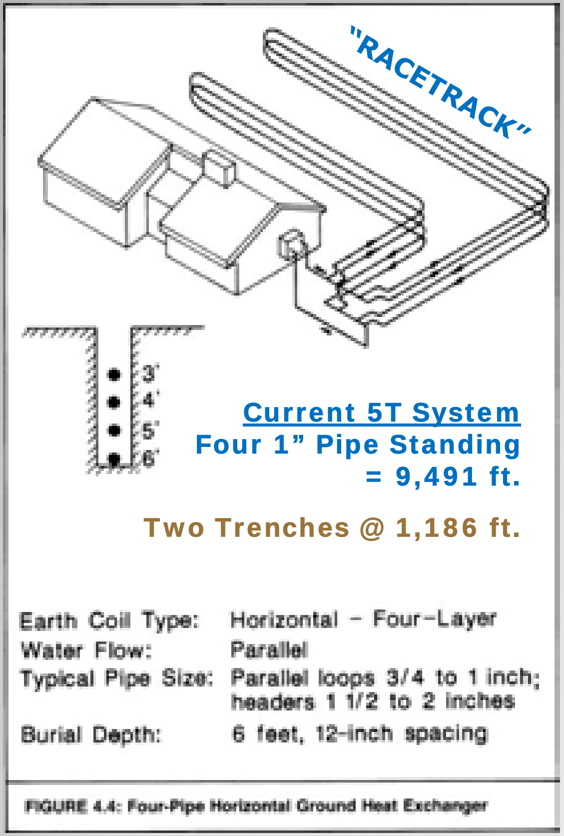
Two Trenches @ 1,186 ft.

Earth Coil Type:	Horizontal – Four-Layer
Water Flow:	Parallel
Typical Pipe Size:	Parallel loops 3/4 to 1 inch; headers 1 1/2 to 2 inches
Burial Depth:	6 feet, 12-inch spacing

FIGURE 4.4: Four-Pipe Horizontal Ground Heat Exchanger

How did we ever get the "slinky"?

Then advanced to multiple parallel circuits using a single common header…



"RACETRACK"

Current 5T System
Four 1" Pipe Standing
= 9,491 ft.

Two Trenches @ 1,186 ft.

Earth Coil Type:	Horizontal – Four-Layer
Water Flow:	Parallel
Typical Pipe Size:	Parallel loops 3/4 to 1 inch; headers 1 1/2 to 2 inches
Burial Depth:	6 feet, 12-inch spacing

FIGURE 4.4: Four-Pipe Horizontal Ground Heat Exchanger

Until someone figured out yet *another* way to conserve time, space, and resources!

(But not without new challenges—clay slurry shown being applied to fill voids inside trench)

How did we ever get the "slinky"?

Closer Spacing = longer pipe requirement, smaller consolidated excavation footprint (500 ft²/T)

Wider Spacing = shorter pipe requirement, expanded excavation footprint (1,000 ft²/T)

“Laying Slinky” Configurations for Colder Climates

Example of excavated 8 Ton “Laying Racetrack” configuration (850 ft^2/T)

Pipe coils are rolled out individually down entire length of trench…and back.

“Laying Racetrack” Configuration is still an option.

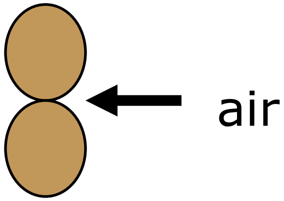
- One loop circuit per Ton of nominal GSHP capacity (as sized to peak heating load!)
- 800′ X ¾" HDPE pipe per coil
- Return loops are spaced 12″ apart (minimum)
- Excavation Footprint ≈ 2′ X 400′ per coil @ approx. 8′ depth

Standard or "Racetrack" Configuration for Cold Climate GHEX Applications

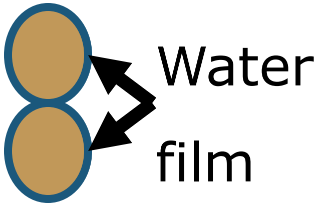
- One loop circuit per Ton of nominal GSHP capacity (as sized to peak heating load!)
- 800′ X ¾" HDPE pipe per slinky coil
- Each coil is 36″ diameter and overlapped every 18″ (equivalent to 8 pipes laying)
- Slinky coil = 95′
- Excavation Footprint ≈ 5′ X 100′ per coil @ approx. 8′ depth

Typical Slinky GHEX Configuration for Cold Climate Geothermal Applications

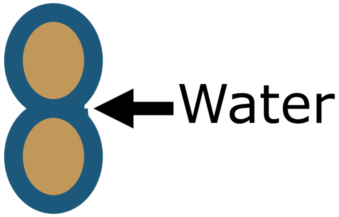
How Moisture Improves Thermal Conductivity of Soil



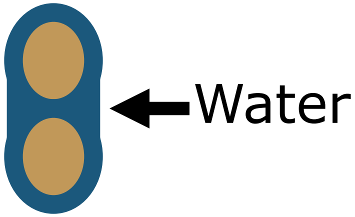
At complete dryness the heat flow passes mainly through the grains, but has to bridge the air-filled gaps between the grains around their contact points.



At very low water contents the soil particles are covered by thin absorbed water layers



The thickness of these layers increases with increasing water content. At a certain Xw liquid rings start to form around the contact points between the grains; they show a curved air-water interface.



From this point on the thermal conductivity increases rapidly with increasing Xw, until the rings almost completely fill the original gap. When Xw increases still further the complete pores are filled with water, up to saturation. This is reflected by the slower increase of k with Xw.

Soaker Systems

A storm water or gray water drain tile piping system can be laid-in on top of a horizontal GHEX to enhance moisture in dry soils.

(This approach may also be considered where driveways or paved parking lots are planned. Generally such systems are also buried much deeper.)

ADVANTAGES:

- Generally costs less than either vertical or horizontal drilling options
- Excavation process remains fairly straight-forward—local (even on-site) operators can usually be used
- Seasonal loop recovery tends to be more forgiving close to the surface where sun and rain have influence (esp. "heat only" GSHP systems)
- Often the most practical, as well as economical, option in challenging or unpredictable geology

Horizontally Trenched GHEX

Horizontally Trenched GHEX

DISADVANTAGES:

- Requires the largest area of available space: Total excavation area = entire GHEX footprint (and then some!)
- Arguably the largest impact with *least* amount of flexibility in loop configuration and placement
- Cannot be placed beneath structures, driveways, septics, parking lots, etc.—with a *few* exceptions
- Other buried services can be affected if crossed
- More vulnerable to damage during installation

Pond & Lake Loops

Pond Heat Exchangers combine exceptional GSHP system performance…

With an aesthetic component you just can't get from a conventional earth loop.

Pond Heat Exchangers

Offer an attractive alternative to buried loops

Pond Heat Exchangers combine exceptional GSHP system performance…

With an aesthetic component you just can't get from a conventional earth loop.

Pond Heat Exchangers

Offer an attractive alternative to buried loops

Conventional 18” pitch slinkies are zip-tied together and covered with chain link mesh…

This 8 Ton GSHP application operates consistently at 36°F EWT throughout winter.

Floated Geo-mat Application

PHEX is constructed on shore, floated & sunk.

Hybrid Pond Heat Exchangers

Hybrid Pond/GHEX for potentially low water

Conventional slinky GHEX can often be laid directly in pond basin (at standard 8’ depth)…

Cover it with 2’ of clean gravel before flooding and it may be more forgiving during drought.

Mountain melt water basin in Steamboat Springs, CO, used for Geo'…and trophy trout!

This 55 Ton application utilizes 4 X 10 loops using 500' coils of 1" *HDPE—33 Tons added later.*

Many Other PHEX Design Options

More condensed arrays…require loose spacing

Pond Heat Exchangers

Cages combine durability with on-site *mobility*

The 700,000 sq. ft. building complex of Great River Medical Center in Burlington, IA, is served by 800 heat pumps and a 1,500 Ton loop system with 82 miles of pipe in a 15 acre lake!

More Facts: http://www.alliantenergygeothermal.com/GeothermalInAction/CommercialGovernmentBuildings/000436

ADVANTAGES:

- Can cost more than a conventional buried loop if pond must be excavated—but less if it is already *existing!*
- Better expected GSHP performance & efficiency: loop temperatures between 33°F and 40°F
- Minimal disturbance to site—excavation generally limited to a single S/R header trench to house
- Aesthetic value

Pond & Lake Loops

DISADVANTAGES:

- Potential for loop freeze-up and failure due to drop in pond level/volume (ways to minimize)
- Exposures—pipe needs protection from boat anchors, fish hooks…and beavers!
- Permits—wetland permit may be required for excavated pond; state water use permit is always required for “lake energy exchanger” placement and/or removal within any MN/WI public water
- No dependable, well established design criteria for pond loops—nominal PHEX configurations are most typical

Pond & Lake Loops

Open Loops

Instead of a buried closed loop GHEX, domestic water from house is simply pumped through the GSHP coil then discharged somewhere outside. *(Pictured is a simple shallow drain tile in sand.)*

Open Loop (Pump-and-Dump) Systems

Far less costly—but might pose other concerns

Open Loop (Pump-and-Dump) Systems

Leaving water temperature is tuned to 37°F.

An open loop flow control assembly typically includes, filter strainer, P/T ports, back-flush bibs, solenoid valve, and flow meter. *(Pictured is an assembly that is “presuperheater” capable.)*

- Lowest safe entering water temperature (EWT) limit = 43°F
- Flow requirements scale upward from 4 to 14 GPM (approx. 3 to 8 Ton GSHP) for residential sizing
- LWT is tuned to 37°F regardless of EWT (determines ultimate system flow rate)
- Up to 10K GPD & 1M GPY allowed without permit in MN

Open Loop systems allow for the same amount of flexibility in GSHP design.

Calculate number of gallons in 1" rainfall on 1 Acre of land:

43,560 sq.ft./Acre

144 sq.in./sq.ft **BUT** 1,728 cu.in./sq.ft.

43,560 X 1,728 = 75,271,680 cu.in./Acre

0.00432900433 gals./cu.in.

75,271,680 X 0.0043290 = 325,851.1 gals.

325,851 gallons fall on 1 Acre of land for every 1" of rainfall.

On a controlled open loop, a 5 Ton cold climate GSHP discharges approximately twice that amount (650,000) gallons in one year.

How much is a "lot" of water?

Diffusion/Reinjection

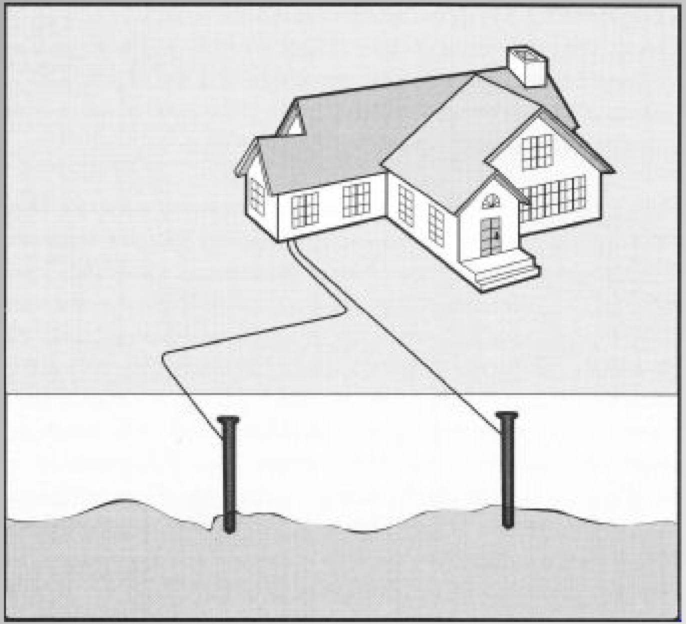


Figure 1.2a. Ground Water Open-Loop GSHP System

Standing Column

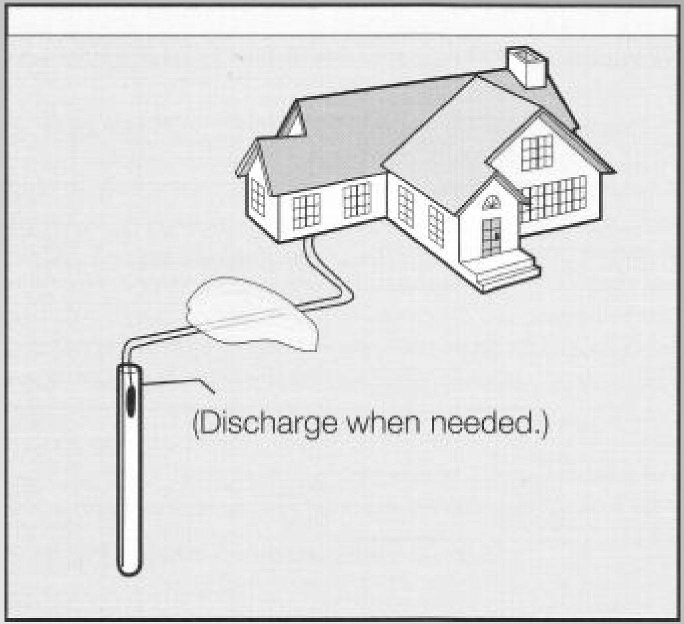
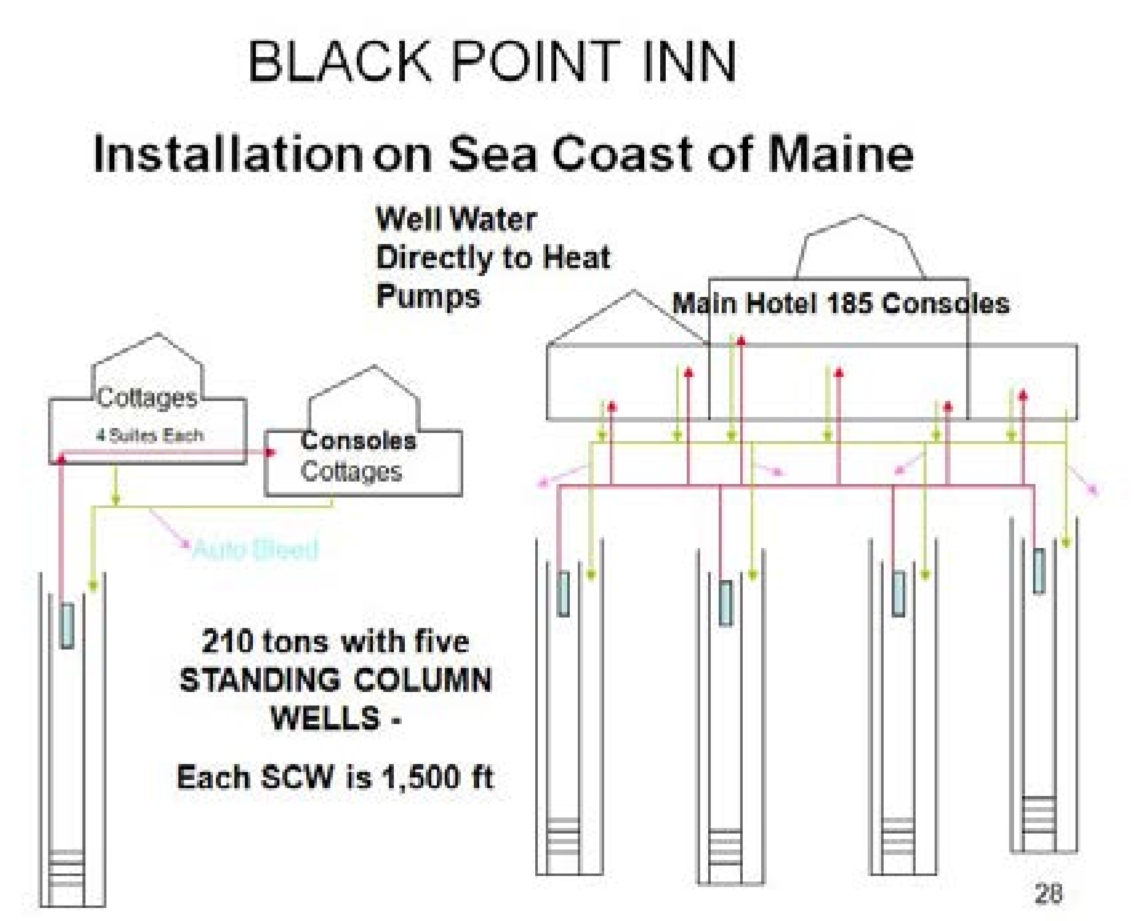


Figure 1.2b. Standing Column Open-Loop GSHP System

Open Loop Reinjection Well Options

Where surface discharge opportunities are limited



BLACK POINT INN

Installation on Sea Coast of Maine

210 tons with five STANDING COLUMN WELLS -

Each SCW is 1,500 ft

Coaxial “Standing Column” Reinjection Wells

Limited to rock formations—Must be precisely engineered

ADVANTAGES:

- Pump-and-Dump design, using existing domestic well, is least expensive loop option available
- Requires minimal disturbance to site—excavation generally limited to single discharge pipe trench
- Higher expected GSHP performance & efficiency: loop temperatures generally fall between 43°F and 48°F in Duluth Complex
- Heat pump sizing can often be scaled back by a nominal Ton—making many forced-air retrofits much easier
- Installation is frequently “plug and play”

Open Loops

DISADVANTAGES:

- Higher domestic water usage can potentially affect aquifer
- At the mercy of the well—water temperature and recovery rate must remain sufficient and stable
- Water quality can also be a factor—routine back-flushing of the GSHP water coil is generally recommended
- Metered city water can be cost prohibitive
- Site discharge opportunities may be limited (no septics or sanitary sewers)
- Reinjection wells are inherently risky in lower temperature formations like Duluth Complex—they are also starting to present other concerns, particularly relating to well water contamination.

Open Loops

QUESTIONS?

RESOURCES:

- Minnesota Geothermal Heat Pump Association
  www.MNGHPA.org
- Wisconsin Geothermal Association
  www.wisgeo.org
- International Ground Source Heat Pump Association
  www.igshpa.okstate.edu
- GeoExchange
  www.GeoExchange.org
- Association of Energy Engineers
  www.aeecenter.org

END