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Ground Heat Exchanger Design Principles and Design Tools

Ed Lohrenz, CGD *GEOptimize, Inc.* Presented Live at the NY-GEO 2023 Conference Albany, New York on April 26, 2023

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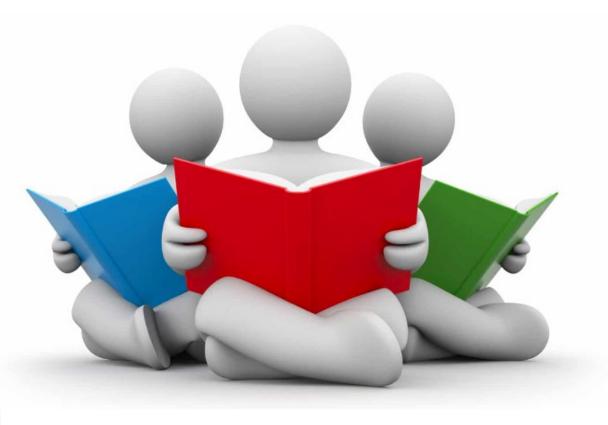
Ground Heat Exchanger Design Principles and Tools

April 26, 2023

GEOptimize

Ed Lohrenz ed@geoptimize.ca 204-318-2156

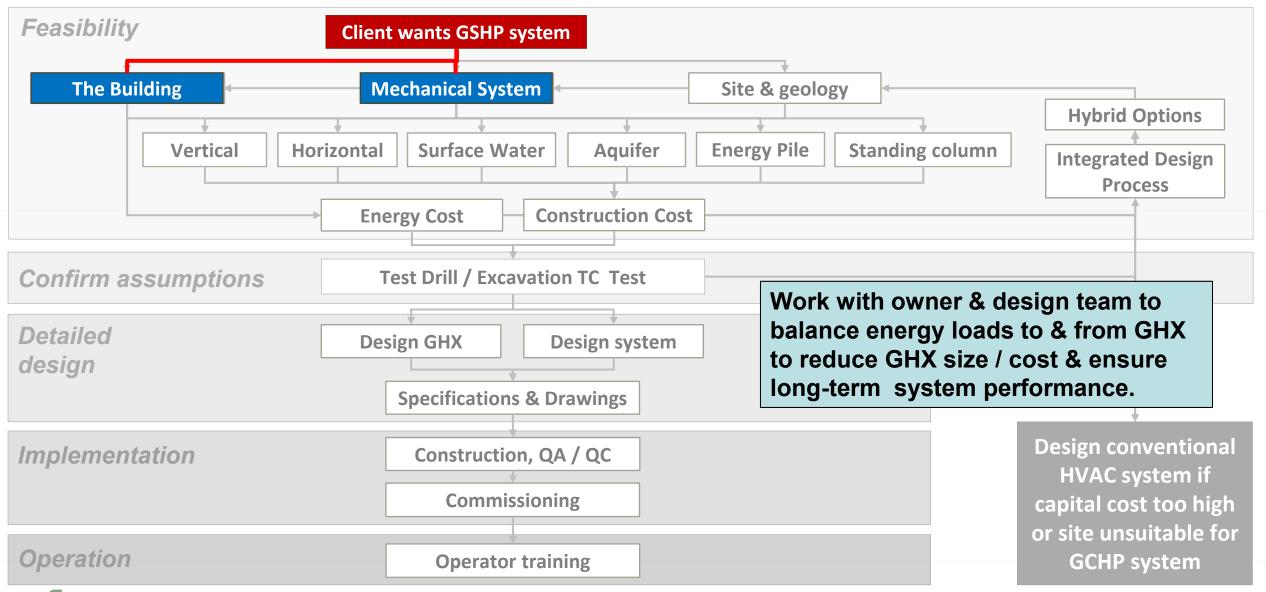
Learning objectives



- See the impact of changes to the building or mechanical system on size, cost and performance of a GHX
- Simulate performance of different ground heat exchanger (GHX) types
- Determine the impact of changes to GHX configuration on size, cost and performance of a GHX
- Where to find information needed to model different GHX types

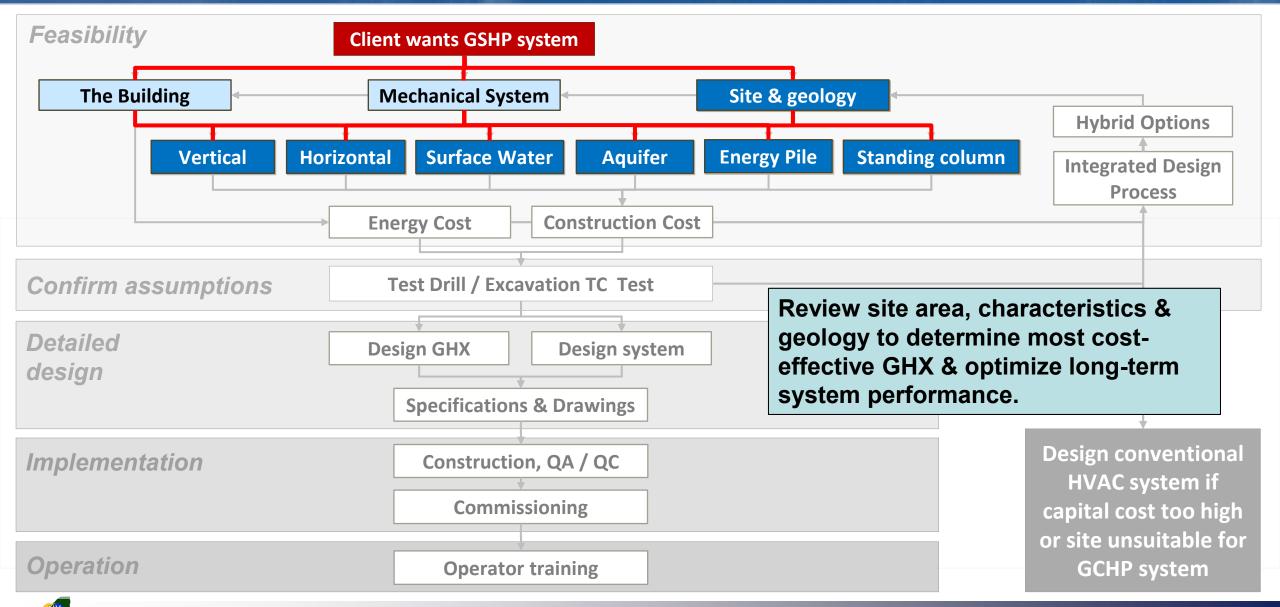


Hourly energy model to determine how much energy GHX has to deal with



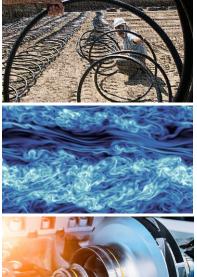


GHX configuration and contractor capabilities



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Five factors to consider when designing a GHX



- Touch enough dirt with enough pipe (loads, site & geology)
- Ensure good heat transfer...fluid selection & flow rates
- Minimize pump power (parasitic loads)



Design for flushing & purging



Design GHX for constructability



Touch enough dirt with enough pipe...know your loads, sit and geology

Veteran's Affairs home, Upstate NY



- 80,000 ft2 Veteran's Affairs home located in Upstate NY. Iterative energy modeling completed includes:
 - Business as usual standard construction built to ASHRAE 90.1
 - Upgrade glass (improved U-value and solar heat gain coefficient)
 - High efficiency ERV plus upgraded glass
 - Add DHW loads



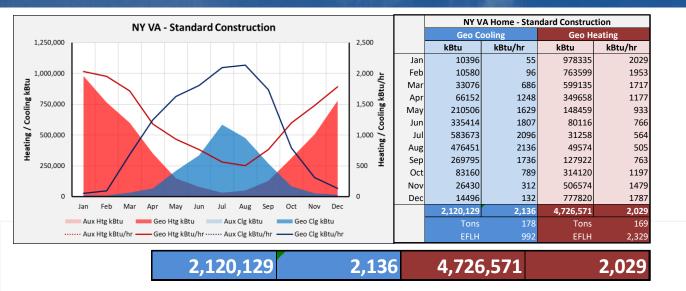
Information needed to design GHX



- Amount of energy the GHX must deal with
- Land area available for construction of the GHX
- Thermal properties of the soil the GHX is built with



What loads to use when designing the GHX

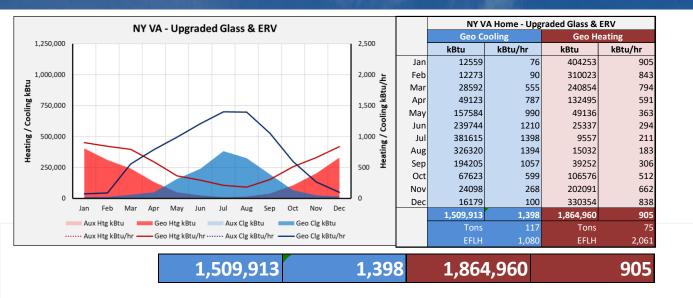


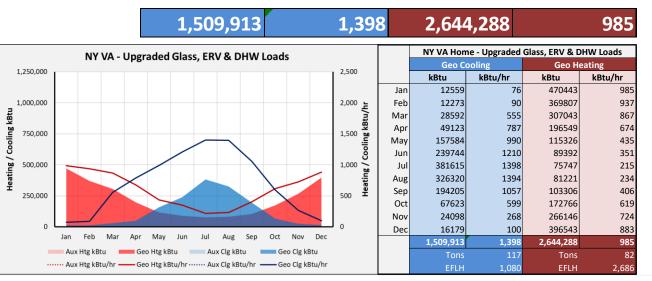
	2,064,198	2,095		4,645	,031		1,975		
NY W	A - Upgraded Glass			N	NY VA Home - Upgraded Glass				
	A - Opgraded Glass		Geo Co	ooling	Geo He	ating			
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1,000,000		2,000 는	Feb	10621	87	748314	1911		
B		tu/l	Mar	32213	662	589764	1665		
750,000		2,000 ,1,500 ,1,500 ,000 ,000 ,000 ,000 ,	Apr	64324	1207	346229	1101		
			May	203702	1594	149101	927		
		č	Jun	324882	1772	80804	767		
500,000			Jul	567809	2054	31487	565		
4 Heating 200,000		Heating	Aug	463541	2095	49683	505		
± 250.000		500 H	Sep	262985	1700	127267	765		
			Oct	82052	763	309723	1102		
			Nov	27035	304	495405	1404		
Jan Feb Mar Apr M	1ay Jun Jul Aug Sep Oct Nov	Dec	Dec	14584	113	760733	1728		
	,			2,064,198	2,095	4,645,031	1,975		
U U	tg kBtu Aux Clg kBtu Geo Clg kBt			Tons	175	Tons	165		
······ Aux Htg kBtu/hr —— Geo H	tg kBtu/hr ······ Aux Clg kBtu/hr —— Geo Clg kBt	tu/hr		EFLH	986	EFLH	2,352		

- Business as Usual:
 - Standard building constructed to ASHRAE 90.1 Standards
- Upgraded glass
 - Cooling loads reduced with lower solar heat gain coefficient
 - Heating loads reduced with lower U-value



Additional efficiency measures & loads



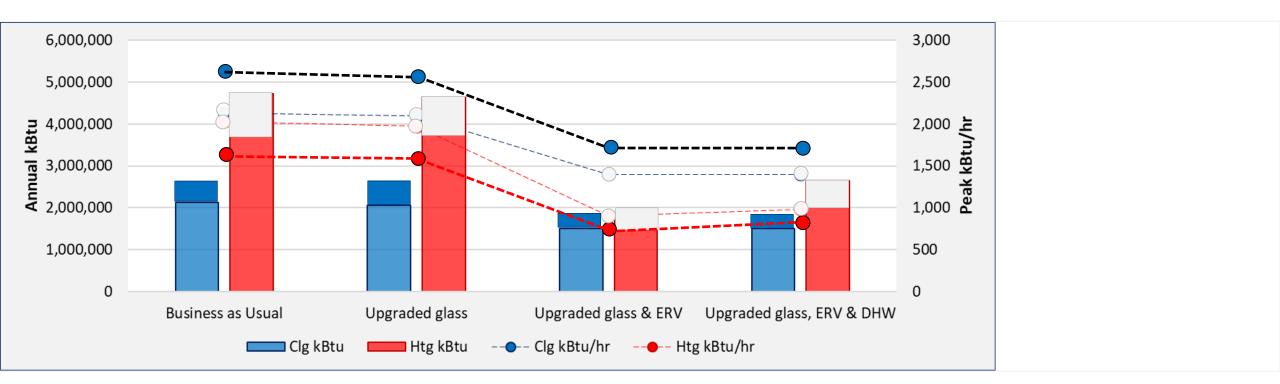


- Upgraded glass plus ERV
 - Peak heating loads down 55%
 - Annual heating loads down 61%
 - Peak cooling loads down 35%
 - Annual cooling loads down 29%
- Adding DHW loads increases
 - Peak heating loads up 8%
 - Annual heating loads up 41%



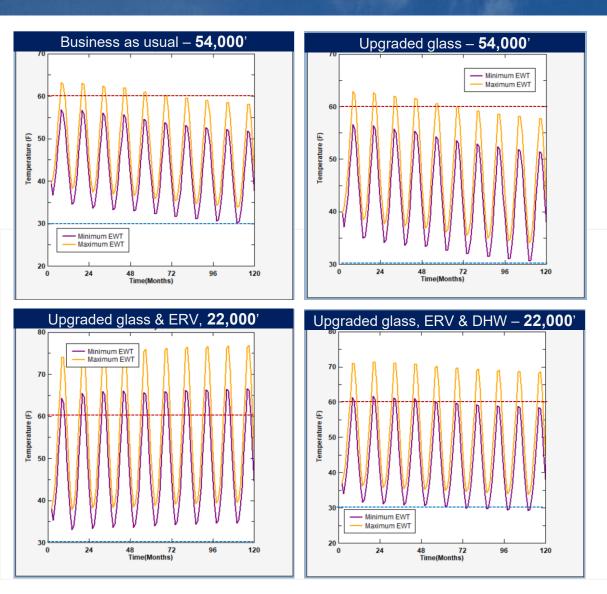
Comparison of energy load profiles with & without compressor energy

- Building energy load profiles change with changes to the building
- Power to run compressors is rejected to the GHX when cooling
- Power to run compressors reduces amount of heat extracted from GHX when heating the building





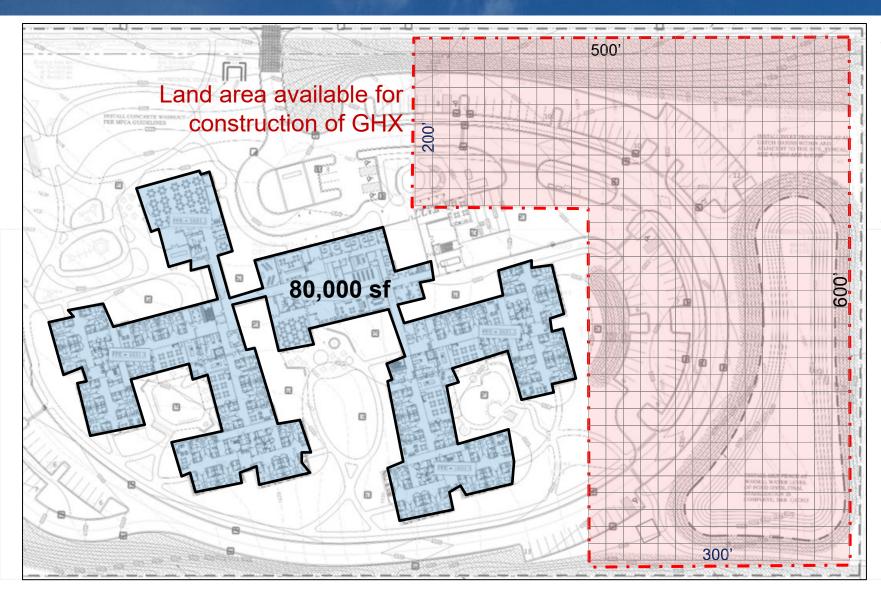
Borehole required to meet four different building loads



- The amount of borehole needed for the for each of the energy models changes significantly as efficiency measures or other loads are connected to the GHX. Loads change
 - Size and cost of GHX
 - Land are required to build GHX
 - Long-term performance
- Preliminary GHX models indicates quickly which iteration of energy model to recommend to owner



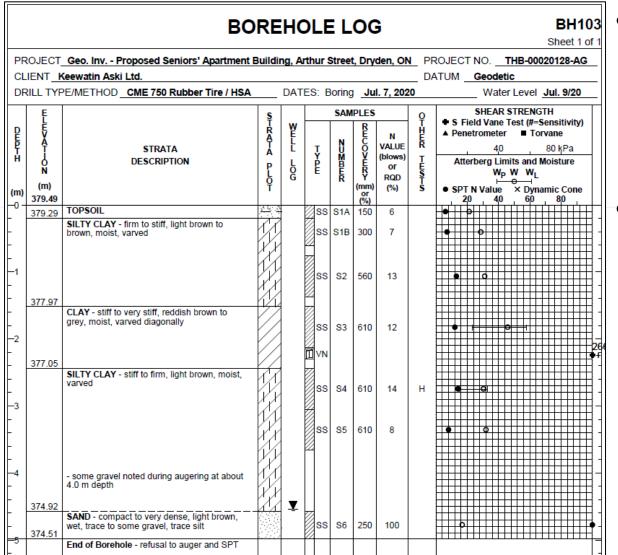
Land area available for construction of GHX



- Configuration & type of GHX is impacted by available land area
- Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered



Geotechnical reports



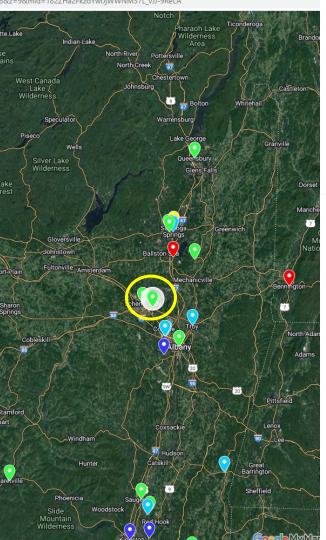
- Geotechnical reports provide detailed information to the depth a horizontally excavated or horizontally bored GHX.
- Thermal properties of the soil for the anticipated burial depth can be estimated from tables in IGSHPA manual or *"Design and Installation of Ground Source Heat Pump Systems", S.Kavanaugh, K.Rafferty, ASHRAE 2014*



Thermal response test databases

← → C 🔒 google.com/maps/d/u/0/viewer?ll=42.88831402421786%2C-73.18829464318678&z=9&mid=182ZHa2FkzdYwIJjWWNM37L_vJJ-9ReLA

	1 2 2 2 2
← Niskayuna High	← Proposed Union College Grad
Project	Project
Niskayuna High School Bore #1	Proposed Union College Graduate Building
City Location	City Location
Niskayuna	Schenectady
State	State
NY	NY
Driller	Driller
Aquifer Drilling & Testing, Inc.	Aquifer Drilling & Testing, Inc.
Formation Thermal Conductivity (Bt	Formation Thermal Conductivity (Bturn-ft-*F)
1.54	1.37
Formation Thermal Diffusivity (ft2/c	Formation Thermal Diffusivity (ft2/da)
1.19	1.01
Undisturbed Formation Temperature 52.5	Undisturbed Formation Temperature 54.8
Date of Test	Date of Test
05/29/2006	06/04/2008
Depth of Test Loop (ft)	Depth of Test Loop (ft)
404	400
U-bend Pipe size (inch)	U-bend Pipe size (inch)
1.25	1.25
Borehole Diameter	Borehole Diameter
6	6
Report	Report
NY-Niskayuna-5-29-06.pdf	NY-Schenectady-6-4-08.pdf
Drill Log	Drill Log
black shale	clay, shale



In areas with significant numbers of commercial GSHP installations you may find databases with thermal response test results.



Interview drilling & excavation contractors, geologists & hydro-geologists



- Drilling and excavation contractors and geologists or hydro-geologists can provide information about:
 - Stratigraphy information needed to estimate thermal properties of soil
 - Cost-effective drilling depth for site
 - Drilling or excavation budget costs



Water well databases

MDH	MDH	Minnesota Departmen Health	t of	Minneso	ota Well	Index	K		
	General Inform	ation							
+	Unique Well ID: Well Elevation (I Township: Subsection: Driller:	132 BABB	3DA	Well Name: Drilled Depth (ft): Range: Use: Co. Entry Date:	Drilled Depth (ft): 257 Well Completed (ft): Range: 43 Dir: Use: monitor well Well Status:				Otter Ta 257 W Active 11/18/2
N Tower	Related Reso Go to MN Well		ll Log Report	<u>Stratigraphy</u>	Report				
Minnesota State	More Details	Stratigraphy	Address	Chemical Data	Construction	Pump Tes	st	Static Water	Con
Cmty & Front College		Desc	ription		From(f	(1)	To(ft)		
	FILL & SAND & F	BOULDERS			0		15		
	SAND & BOULD	ERS		15		20			
	CLAY & SAND S	TREAKS		20		26			
W Lincoln Ave	CLAY WITH BOU	JLDERS		26		35			
	CLAY & SAND S	TREAKS			35		44		
m +	MED. SAND & C	OARSE GRAVEL			44		50		
Park	CLAY WITH MEE	D. FINE SAND STREAK	(S		50		70		
TowerRd	CLAY WITH BOU	JLDERS			70		74		
d	CLAY				74		93		
	SANDY CLAY W	ITH BOULDERS			93		130		
	FINE SILTY SAN	ID CLAY STREAKS			130		198		
	SANDY CLAY			198 209					
•	SANDY CLAY W	ITH BOULDERS			209		211		
	SAND WITH CLA	AY STREAKS			211		215		
	COARSE SAND	& LOOSE GRAVEL				227			
	CLAY				227				
	CLAY WITH GRA	AVEL STREAK			230		235		
52	CLAY WITH BOU	JLDERS			235		237		
	SAND WITH CL	AY STREAKS			237		240		
	CLAY				240		257		

- Some jurisdictions have extensive water well databases showing stratigraphy, static water levels, pump test results, etc.
- TC and TD can be estimated by creating a weighted average of the thermal properties of the lithology.



Preliminary GHX modeling with monthly energy loads

A5	; v	$\therefore f_x = f_x$		NY VA H	Home - Up	ograg	ed Glass, ERV a	& DHW
4	А	B C		Geo C	ooling		Geo He	eating
_		Boilers load (kBtu/h) boston_off.aps						
3	boston_or	boston_on.aps		kBtu	kBtu/l	n	kBtu	kBtu/hr
4			Jan	22954		132	1448778	2999
5	0	1457.848	Feb	2285		180	1133406	2890
6 7	0	1543.413 1614.678						
8	0	1684.256	Mar	61668		1242	906178	2461
9	5.54658	1763.168	Apr	115275		2035	546207	1804
10	6.61337	1891.015						
11	5.748	1867.348	May	368089		2608	263785	1300
12 13	11.17832 11.84287	1710.941 1735.915	Jun	5751/59		3016	169508	1066
14	28.19031	1703.237			!			
15	38.99178	1646.194	Jul	\$65 to	7	3493	107005	779
16	32.54088	1579.55	Aug	/ 80/ ~ 1		3530	130796	694
17	31.84263	1418.279	-					
18 19	33.22857 35.29769	1374.319 1273.534	Sep	4 199	4	2793	231229	1078
20	51.46631	1128.692	Oct	4 199 1197 1197 1199 1199 1199 1199 1199		1388	486886	1812
21	48.38217	1154.039		SI Aprop				
22	34.67711	1094.363	No DAY	5 90528 930675 5 30,043 Tons		580	772720	2158
23	30.22018	957.4687		830675		232	1174363	2573
24 25	29.79956 22.99127	822.1762 812.6953	$\vdash \not\prec$					
26	14.42231	819.7145	l cooling l	0,30,043	ే	,530	7,370,860	2,999
27	13.44765	776.6334		ଁ Tons		294	Tons	250
28	12.62103	810.8748	1/8/					
29	9.76974	911.3629	/ ŭ	EFLH	1	,028	EFLH	2,458
30 31	10.13636 9.57984	1053.87 1157.852	lotal	Q /				
32	9.09078	1249.956	.8	$\overline{\gamma}$				
33	37.48852	1319.934		1				
34	21.10593	1481.956	1					
35	20.8102	1467.026	1 1					
36	22.03705	1383.609	l = l					
37 38	30.13111 47.99771	1424.343 1364.315						
38 39	47.99771 51.01344	1364.315	1					
40	46.02955	1398.741	1					
41	45.69978	1366.154 ह	1					
+ I								

- Monthly cooling loads are extracted from the 8,760 hourly loads
 - Total of the 744 hours in January equals the January kBtu in cooling
 - Peak cooling load in January equals the maximum hourly peak cooling load



Preliminary modeling with monthly energy loads

A5	5 v	$\therefore f_x = f_x$		NY VA H	Home - Upgrag	ed Glass, ERV a	& DHW
4	A	B C		Geo C	ooling	Geo He	eating
_		Boilers load (kBtu/h) boston_off.aps		kBtu	kBtu/hr	kBtu	kBtu/hr
3							
4			Jan	22954	132	1448778	2999
5 6	0	1457.848 1543.413	Feb	22853	180	1133406	/ 2890
7	0	1614.678	Mar	61668	1242	906178	2461
8	0	1684.256				1	1 - I
9 10	5.54658 6.61337	1763.168 1891.015	Apr	115275	2035	546207	1804
11	5.748	1867.348	May	368089	2608	263785	1300
12	11.17832	1710.941					
13	11.84287	1735.915	Jun	575158	3016	169508	1066
14 15	28.19031 38.99178	1703.237 1646.194	Jul	965289	3493	/ 27005	779
16	32.54088	1579.55	٨١١σ	802771	2520	97005 90796	694
17	31.84263	1418.279	Aug		3530		
18	33.22857	1374.319	Sep	463999	2793	231229	1078
19 20	35.29769 51.46631	1273.534 1128.692	Oct	150782	1388	486886	1812
20	48.38217	1128.032			1500		
22	34.67711	1094.363	Nov	50528	58	772720	2158
23	30.22018	957.4687	Dec	30675⁄	4 4 5 4 5 4 9 4 5 4 9 4 5 4 9 4 5 9 4 5 9 4 5 5 9 4 5 5 9 4 5 5 9 4 5 5 9 4 5 5 5 1,028 5 5 5 1,028 1,028 1,028 1,028 1,028 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1,028 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1174363	2573
24 25	29.79956 22.99127	822.1762 812.6953					
26	14.42231	819.7145		3,630,0		7,370,860	2,999
27	13.44765	776.6334			\$ 94	Tons	250
28	12.62103	810.8748			2000	FFUL	
29 30	9.76974 10.13636	911.3629 1053.87		North CH		EFLH	2,458
30 31	9.57984	1157.852		2/			
32	9.09078	1249.956			7		
33	37.48852	1319.934					
34	21.10593	1481.956					
35 36	20.8102 22.03705	1467.026 1383.609		1	1		
37	30.13111	1424.343					
38	47.99771	1364.315	1				
39	51.01344	1402.147					
40	46.02955	1398.741					
41	45.69978	1366.154 🚈					
	< >	Sheet 1 –					

- Monthly heating loads are extracted from the 8,760 hourly loads
 - Total of the 744 hours in January equals the January kBtu in heating
 - Peak cooling load in January equals the maximum hourly peak heating load



Importing monthly loads into GHX design software

Average Bloc	k Loads			
	88 🖉			Untitled.zon
Monthly Load	Data		2	
Update	Cool Total	ing 📐 🖄 Peak	Heat Total	ting 🔛 Peak
Cancel			(kBtu) 이(
January	10396	55	978335	2029
February	10580	96	763599	1953
March	33076	686	599135	1717
April	66152	1248	349658	1177
May	210506	1629	148459	933
June	335414	1807	80116	766
July	583673	2096	31258	564
August	476451	2136	49574	505
September	269795	1736	127922	763
October	83160	789	314120	1197
November	26430	312	506574	1479
December	14496	132	777820	1787
Total:	2120129	3.0 Hours at Peak	4726570	3.0 Iours at Peak
Flow Rate	Linit T	nlet (ºF):	90.0	40.0
1 31-11/14				

- Monthly energy loads are the minimum required to calculate the size and performance of a GHX
- Some GHX design software can import hourly energy loads and calculate the size and performance of a GHX with greater granularity



Heat pump selection has an impact on loads to GHX

Average Block Loads										
	Untitled.zon									
Reference Label:										
Design Day Loads Topology Design 7.0 Days / Week Time of Day Hourly Data Time of Day Time of Day	n Day Loads Heat Gains Heat Losses (kBtu/Hr) (kBtu/Hr)									
Transfer8 a.m NoonCalculate HoursNoon - 4 p.m.Monthly Loads8 p.m 8 p.m.	341.3 2029.0 2136.0 1172.2 341.3 1172.2 341.3 1172.2 341.3 1172.2									
Annual Equivalent Full-Load Hours: Heat Pump Specifications at Design Temperat	993 2330									
Pump Name HE038 Select Pump Cancel										
Flow Rate 3.0 gpm/ton Unit Inlet (°F):	90.0 40.0									

- Equipment selection determines compressor energy to / from GHX
 - Electric motors in heat pump compressors are cooled by refrigerant flowing through the compressor
 - Compressor energy is rejected to the GHX in addition to heat removed from the building
 - Compressor energy contributes heat to the building when heating...reducing amount of heat extracted from GHX



More efficient heat pumps have less impact on the GHX

	verage Block Loads							
B	🖉 Average Block Loa	ds		- 0 💌				
Re		3 <i>4</i>		Untitled.zon				
-De	Reference Label:							
Г	Design Day Loads	Design	Day Load	s Heat Losses				
	Hourly Data	Time of Day	(kBtu/Hr)	(kBtu/Hr)				
	Transfer Calculate Hours	8 a.m Noon Noon - 4 p.m. 4 p.m 8 p.m.	341.3 2136.0 341.3	2029.0 1172.2 1172.2				
	Monthly Loads	8 p.m 8 a.m.	341.3	1172.2				
He	Annual Equ	uivalent Full-Load Hours:	993	2330				
	Heat Pump Specificat	ions at Design Temperatu	ons at Design Temperature and Flow Rate					
11	Custom Pump	Pump Name		038				
	Select	Capacity (kBtu/Hr)	Cooling 2735.2	Heating				
	Details	Power (kW) EER/COP	148.11	142.67				
	Clear	EER/COP Flow Rate (gpm) Partial Load Factor	534.0	4.2 507.3 1.00				
Flow 3	Flow Rate 3.0 gpm/ton	Unit Inlet (°F):	90.0	40.0				

- More efficient heat pumps:
 - Add less heat to building when heating
 - Reject less heat to GHX when cooling
- Changing heat pump efficiency can have an impact on the energy balance and affect the size, cost and performance of a GHX



Default parameters built into GHX software

🛛 Average	Block Loads			×				
🕒 🛛 A	verage Block Loads			• •				
<u> </u>	🖉 Average Block Loa	ds			x			
Re De Re		3 🥏		Untitled.:	zon			
	Reference Label:							
	Design Day Loads		n Day Load		1			
	Hourly Data	Time of Day	Heat Gains (kBtu/Hr)	Heat Losses (kBtu/Hr)				
	Transfer	8 a.m Noon Noon - 4 p.m.	341.3 2136.0	2029.0				
	Calculate Hours	4 p.m 8 p.m.	341.3	1172.2				
He	Monthly Loads	8 p.m 8 a.m.		1172.2				
□ □ □ He	Annual Equ	uivalent Full-Load Hours:	valent Full-Load Hours: 993 2330					
I I	Heat Pump Specificat	ions at Design Temperatu	ure and Flow Rate					
	Custom Pump	Pump Name	TMM	/ 360				
í.			Cooling	Heating				
-	Select	Capacity (kBtu/Hr)	2136.0	2177.3				
	Details	Power (kW)	155.42	176.65				
	Clear	EER/COP Flow Rate (gpm)	534.0	507.3				
Flow		Partial Load Factor	1.00	0.93				
J Flov					1			
3	Flow Rate 3.0 gpm/ton	Unit Inlet (°F):	90.0	40.0				
	,							

- Mechanical system design can have an impact on heat pump efficiency:
 - The default settings for water to water heat pumps shows heat pump efficiency for typical operation with air handling units selected with 45°F chilled water in cooling and 110°F water in heating
 - COPh = 3.6
 - EER = 13.7



Adjusting heat pump operating parameters to match design

Refi Reference Label: 7.0 Days / Week Design Day Loads 7.0 Days / Week Time of Day Hourly Data (kBtu/Hr) (kBtu/Hr) (kBtu/Hr) (kBtu/Hr) (kBtu/Hr) Image: Color of the state	🛛 Av	erage	Block L	oads			
Re Reference Label: Design Day Loads Design Day Loads To Days / Week Design Day Loads Heurly Data (kBtu/Hr) Calculate Hours 4 p.m 8 p.m. Annual Equivalent Full-Load Hours: 993 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: ClimateMaster Pump Type: Water to Water Entering Water Temperatures and Flow Rate Pump Type: Water to Water Entering Water Temperatures and Flow Rate Pump Type: Water to Water Entering Water Temperatures and Flow Rate Pump Type: Water to Water Entering Water Temperatures and Flow Rate Pump Type: Water to Water Entering Water Temperatures and Flow Rate Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 Flow 3.1 Flow Rate Durit Inlet (%F): 90.0 40.0	D	🛛 Av	erage B	lock Loads			×
Re Reference Label: Pesign Day Loads Pesign Day Loads To Days / Week Time of Day Hourly Data (KBtu/Hr) (KBtu/Hr) (KBtu/Hr) Collulate Hours 4 p.m 8 p.m. Annual Equivalent Full-Load Hours: 993 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: ClimateMaster Pump Series: TMW (water to water) Pump Series: TMW (water to water) Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 °F Heating: 100.0 Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 °F Heating: 100.0 How Rate Load EWT: Cooling: 65.0 °F Heating: 100.0 Flow 3		B	🛛 Ave	rage Block Loads			
Reference Label: Pesign Day Loads Design Day Loads Time of Day Heat Gains Heat Losses Hourly Data Time of Day Heat Gains C Transfer 8 a.m Noon 341.3 2029.0 Noon - 4 p.m. 2136.0 1172.2 Annual Equivalent Full-Load Hours: 993 2330 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: ClimateMaster Pump Series: TMW (water to water) Pump Type: Water to Water Flow 3.1 Flow Rate Load 100.0 How Rate Load Load 100.0 Flow	Re	_	B ,	🖊 Average Block Loa	ads		- • 💌
Pesign Day Loads Design Day Loads 7.0 Days / Week Time of Day Heat Gains Heat Losses Hourly Data Transfer 8 a.m Noon 341.3 2029.0 Noon - 4 p.m. 2136.0 1172.2 Calculate Hours 4 p.m 8 p.m. 341.3 1172.2 Monthly Loads 8 p.m 8 a.m. 1172.2 100.0 Flow Theat Pump Sereise: TMW (water to water)	-De		Reft				Untitled.zon
He He Design Day Loads Transfer 8 a.m Noon 341.3 2029.0 Noon - 4 p.m. 2136.0 1172.2 Calculate Hours 4 p.m 8 p.m. 341.3 1172.2 Monthly Loads 8 p.m 8 a.m. 341.3 1172.2 Pump Specifications at Design Temperature and Flow Rate Pump Type: Water to Water Pump Type: Water to Water Etwit: Cooling: 55.0 Fl	Ē	Ī		Reference Label:			
He Hourly Data Time of Day Heat Gains Heat Losses He Hourly Data 8 a.m Noon 341.3 2029.0 Noon - 4 p.m. 2136.0 1172.2 Question 4 p.m 8 p.m. 341.3 1172.2 Monthly Loads 8 p.m 8 a.m. 341.3 1172.2 Monthly Loads TMW (water towater 993 2330 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: Climate Master Pump Type: Water to Water Return Pump Type: Water to Water EWT: Cooling: 55.0 90.0 40.0 </td <td>-</td> <td>H</td> <td>7.</td> <td></td> <td>k Desigi</td> <td>n Day Loads</td> <td>5</td>	-	H	7.		k Desigi	n Day Loads	5
He He <td< td=""><td>-</td><td>-</td><td>H</td><td></td><td>Time of Day</td><td></td><td></td></td<>	-	-	H		Time of Day		
He Monthly Loads 4 p.m 8 p.m. 341.3 1172.2 Monthly Loads 8 p.m 8 a.m. 341.3 1172.2 Annual Equivalent Full-Load Hours: 993 2330 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: ClimateMaster Pump Series: TMW (water to water) Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 °F Heating: 100.0 Flow 3.1 Flow 3.1	-		c	Transfer			
He Monthly Loads 8 p.m 8 a.m. 341.3 1172.2 Annual Equivalent Full-Load Hours: 993 2330 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: ClimateMaster Pump Series: TMW (water to water) Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 °F Heating: 100.0 % 3.1 Flow 3.1	He		Ν	Calculate Hours			
Heat Annual Equivalent Full-Load Hours: 993 2330 Heat Pump Specifications at Design Temperature and Flow Rate Pump Manufacturer: ClimateMaster Return Pump Series: TMW (water to water) Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 °F Heating: 100.0 Flow 3.1 Flow 3.1		He		Monthly Loads	8 p.m 8 a.m.	j 341.3	1172.2
Pump Manufacturer: ClimateMaster Return Pump Series: TMW (water to water) Pump Type: Water to Water Entering Water Temperatures and Flow Rate - Load EWT: Cooling: 55.0 °F Heating: 100.0 Flow 3.1 Flow 3.1			Hea	Annual Eq	uivalent Full-Load Hours:	993	2330
Flow 3 Flow 3 Flow 3 Flow 3 Flow 3 Flow 4 0 4 0 5 0 5 0 6 0 7 0 6 0 7 0 7 0 90 40		F				ure and Flow	Rate
Flow 3 Flow 3 Flow 3 Flow 3 Flow 3 Flow 4 100.0 °F						_	Return
Flow 3 Flow 3 Flow 3 Flow 3 Flow 3 Flow 40.0 40.0 40.0							
3 Flow 3 Flow 3 Flow 3 Flow 3 Flow 40.0				Entering Water Ter	mperatures and Flow Rate	e - Load	
3.(Flow Rate		_		EWT: Coo	oling: 55.0 ºF H	leating: 10	0.0 ℉
Unit Inlet (°F): 90.0 40.0		3					
gpinycon			3.0	Flow Rate	Unit Inlet (°F):	90.0	40.0

 Selecting heat pump output temperatures to match requirements for a radiant floor heating and cooling or chilled beams changes heat pump efficiency



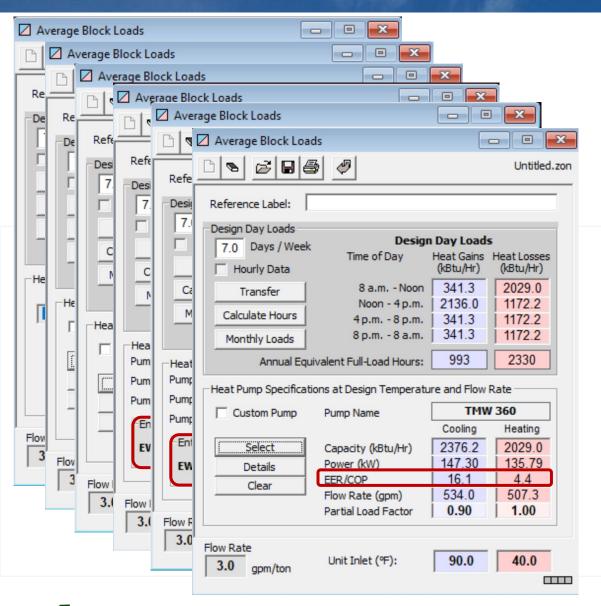
Adjusting heat pump parameters for more efficient performance

Average Block Loads		
🕒 🛛 Average Block L	oads 🗖 🗖 🗖	×
Average Bl	lock Loads	
De Re	Average Block Loads	
De Refe		Untitled.zon
Desi Refe	Reference Label:	
	Design Day Loads 7.0 Days / Week Design Day	
	Time of Day Hea	t Gains Heat Losses tu/Hr) (kBtu/Hr)
	Induster	41.3 2029.0 36.0 1172.2
		41.3 1172.2
	Monthly Loads 8 p.m 8 a.m. 34	41.3 1172.2
Hea	Annual Equivalent Full-Load Hours:	93 2330
E Pum	└── ⊢Heat Pump Specifications at Design Temperature ar	nd Flow Rate
Pum	Pump Manufacturer: ClimateMaster	Return
Pum	Pump Series: TMW (water to water)	
	Pump Type: Water to Water	
Flov EV	Entering Water Temperatures and Flow Rate - Lo	ad
	EWT: Cooling: 70.0 °F Heatin	g: 86.0 °F
3 Flow I		
3.1 Flow I	Size Bata	
3.0	Flow Rate 3.0 gpm/ton Unit Inlet (%):	90.0 40.0

- Adjusting the default temperature parameters a water to water heat pump is designed to operate at changes system efficiency
- This will have an impact on the size, cost and long-term performance of the system



Telling the software about the system



- Reducing hot water supply temperature to the building from 110°F to 90°F increases COP from 3.6 to 4.4
- Increasing chilled water supply temperature to the building from 45°F to 65°F increases EER from 13.7 to 16.1







Estimating thermal properties of from a borehole log

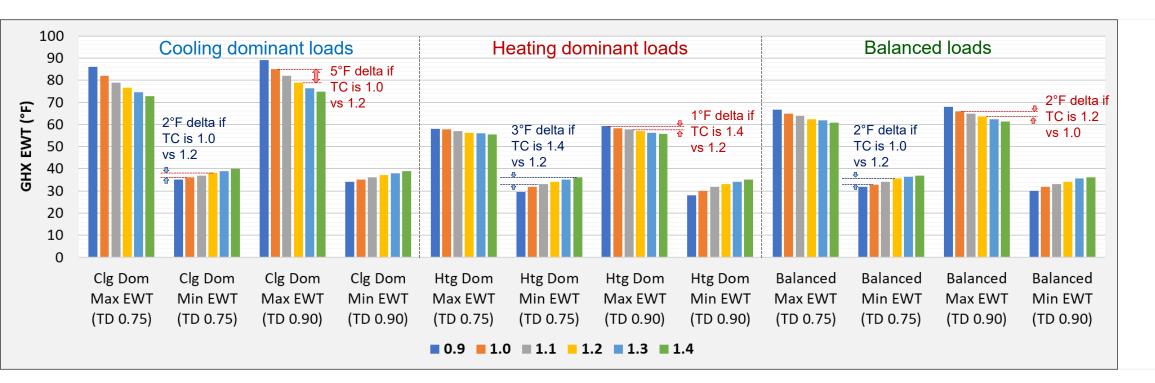
 Creating a weighted average of the stratigraphy of a borehole log provides preliminary information needed to model GHX

Der	oth			Laver	Conduc	tivity	Lave	er Diffus	ivity	Weighted TC			We	eighted	TD
Start	End	Layer	Lithology	Low	Avg	, High	Low	Avg	, High	Low	Avg	High	Low	Avg	High
0	15	15	Sand 80 lb 10%	0.60	0.85	1.10	0.40	0.47	0.53	0.16	0.23	0.30	0.11	0.13	0.14
15	20	5	Sandy clay 10%	0.80	1.05	1.30	0.60	0.75	0.90	0.07	0.10	0.12	0.05	0.07	0.08
20	26	6	Clay 120 lb 15%	0.80	0.95	1.10	0.46	0.55	0.63	0.09	0.10	0.12	0.05	0.06	0.07
26	35	9	Clay 120 lb 15%	0.80	0.95	1.10	0.46	0.55	0.63	0.13	0.16	0.18	0.08	0.09	0.10
35	44	9	Sand 120 lb 15%	1.60	1.90	2.20	0.91	1.06	1.20	0.26	0.31	0.36	0.15	0.17	0.20
44	50	6	Sand 120 lb 15%	1.60	1.90	2.20	0.91	1.06	1.20	0.17	0.21	0.24	0.10	0.12	0.13
50	55	5	Clay 120 lb 15%	0.80	0.95	1.10	0.46	0.55	0.63	0.07	0.09	0.10	0.04	0.05	0.06
55		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth	55	4	Average Estimated Thermal Conductivity & Diffusivity of Borehole0.961.191.420.580.680.78												



Thermal conductivity and diffusivity estimates for vertical GHX

- Test borehole & TC test cost from \$15,000 to \$40,000
- Information may be available to estimate TC
- If estimated TC & TD is within 15% of actual properties the impact on operating temperatures can be expected to be within 1° to 5°F

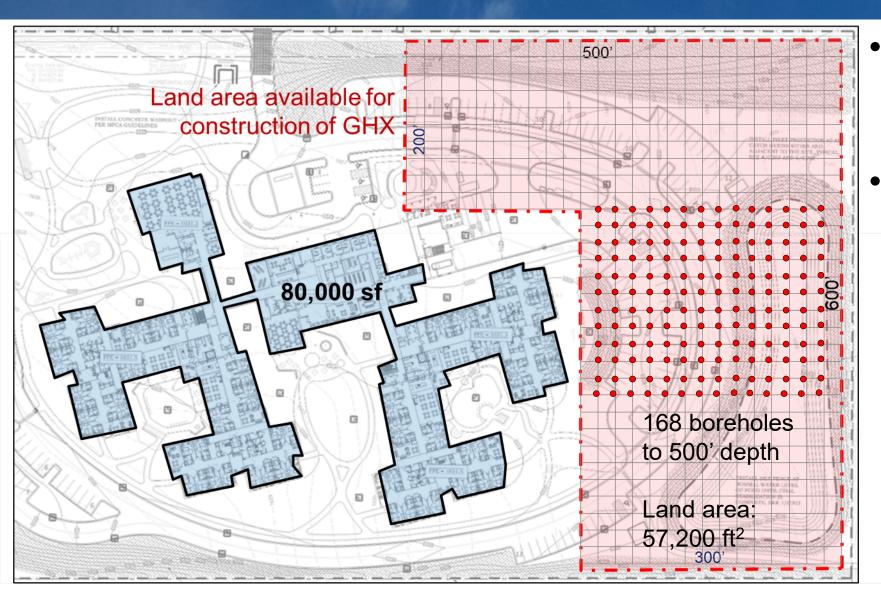




Fluid Soil Bore Pattern Extra kW Informa	tesults Fluid Soil Bore Pattern Extra kW Information	luid Soil Bore Pattern Extra kW Information	esults Fluid Soil Bore Pattern E	Extra kW Inform	nation
listurbed Ground Temperature		l Grid Arrangement		COOLING	HEATING
Ground Temperature: 50.0 °F	Borehole Thermal Resistance: 0.383 h*ft*°F/Btu Pipe Parameters U-Tube Configuration Borehole Diameter: 5.00 in Borehole Diameter: 5.00 in	Borehole Number: 168 GMap Rows Across: 14 Rows Down: 12	Total Bore Length (ft): Borehole Number: Borehole Length (ft):	84000.0 168 500.0	84000.0 168 500.0
I Thermal Properties		Borehole Separation: 20.0 ft	Ground Temperature Change (°F):	N/A	N/A
View Layer Calculator Thermal Conductivity: 1.40 Btu/(h*ft*°F)	Coaxial Coaxial	se External File Select Clear Create	Peak Unit Inlet (°F): Peak Unit Outlet (°F):	67.0 74.4	31.4 27.1
Thermal Diffusivity: 0.90 ft^2/day	Check Pipe Tables	Filename: No File	Total Unit Capacity (kBtu/Hr): Peak Load (kBtu/Hr):	3530.0 3530.0	2923.0 2923.0
Diffusivity Calculator Check Soil Tables	S Pipe Resistance: 0.104 h*ft*⁰F/Btu Radial Pipe Placement Pipe Size: 1 1/4 in. (32 mm) ✓ ✓ Close Together Outer Diameter: 1.660 in ✓ ✓	Bores Per Circuit	Peak Demand (kW): Heat Pump EER/COP: Seasonal Heat Pump EER/COP: Avg. Annual Power (kWh):	106.3 33.1 35.5 1.02E+5	201.7 4.2 4.3 4.53E+5
deling Time Period	Inner Diameter: 1.358 in	anoth Mode	System Flow Rate (gpm):	882.5	730.8
Prediction Time: 10.0 years	Pipe Type: SDR11 Flow Type: Turbulent	n/Off Borehole Length 500 ft	– Optional Hybrid System: Off Cooling	Н	leating



Vertical GHX for standard building or building with upgraded glass



Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

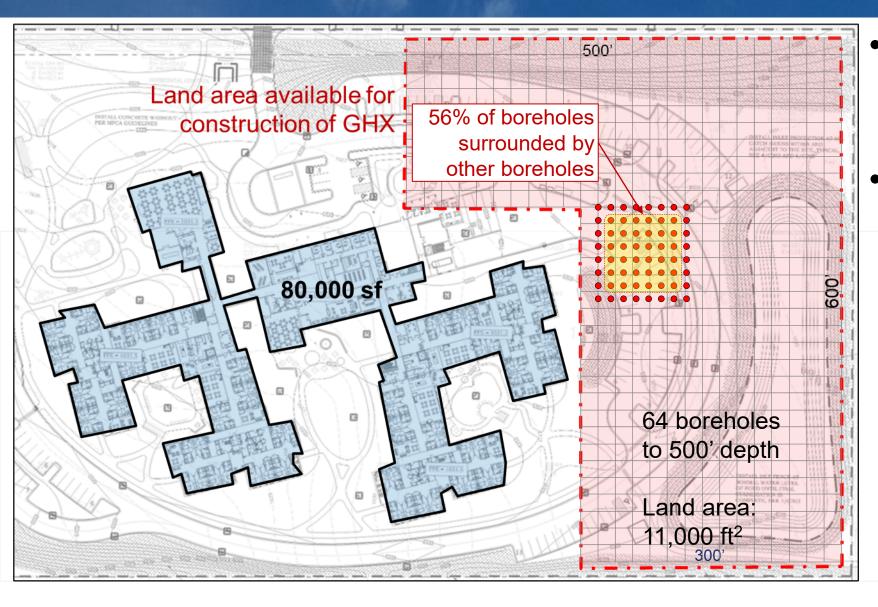


Modeling for vertical borehole GHX

·				
s Fluid Soil Bore Pattern Extra kW Informati	sults Fluid Soil Bore Pattern Extra kW Information	ud Soil Bore Pattern Extra kW Information	esults Fluid Soil Bore Pattern E	Extra kW Information
disturbed Ground Temperature		Grid Arrangement		COOLING HEATING
	Borehole Thermal Resistance: 0.383 h*ft*°F/Btu	Borehole Number: 64 GMag	Total Bore Length (ft):	32000.0 32000.0
Ground Temperature: 50.0 °F	Pipe Parameters	Rows Across: 8	Borehole Number:	64 64
,	U-Tube Configuration Borehole Diameter Single Borehole Diameter: 5.00 in	Rows Down: 8	Borehole Length (ft):	500.0 500.0
il Thermal Properties		Borehole Separation: 15 ft	Ground Temperature Change (°F):	N/A N/A
View Layer Calculator	C Double Backfill (Grout) Information		Peak Unit Inlet (°F):	65.9 32.6
Thermal Conductivity: 1.40 Btu/(h*ft*°F)	(O) C Coaxial	e External File Select Clear Crea	Peak Unit Outlet (°F):	73.4 28.8
Thermal Diffusivity: 0.90 ft^2/day	Check Pipe Tables	ename: No File Grid Build		1398.0 985.0
		es per Parallel Circuit	Peak Load (kBtu/Hr): Peak Demand (kW):	1398.0 985.0 41.8 68.9
Diffusivity Calculator Check Soil Tables	Pipe Resistance: 0.104 h*ft**F/Btu Radial Pipe Placement	Bores Per Circuit	Heat Pump EER/COP:	33.3 4.2
	Pipe Size: 1 1/4 in. (32 mm) 💌 🐼 C Close Together		Seasonal Heat Pump EER/COP:	36.2 4.3
	Duter Diameter: 1.660 in 000 @ Average		Avg. Annual Power (kWh):	4.17E+4 1.80E+5
ideling Time Period	Tanar Diamatary 1250 in	nath Mode	System Flow Rate (gpm):	349.5 246.3
Prediction Time: 10.0 years	Pipe Type: SDR11 C Along Outer Wall		Optional Hybrid System: Off	
	Flow Type: Turbulent	/Off Borehole Length 500 ft	Cooling	Heating



Vertical GHX for building with upgraded glass, ERV & DHW



Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

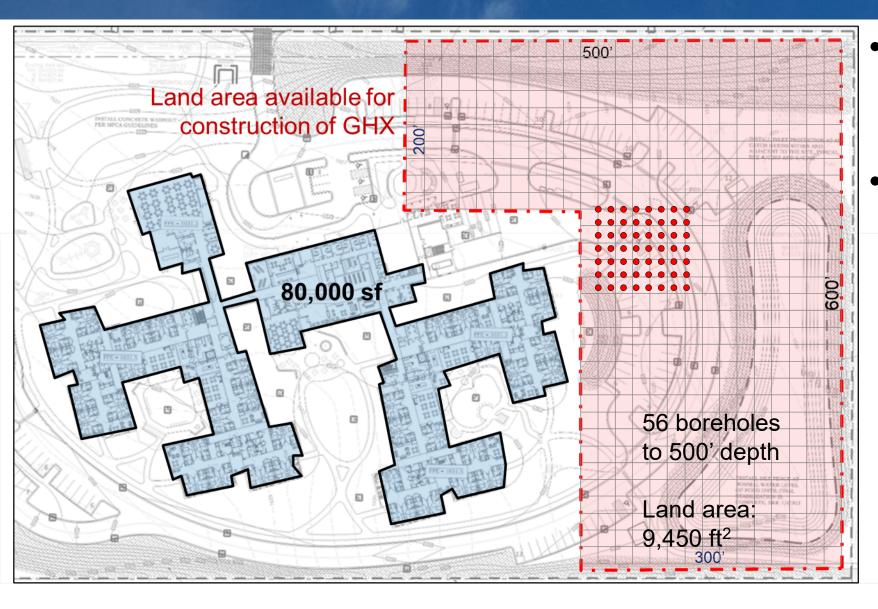


Modeling for vertical borehole GHX

Fluid Soil Bore Pattern Extra kW Informat	aults Fluid Soil Bore	Pattern Extra kW Information	luid	Soil Bore P	Pattern Extra kW	Information	sults Fluid Soil Bore Pattern E	Extra kW Infor	rmation
disturbed Ground Temperature	Calculated Borehole Equivalent Thermal Resistance Borehole Thermal Resistance: 0.197 h*ft*°F/Btu			Grid Arrangement			COOLING	HEATING	
Ground Temperature: 50.0 °F	Pipe Parameters	Borehole Diameter	Br	Borehole Numbe Rows Acros Rows Dow	os: 7		Total Bore Length (ft): Borehole Number: Borehole Length (ft):	28000.0 56 500.0	28000.0 56 500.0
il Thermal Properties	(in Single	Borehole Diameter: 5.00 in	Bor	orehole Separatio			Ground Temperature Change (°F):	N/A	N/A
View Layer Calculator Thermal Conductivity: 1.40 Btu/(h*ft*°F)	C Double	Backfill (Grout) Information		xternal File			Peak Unit Inlet (°F): Peak Unit Outlet (°F):	65.1 72.6	33.0 29.2
Thermal Diffusivity: 0.90 ft^2/day	Check Pipe Tables	Thermal Conductivity: 1.20 Btu/	(n•nt•+)	ame: No File		Grid Builde	Total Unit Capacity (kBtu/Hr): Peak Load (kBtu/Hr):	1398.0 1398.0	985.0 985.0
Diffusivity Calculator Check Soil Tables	Pipe Size: 1 1/4 in.	04 h*ft**F/Btu Radial Pipe Placeme in. (32 mm) ▼ 60 in	Bores	res Per Circuit	מת היו	[[[] [] [] [] [] [] [] [] [] [] [] [] []	Peak Demand (kW): Heat Pump EER/COP: Seasonal Heat Pump EER/COP: Avg. Annual Power (kWh):	41.2 33.8 36.8 4.10E+4	68.5 4.2 4.3 1.80E+5
deling Time Period		58 in (• Average			1 2	3	System Flow Rate (gpm):	349.5	246.3
Prediction Time: 10.0 years	Pipe Type: SDR 11 Flow Type: Turbuler		iter Wall <mark>ength</mark> h/Off		Borehole Length		Optional Hybrid System: Off Cooling		Heating



Vertical GHX for building with upgraded glass, ERV & DHW



Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

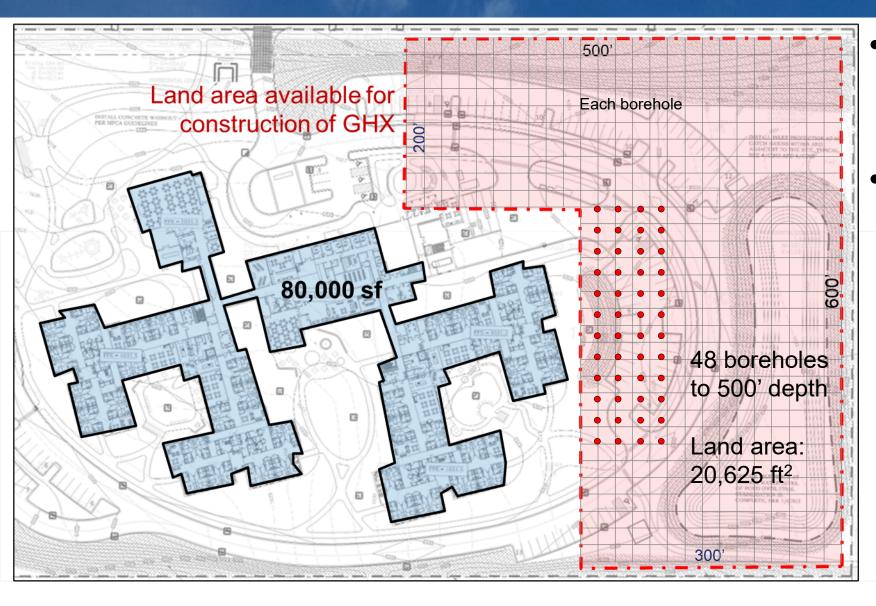


Modeling for vertical borehole GHX

Fluid Soil Bore Pattern Extra kW Informat	ti ^{sults} Fluid Soil Bore Pattern Extra kW Information	id Soil Bore Pattern Extra kW Information	sults Fluid Soil Bore Pattern Ex	ktra kW Information
disturbed Ground Temperature		Grid Arrangement		COOLING HEATING
disturbed dround remperature	Borehole Thermal Resistance: 0.197 h*ft*°F/Btu	Borehole Number: 48 GMap	Tatal Bara Langth (ft):	24000.0 24000.0
Ground Temperature: 50.0 °F	Pipe Parameters U-Tube Configuration Borehole Diameter		Total Bore Length (ft): Borehole Number:	24000.0 24000.0 48 48
	(◦) (◦) <td>Rows Down 12</td> <td>Borehole Length (ft):</td> <td>500.0 500.0</td>	Rows Down 12	Borehole Length (ft):	500.0 500.0
il Thermal Properties		Borehole Separation 25 ft	Ground Temperature Change (°F):	N/A N/A
View Layer Calculator Thermal Conductivity: 1.40 Btu/(h*ft*°F)	O Double Backfill (Grout) Information	External File Select Clear Create	Peak Unit Inlet (°F):	68.2 32.9 75.8 29.1
Thermal Diffusivity: 0.90 ft^2/day	Check Pipe Tables	name: No File	Total Unit Capacity (kBtu/Hr): Peak Load (kBtu/Hr):	1398.0 985.0 1398.0 985.0
Diffusivity Calculator Check Soil Tables	Radial Pine Placement	s per Parallel Circuit	Peak Demand (kW): Heat Pump EER/COP: Seasonal Heat Pump EER/COP:	43.6 68.5 31.9 4.2 35.5 4.4
	Outer Diameter: 1 660 in		Avg. Annual Power (kWh):	4.26E+4 1.77E+5
odeling Time Period	Inner Diameter: 1 359 in		System Flow Rate (gpm):	349.5 246.3
Prediction Time: 10.0 years	Pipe Type: SDR11 Flow Type: Turbulent	/Off Borehole Length 500 ft	Optional Hybrid System: Off Cooling	Heating
			Cooming	riceding

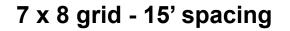


Vertical GHX for building with upgraded glass, ERV & DHW

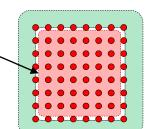


Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

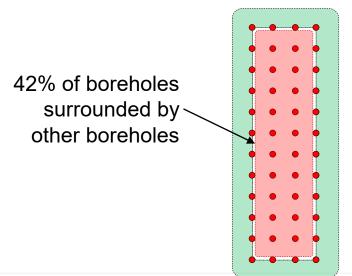




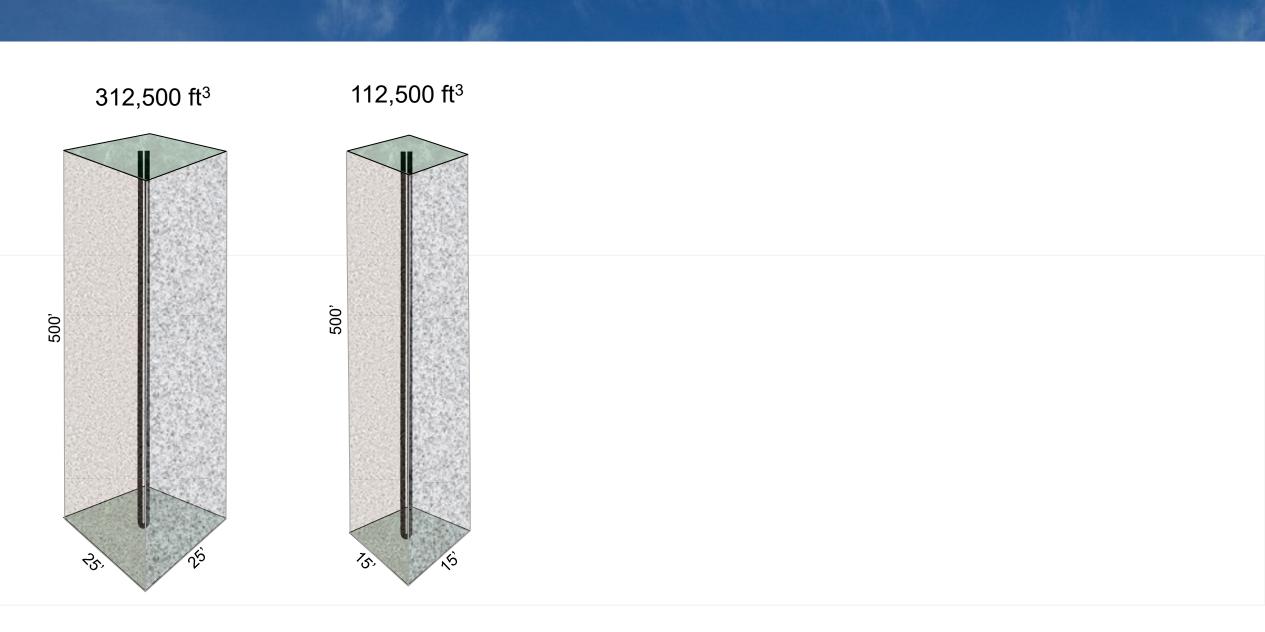
56% of boreholes surrounded by ~ other boreholes



4 x 12 grid - 20' spacing



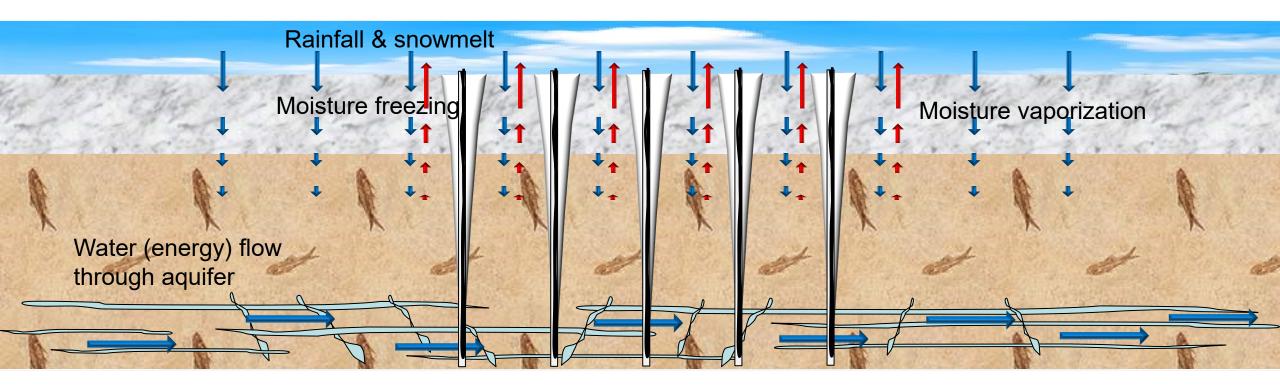






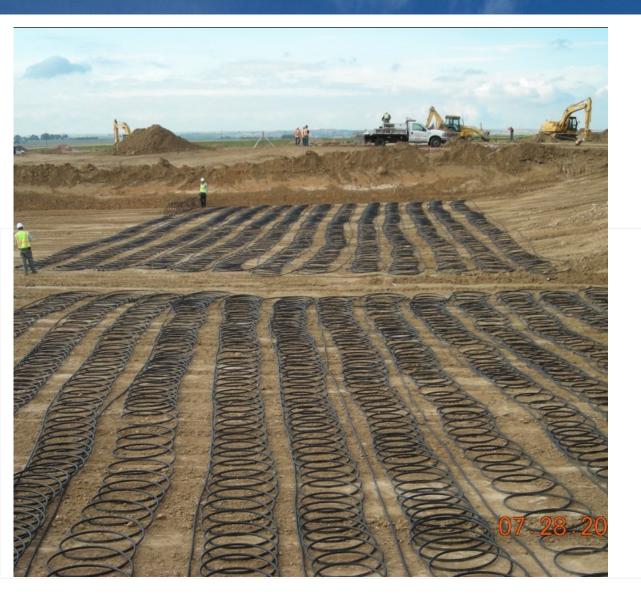
GHX design software limitations...doesn't consider

- Groundwater flow across boreholes
- Rainfall infiltration or snowmelt in spring
- Vaporization or freezing of moisture in the ground





Horizontal excavation for slinky GHX





Thermal properties estimated for excavated horizontal GHX

- Horizontal excavated GHX typically installed 5-10' below grade. Thermal conductivity and diffusivity can be estimated with geo-tech borehole logs
- Select the TC and TD of the strata in which the GHX will be embedded

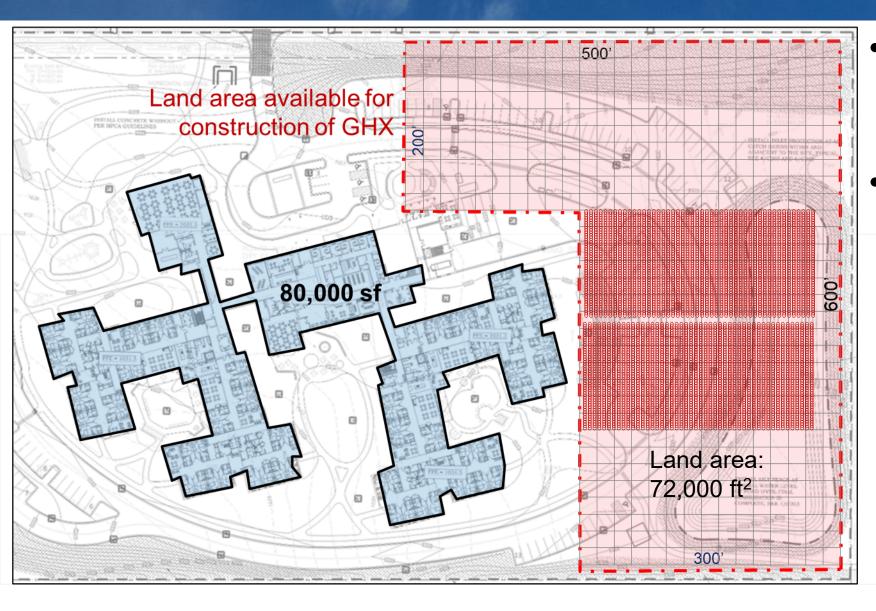
Dej	oth	Lover	Lithology	Layer	Conduc	tivity	Laye	r Diffus	ivity	We	eighted	тс	We	eighted	TD
Start	End	Layer	Lithology	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
0	4	4	Silty clay 15%	0.70	0.80	0.90	0.55	0.75	0.95	0.19	0.21	0.24	0.15	0.20	0.25
4	7	3	Clay 120 lb 10%	0.60	0.70	0.80	0.40	0.47	0.53	0.12	0.14	0.16	0.08	0.09	0.11
7	15	8	Silty clay 15%	0.70	0.80	0.90	0.55	0.75	0.95	0.37	0.43	0.48	0.29	0.40	0.51
15		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth	15	Α	verage Estimated The	rmal Co	onducti	vity & C) iffusivi	ty of Bo	orehole	0.68	0.78	0.88	0.52	0.69	0.87



Fluid Soil Piping Configuration Extra kW Informati	luid Soil Piping Confi	iguration Extra kW Inf	s Fluid Soil Piping Config	uration Extra kW Inform	sults Fluid Soil Piping Configuratio	on Extra kW	Information
disturbed Ground Temperature			ed Area Mode				
a	arameters		On/Off Total Area:	72403.2 ft^2		COOLING	HEATING
Ground Temperature: 50.0 °F					Total Trench Length (ft):	11379.5	12069.3
			Width: 576.0 ft x	Length: 125.7 ft	Trench Number:	96	96
Thermal Properties			nch Layout		Single Trench Length (ft):	118.5	125.7
	Pipe Resistance:	0.156 h*ft*°F/Btu	Number: 96	Depth: 7.0 ft	Total Pipe Length (ft):	87093.1	92373.3
Thermal Conductivity: 0.70 Btu/(h*ft*°F)	Pipe Size:	1 in. (25 mm) 🔻	Separation: 6.0 ft	Width: 36.0 in	Single Trench Pipe Length (ft):	907.2	962.2
Thermal Diffusivity: 0.47 ft^2/day				1100.0 II		00.0	22.0
	Outer Diameter:	1.32 ⁱⁿ	e Configuration in Trench		Unit Inlet (°F):	80.0	32.0
Diffusivity Calculator Check Soil Tables	Inner Diameter:	1.08 in			Unit Outlet (°F):	89.1	26.2
					Total Unit Capacity (kBtu/Hr):	1590.5	985.0
ound Temperature Corrections at Given Depth	Pipe Type:	SDR11 -			Peak Load (kBtu/Hr):	1398.0	985.0
Decised Air Terresetture Curines 25.0	Flow Type:	Turbulent 👻		с •	Peak Demand (kW):	62.5	77.5
Regional All Temperature Swing. 25.0					Heat Pump EER/COP:	22.4	3.7
Winter Summer		,		op Pitch [P]: 20.0 in	System EER/COP:	22.4	3.7
Coldest/Warmest Day in Year (1-365): 38 220	Check Pip	e Tables		Diameter [D]: 36.0 in	System Flow Rate (gpm):	349.5	246.3
Check Swing Temperature Table					Optional Hybrid System: Off Cooling	F	leating



Horizontal slinky GHX for building with upgraded glass, ERV & DHW



Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered



Thermal properties for horizontal directionally drilled GHX

Dep	oth	Lavor	Lithology	Layer	Conduc	tivity	Laye	er Diffus	ivity	We	eighted	ТС	We	eighted	TD
Start	End	Layer	Litilology	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
0	4	4	Silty clay 15%	0.70	0.80	0.90	0.55	0.75	0.95	0.08	0.09	0.10	0.06	0.09	0.11
4	7	3	Clay 100 lb 10%	0.50	0.55	0.60	0.40	0.44	0.48	0.04	0.05	0.05	0.03	0.04	0.04
7	15	8	Silty clay 15%	0.70	0.80	0.90	0.55	0.75	0.95	0.16	0.18	0.21	0.13	0.17	0.22
15	17	2	Sand 120 lb 15%	1.60	1.90	2.20	0.91	1.06	1.20	0.09	0.11	0.13	0.05	0.06	0.07
17	26	9	Sandy clay 15%	0.90	1.15	1.40	0.65	0.80	0.95	0.23	0.30	0.36	0.17	0.21	0.24
26	35	9	Sandy clay 15%	0.90	1.15	1.40	0.65	0.80	0.95	0.23	0.30	0.36	0.17	0.21	0.24
35		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth	35	A	verage Estimated The	rmal Co	onducti	vity & C	oiffusivi	ty of Bo	orehole	0.84	1.02	1.21	0.61	0.77	0.92



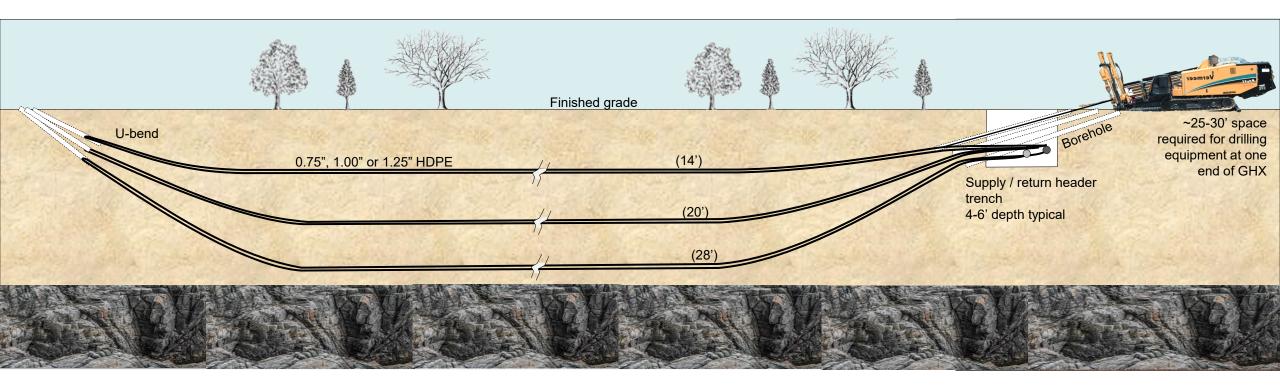
Modeling horizontal directionally drilled GHX

Fluid Soil Piping Configuration Extra kW Informati	Fluid Soil Piping Configuration Extr	ra kW Infos F	Fluid Soil Piping (Configuration	Extra kW Inform	sults Fluid Soil Piping Co	nfiguration Extra kW	Information
disturbed Ground Temperature	arameters	d A	rea Mode					
······································	arameters	On/	/Off Total /	Area: 58478.4	ft^2		COOLING	HEATING
Ground Temperature: 50.0 °F		144	/idth: 144.0 ft	w long	gth: 406.1 ft	Total Trench Length (ft):	6516.8	7310.6
			Layout	x Leng	gth: 406.1 ft	Trench Number:	18	18
I Thermal Properties	Pipe Resistance: 0.156 h*	*ft*°F/Btu	Layout			Single Trench Length (ft):	362.0	406.1
	Pipe Size: 1 in. (25 mm)	•	Number: 18	Dep	oth: 32.0 ft	Total Pipe Length (ft):	39100.9	43863.7
Thermal Conductivity: 1.15 Btu/(h*ft*°F)			Separation: 8.0	ft Wid	dth: 4.0 in	Single Trench Pipe Length (ft)): 2172.3	2436.9
Thermal Diffusivity: 0.8 ft^2/day	1.52		onfiguration in Trench			Unit Inlet (°F):	80.0	35.0
Diffusition Colorban	Inner Diameter: 1.08 in	l				Unit Outlet (°F):	89.1	29.1
Diffusivity Calculator Check Soil Tables	Pipe Type: SDR11	-	0000	000		Total Unit Capacity (kBtu/Hr):	1517.4	985.0
ound Temperature Corrections at Given Depth	Flow Type: Turbulent	-	° ° °	000		Peak Load (kBtu/Hr):	1398.0	985.0
und Temperature Corrections at Given Depth	rabalene		· ·	0 0	o o	Peak Demand (kW):	62.5	74.2
Regional Air Temperature Swing: 25.0 °F					□ Offset	Heat Pump EER/COP:	22.4	3.9
Winter Summer	Check Pipe Tables		Tota	al Number of Pi	ipes: 6 ÷	System EER/COP:	22.4	3.9
Coldest/Warmest Day in Year (1-365): 38 220			T		[Y]: 96.0 in	System Flow Rate (gpm):	349.5	246.3
Check Swing Temperature Table					[X]: 4.0 in	Optional Hybrid System: Off—	Cooling	Heating



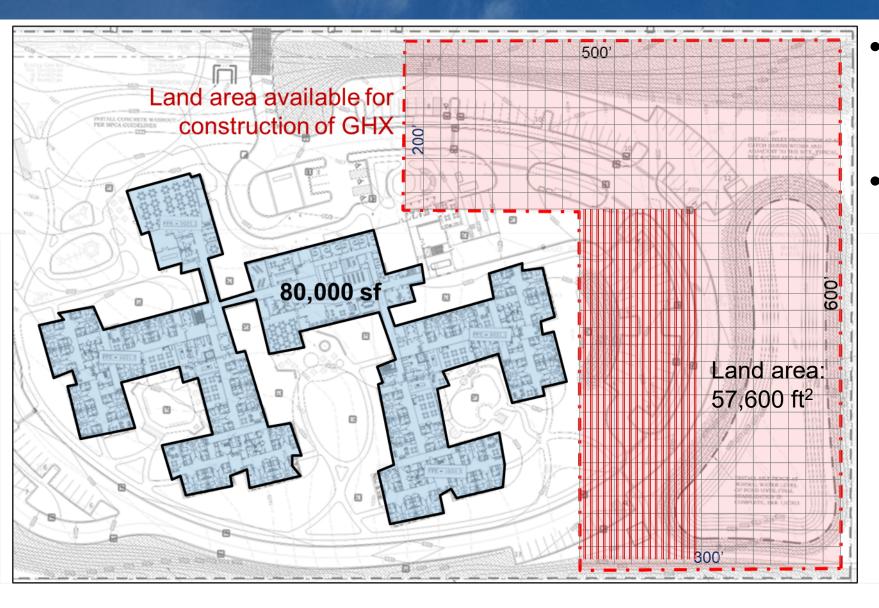
Horizontal directional drilling GHX

- A horizontal directionally drilled GHX can be considered in silt, clay or sandy soil without large rocks and boulders.
- Can be drilled in a number of layers up to 30-40' depth





Horizontal drilled boreholes - building with upgraded glass, ERV & DHW



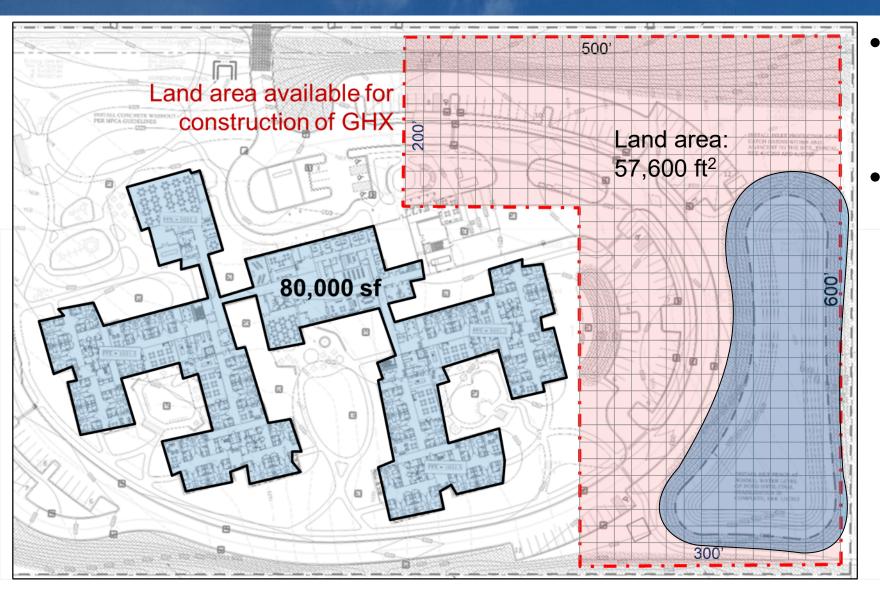
Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered



Surface water heat exchangers



Surface water heat exchanger



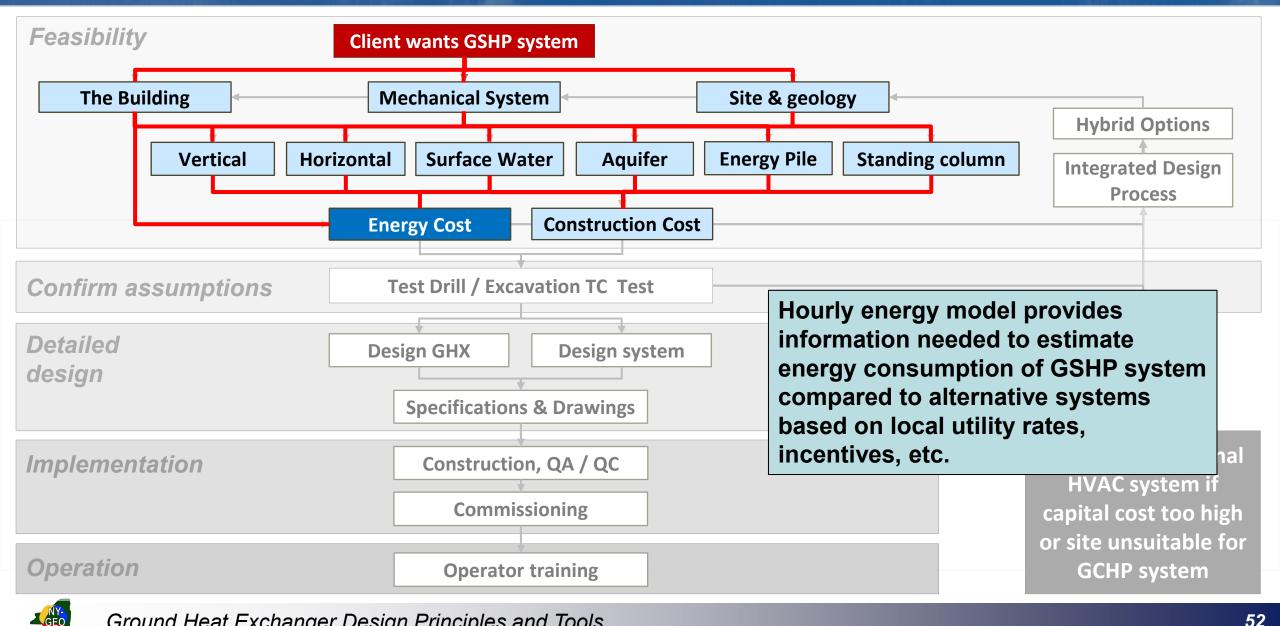
Configuration & type of GHX is impacted by available land area Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered



Modeling surface water heat exchanger



Energy modeling and utility rates



Dep	oth	Lavor	Lithology	Layer	Conduc	tivity	Laye	r Diffus	ivity	We	eighted	тс	We	eighted	TD
Start	End	Layer	Lithology	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
0	15	15	Sand 80 lb 10%	0.60	0.85	1.10	0.40	0.47	0.53	0.18	0.26	0.33	0.12	0.14	0.16
15	20	5	Sandy clay 10%	0.80	1.05	1.30	0.60	0.75	0.90	0.08	0.11	0.13	0.06	0.08	0.09
20	26	6	Clay 120 lb 15%	0.80	0.95	1.10	0.46	0.55	0.63	0.10	0.11	0.13	0.06	0.07	0.08
26	35	9	Clay 120 lb 15%	0.80	0.95	1.10	0.46	0.55	0.63	0.14	0.17	0.20	0.08	0.10	0.11
35	44	9	Sand 120 lb 15%	1.60	1.90	2.20	0.91	1.06	1.20	0.29	0.34	0.40	0.16	0.19	0.22
44	50	6	Sand 120 lb 15%	1.60	1.90	2.20	0.91	1.06	1.20	0.19	0.23	0.26	0.11	0.13	0.14
50		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0		0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth	50	A	verage Estimated The	rmal Co	onducti	vity & D	oiffusivi	ty of Bo	orehole	0.98	1.22	1.45	0.59	0.69	0.80



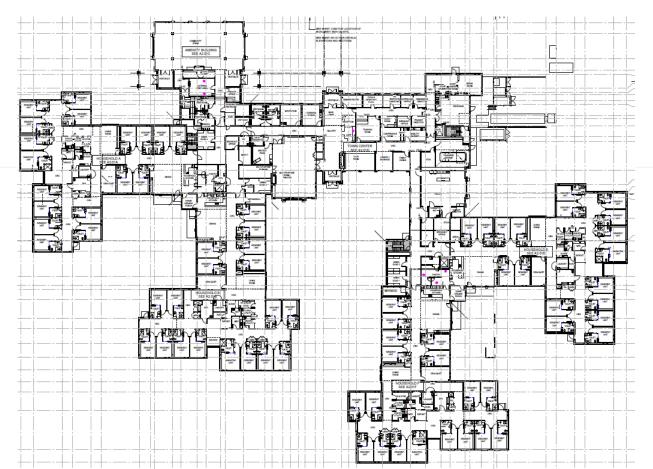
Energy piles

 HDPE U-tubes can be installed in driven tubular steel piles, helical piles, small or large diameter poured concrete piles and can transfer energy to and from the earth





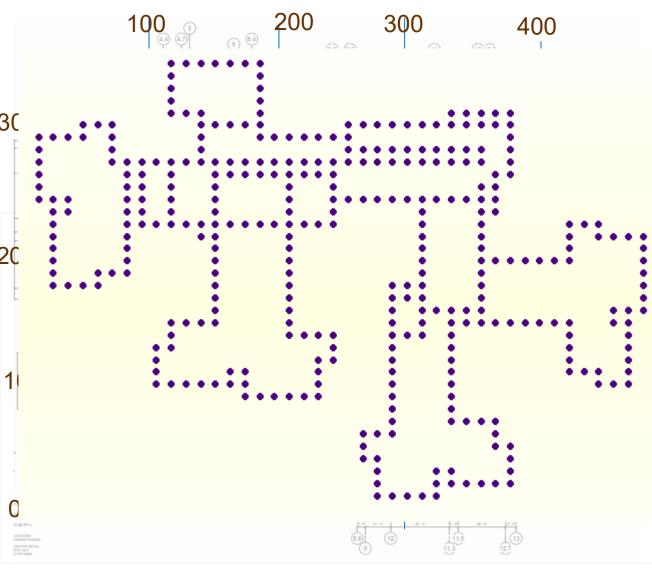
Energy piles foundation



 352 helical steel piles proposed for this project to a depth of approximately 55'

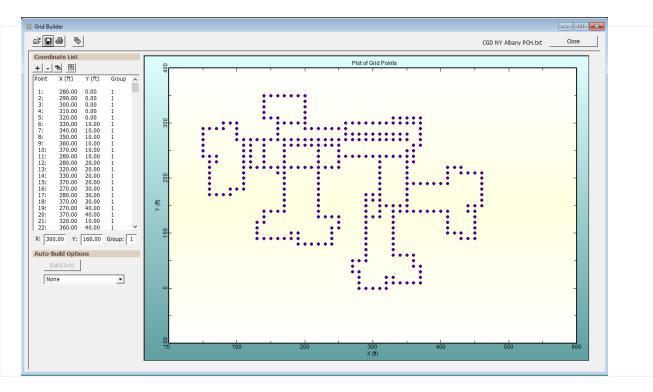


Energy piles



- Pile diameter: 7.00"
- Pile depth: 55'
- Average spacing: 15;
- Concrete grout installed with
 - tremie line after U-tube insertion
- Foundation plan needed to create a grid file for GHX design software
 to model interaction between Utubes accurately







Fluid Soil Bore Pattern Extra kW Information	ults Fluid Soil Bore	Pattern Extra k	(W Information	ults Fluid Soil Bore	Pattern Extra kW I	Information	sults Fluid Soil Bore P	attern Ext	tra kW Infor	mation
disturbed Ground Temperature	Calculated Borehole Equ		_	ertical Grid Arrangeme	nt				COOLING	HEATING
Ground Temperature: 50.0 °F	Borehole Thermal Re Pipe Parameters	,		Borehole Nur Rows A		GMap	Total Bore Length (ft): Borehole Number:		19360.0 352	19360.0 352
l Thermal Properties	U-Tube Configuration	Borehole Diameter	eter: 7.00 in		own: 16		Borehole Length (ft):	(55.0	55.0
View Layer Calculator	O Double			Borehole Separ	ation: 15.0 ft		Ground Temperature Chang	ie (°F):	N/A	N/A
Thermal Conductivity: 1.19 Btu/(h*ft*°F) Thermal Diffusivity: 0.68 ft^2/day	C Coaxial	-Backfill (Grout) 1		🗍 Use External File	Select Clea	ar Create	Peak Unit Inlet (°F): Peak Unit Outlet (°F):		74.3 81.9	24.3 20.6
Diffusivity Calculator Check Soil Tables	Check Pipe Tables	Thermal Conductivi	ity: 1.00 Btu/(h*ft*%)	Filename: No File		Grid Builder	Total Unit Capacity (kBtu/Hr Peak Load (kBtu/Hr):	r):	1398.0 1398.0	985.0 985.0
	Pipe Resistance: 0.104	4 h*ft*⁰F/Btu	Radial Pipe Placement	oreholes per Parallel Ci			Peak Demand (kW):		48.6	78.7
	Pipe Size: 1 in. (25		◯ ⊂ Close Together	Bores Per Circuit	ຳ ຳ ແ	וחחר ו	Heat Pump EER/COP: Seasonal Heat Pump EER/CO	OP:	28.6 33.5	3.7 4.1
Prediction Time: 10.0 years		2 in 3 in	00 (Average	,		J UUU	Avg. Annual Power (kWh):		4.50E+4	1.89E+5
	nner Diameter: 1.08 Pipe Type: SDR 11		O Along Outer Wall	fixed Length Mode			System Flow Rate (gpm): Optional Hybrid System: Off		349.5	246.3
	low Type: Turbule	ent 💌		🔽 On/Off	Borehole Length	55 ft		Cooling	1	Heating



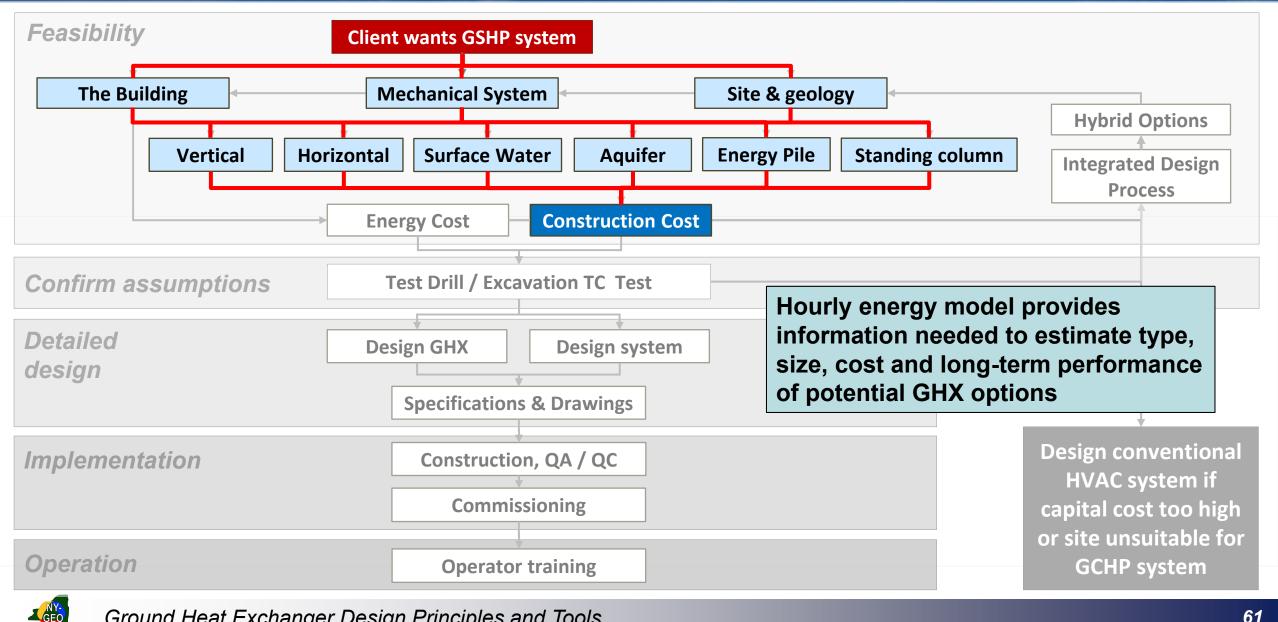
	NY VA Hom	ne - Upgraded G	Blass, ERV & D	HW Loads	sults Fluid Soil Bore Pattern E	Sutro IAA L Tofo	rmation	Monthly Data								
	Geo Co	ooling	Geo He	ating	sults Fluid Soil Bore Pattern E		ormation	80								
	kBtu	kBtu/hr	kBtu	kBtu/hr		COOLING	HEATING	- Minimum EWT -								
Jan	12559	76	470443	985	Total Bore Length (ft):	19360.0	19360.0									
Feb	12273	90	369807	937	Borehole Number:	352	352									
Mar	28592	555	307043	867	Borehole Length (ft):	55.0	55.0									
Apr	49123	787	196549	674	Ground Temperature Change (°F):	N/A	N/A									
May	157584	990	115326	435		-	-									
Jun	239744	1210	89392	351	Peak Unit Inlet (°F):	74.3	24.3	툴 50								
Jul	381615	1398	75747	215	Peak Unit Outlet (°F):	81.9	20.6									
Aug	326320	1394	81221	234	Total Unit Capacity (kBtu/Hr):	1398.0	985.0									
Sep	194205	1057	103306	406	Peak Load (kBtu/Hr): Peak Demand (kW):	1398.0 48.6	985.0 78.7									
Oct	67623	599	172766	619	Heat Pump EER/COP:	28.6	3.7									
Nov	24098	268	266146		Seasonal Heat Pump EER/COP:	33.5	4.1	30 - V V V V V V V V V -								
Dec	16179	100	396543	883	Avg. Annual Power (kWh):	4.50E+4	1.89E+5									
	1,509,913	1,398	2,644,288	985	System Flow Rate (gpm):	349.5	246.3	20								
	Tons	117	Tons	82				0 24 48 72 96 120 Time(Months)								
	EFLH	1,080	EFLH	2,686			Heating									



	NY V	A Home - Upgr	aded Glass &	ERV		and and the first	metical.				Mo	nthly Da	ta				
	Geo Co	ooling	Geo He	eating	sults Fluid Soil Bore Pattern E	Extra KVV Info	rmation	90		1	1	inting bu					
	kBtu	kBtu/hr	kBtu	kBtu/hr		COOLING	HEATING	-	— Avera							-	
Jan	12559	76	404253	905	T (1) () ()	400.000	40000	80 -	Minim Maxin	num EWT num EWT		к К	N	Ν	h	<u>N-</u>	
Feb	12273	90	310023	843	Total Bore Length (ft): Borehole Number:	19360.0	19360.0		1	8	8	n n		- 11	- 11	- 81	
Mar	28592	555	240854	794	Borehole Length (ft):	352 55.0	352 55.0		A A					A	A.	N1	
Apr	49123	787	132495	591	Ground Temperature Change (°F):	N/A	N/A	70-	A A	A	A	n n			- 11		
May	157584	990	49136	363		-	-	re (F)	A N	- 11	11 1						
Jun	239744	1210	25337	294	Peak Unit Inlet (°F):	81.7	31.0	- 06 II	$\Lambda \Lambda$		11 1				-11		
Jul	381615	1398	9557	211	Peak Unit Outlet (°F):	89.4	27.5	du	11 11		11 1	11					
Aug	326320		15032	183	Total Unit Capacity (kBtu/Hr):	1398.0	905.0	Te	Π		111						
Sep	194205	1057	39252		Peak Load (kBtu/Hr):	1398.0	905.0	50 -	Π							11	
Oct	67623	599	106576	512	Peak Demand (kW): Heat Pump EER/COP:	55.9 24.9	66.9 3.9			111	111	M.	M.				
Nov	24098	268	202091	662	Seasonal Heat Pump EER/COP:	30.1	4.3	40 -			$ \rangle$	M	M.			-	
Dec	16179	100	330354		Avg. Annual Power (kWh):	5.02E+4	1.27E+5		' M	M M	M	M	M	M	M	Ø -	
	1,509,913	1,398	1,864,960	905	System Flow Rate (gpm):	349.5	226.3	30	<u>v</u>	V V	V	<u>v</u>	V	V	۷	×	
	Tons	117	Tons	75	Optional Hybrid System: Off			0	2	24	48 Tim	e(Months	72)	96	5	120	
	EFLH	1,080	EFLH	2,061	Cooling		Heating										

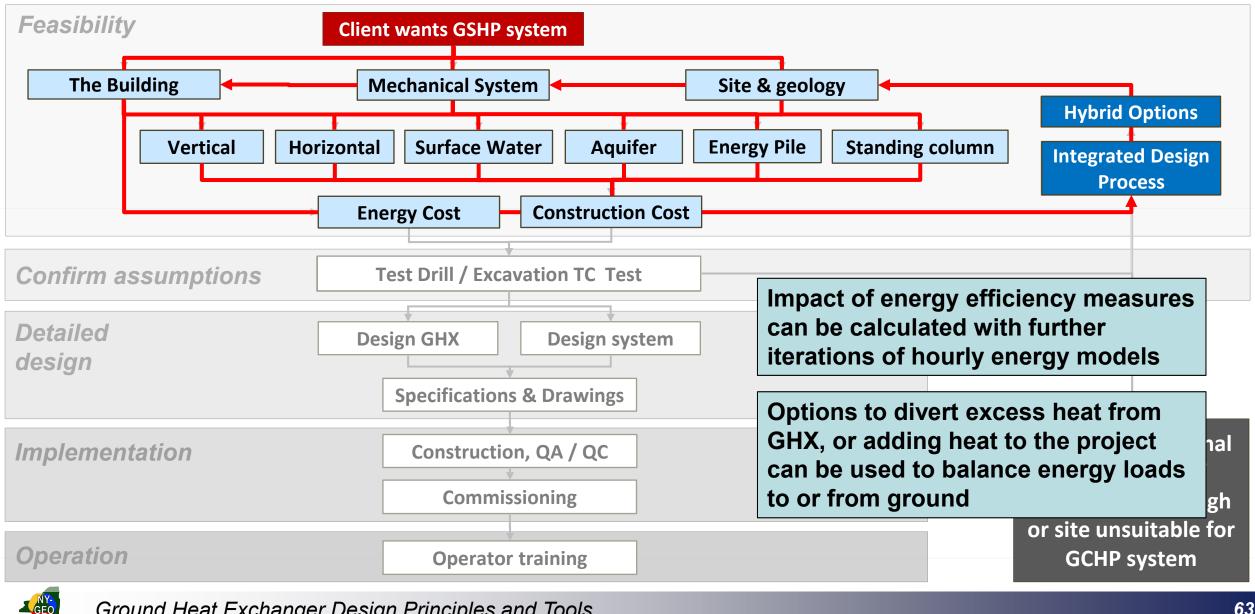


Contractor capabilities, geology, site constraints





Iterative process to achieve energy load balance to GHX





Question 1





- If a low-efficiency heat pump is installed in a system, what is the impact on the GHX? GHX temperature will be:
 - Higher in summer & lower in winter
 - Lower in summer & winter
 - Higher in summer & winter
 - Lower in summer & higher in winter



Answer





- If a low-efficiency heat pump is installed in a system, what is the impact on the GHX? GHX temperature will be:
 - Higher in summer & lower in winter
 - Lower in summer & winter
 - Higher in summer & winter
 - Lower in summer & higher in winter



Question 2





- A horizontal directionally drilled GHX:
 - Can be more cost-effective to build than other GHX configurations because less excavation is needed
 - Is not cost-effective because horizontal drilling is more expensive than vertical drilling
 - Does not perform reliably over the long term because of long-term temperature degradation
 - Should not be considered for large scale commercial projects because of high pressure drops encountered in long horizontal boreholes



Answer





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Question 3



- A test borehole and thermal conductivity test should be:
 - The first step of a feasibility assessment for any GSHP project
 - Based on the estimated peak heating and cooling loads of the project
 - Based on results of an hourly energy model & preliminary GHX modeling after reviewing site are and geology of the site
 - Conducted for any project greater than 20 tons



Answer



- A test borehole and thermal conductivity test should be:
 - The first step of a feasibility assessment for any GSHP project
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Question 4



- A variable that GHX design software cannot take into consideration is:
 - Thermal conductivity of the rock and soil the borehole is drilled in
 - Groundwater flow and rainfall infiltration in a borehole field
 - Ambient temperature of the rock and soil in a region
 - Thermal conductivity of the grout specified in the borehole design



Answer



- A variable that GHX design software cannot take into consideration is:
 - Thermal conductivity of the rock and soil the borehole is drilled in
 - Groundwater flow and rainfall infiltration in a borehole field
 - Ambient temperature of the rock and soil in a region
 - Thermal conductivity of the grout specified in the borehole design



Design a GHX contractors in the area can build cost-effectively