# 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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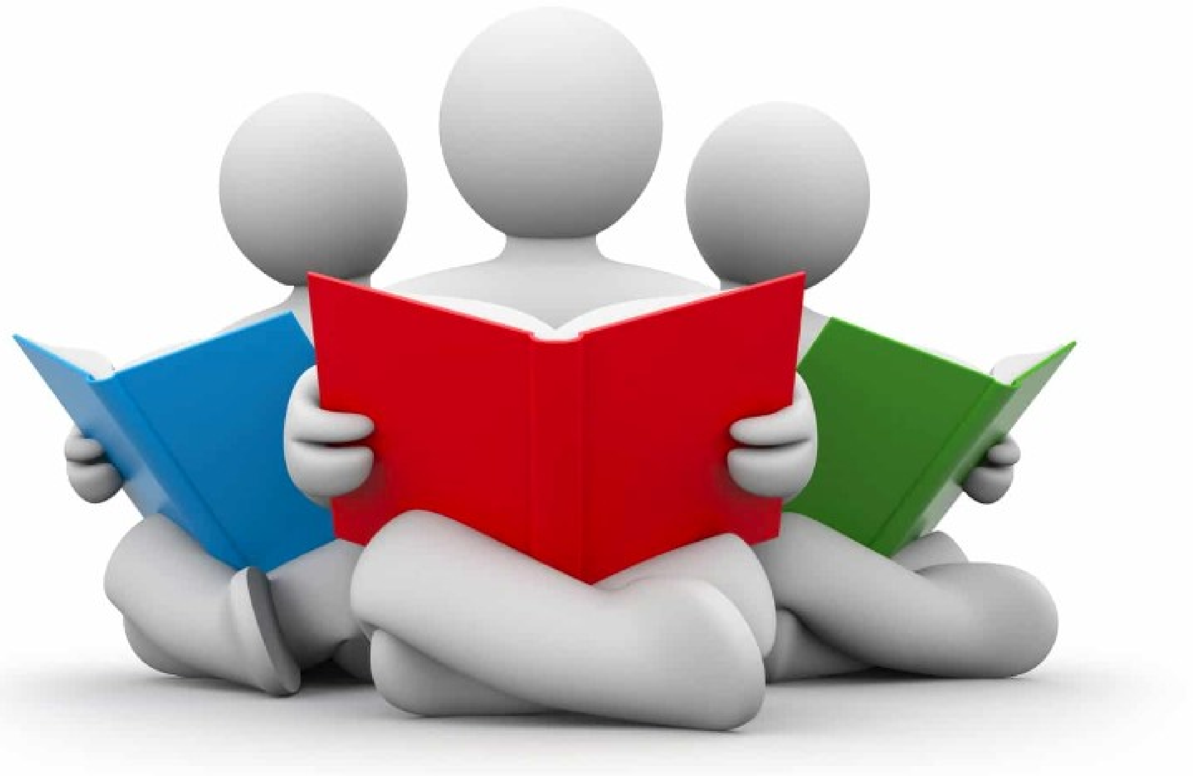
# Ground Heat Exchanger Design Principles and Tools

April 26, 2023

**GE**Optimize

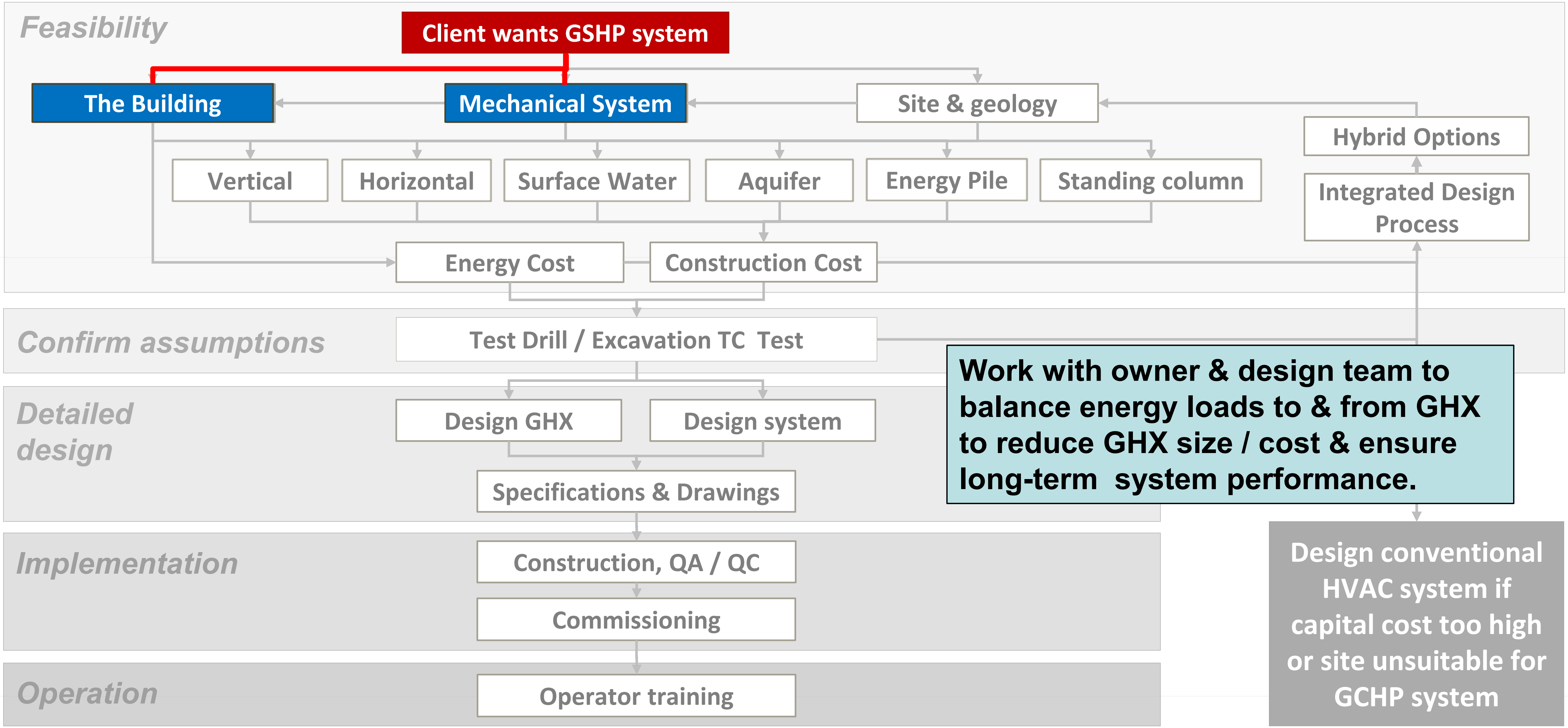
Ed Lohrenz
ed@geoptimize.ca
204-318-2156

# Learning objectives

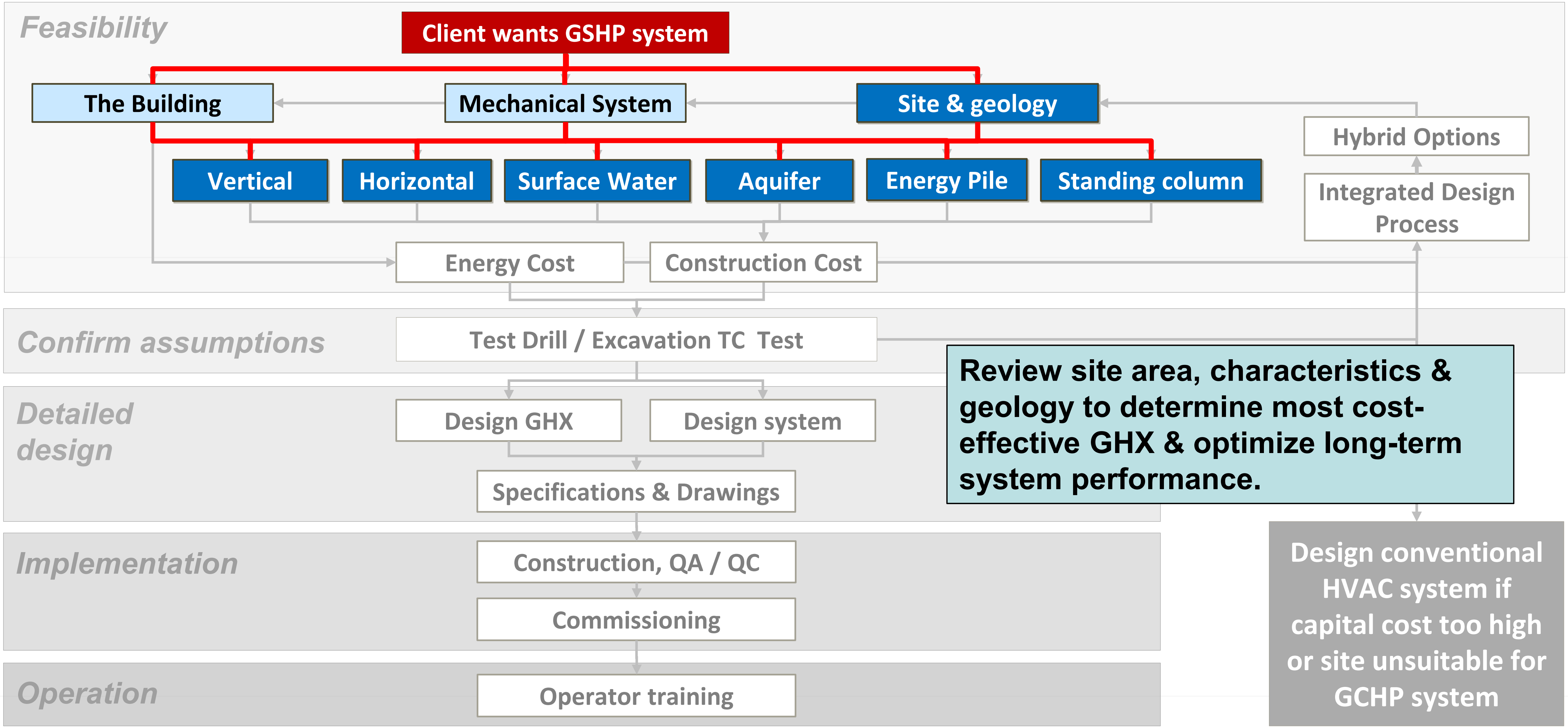


- See the impact of changes to the building or mechanical system on size, cost and performance of a GHX
- Simulate performance of different ground heat exchanger (GHX) types
- Determine the impact of changes to GHX configuration on size, cost and performance of a GHX
- Where to find information needed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

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

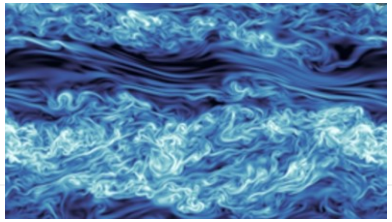


# GHX configuration and contractor capabilities

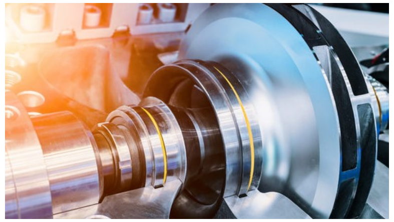


# Five factors to consider when designing a GHX

- 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

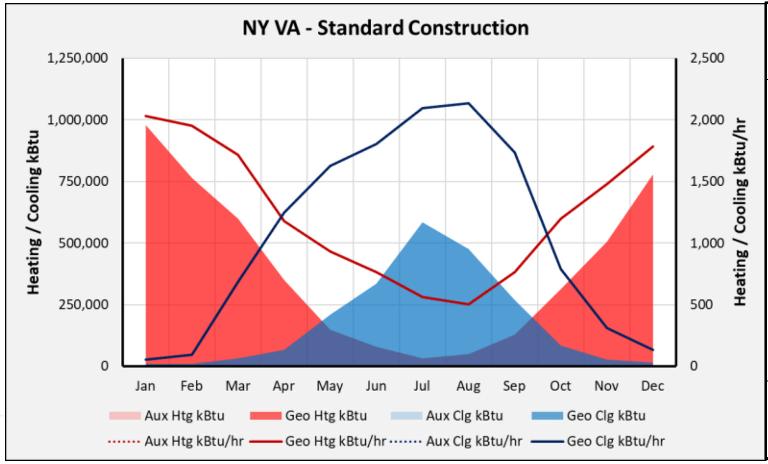
# Information needed to design GHX

- 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

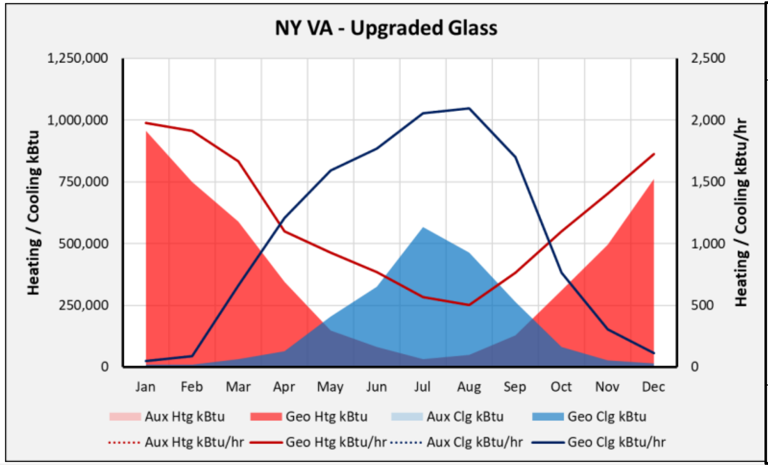
# What loads to use when designing the GHX




| NY VA Home - Standard Construction | Geo Cooling | | Geo Heating | |
|---|---|---|---|---|
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 10396 | 55 | 978335 | 2029 |
| Feb | 10580 | 96 | 763599 | 1953 |
| Mar | 33076 | 686 | 599135 | 1717 |
| Apr | 66152 | 1248 | 349658 | 1177 |
| May | 210506 | 1629 | 148459 | 933 |
| Jun | 335414 | 1807 | 80116 | 766 |
| Jul | 583673 | 2096 | 31258 | 564 |
| Aug | 476451 | 2136 | 49574 | 505 |
| Sep | 269795 | 1736 | 127922 | 763 |
| Oct | 83160 | 789 | 314120 | 1197 |
| Nov | 26430 | 312 | 506574 | 1479 |
| Dec | 14496 | 132 | 777820 | 1787 |
| | 2,120,129 | 2,136 | 4,726,571 | 2,029 |
| | Tons | 178 | Tons | 169 |
| | EFLH | 992 | EFLH | 2,329 |

| | | | |
|---|---|---|---|
| 2,120,129 | 2,136 | 4,726,571 | 2,029 |

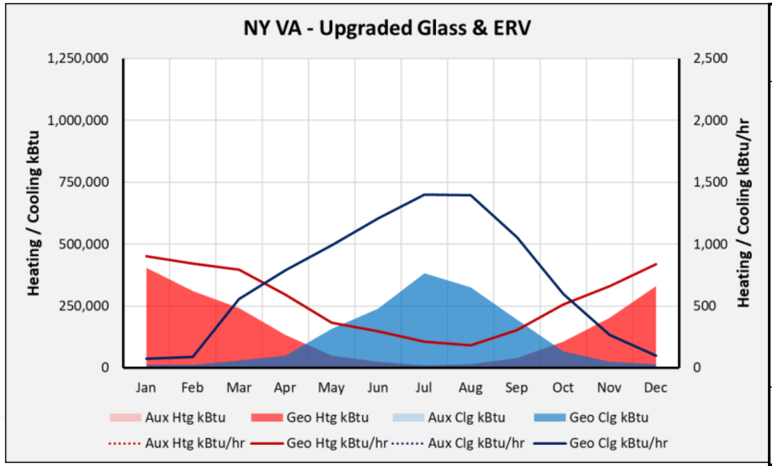
| | | | |
|---|---|---|---|
| 2,064,198 | 2,095 | 4,645,031 | 1,975 |




| NY VA Home - Upgraded Glass | Geo Cooling | | Geo Heating | |
|---|---|---|---|---|
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 10449 | 51 | 956520 | 1975 |
| Feb | 10621 | 87 | 748314 | 1911 |
| Mar | 32213 | 662 | 589764 | 1665 |
| Apr | 64324 | 1207 | 346229 | 1101 |
| May | 203702 | 1594 | 149101 | 927 |
| Jun | 324882 | 1772 | 80804 | 767 |
| Jul | 567809 | 2054 | 31487 | 565 |
| Aug | 463541 | 2095 | 49683 | 505 |
| Sep | 262985 | 1700 | 127267 | 765 |
| Oct | 82052 | 763 | 309723 | 1102 |
| Nov | 27035 | 304 | 495405 | 1404 |
| Dec | 14584 | 113 | 760733 | 1728 |
| | 2,064,198 | 2,095 | 4,645,031 | 1,975 |
| | Tons | 175 | Tons | 165 |
| | 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

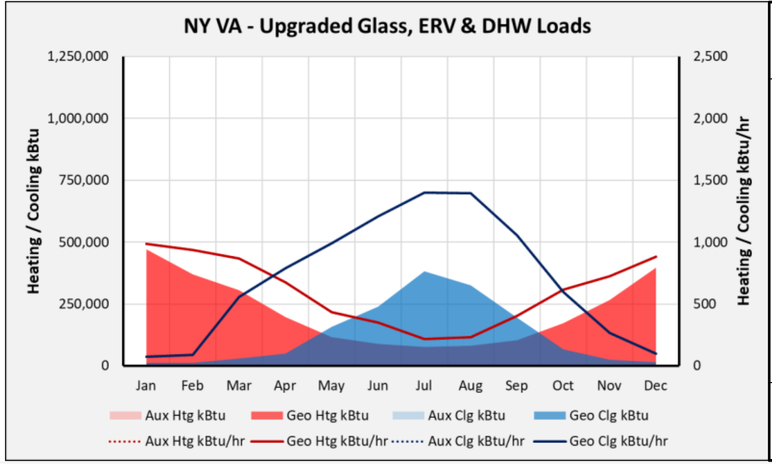
# Additional efficiency measures & loads




| | NY VA Home - Upgraded Glass & ERV | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 12559 | 76 | 404253 | 905 |
| Feb | 12273 | 90 | 310023 | 843 |
| Mar | 28592 | 555 | 240854 | 794 |
| Apr | 49123 | 787 | 132495 | 591 |
| May | 157584 | 990 | 49136 | 363 |
| Jun | 239744 | 1210 | 25337 | 294 |
| Jul | 381615 | 1398 | 9557 | 211 |
| Aug | 326320 | 1394 | 15032 | 183 |
| Sep | 194205 | 1057 | 39252 | 306 |
| Oct | 67623 | 599 | 106576 | 512 |
| Nov | 24098 | 268 | 202091 | 662 |
| Dec | 16179 | 100 | 330354 | 838 |
| | 1,509,913 | 1,398 | 1,864,960 | 905 |
| | Tons | 117 | Tons | 75 |
| | EFLH | 1,080 | EFLH | 2,061 |

| | | | |
|---|---|---|---|
| 1,509,913 | 1,398 | 1,864,960 | 905 |

| | | | |
|---|---|---|---|
| 1,509,913 | 1,398 | 2,644,288 | 985 |

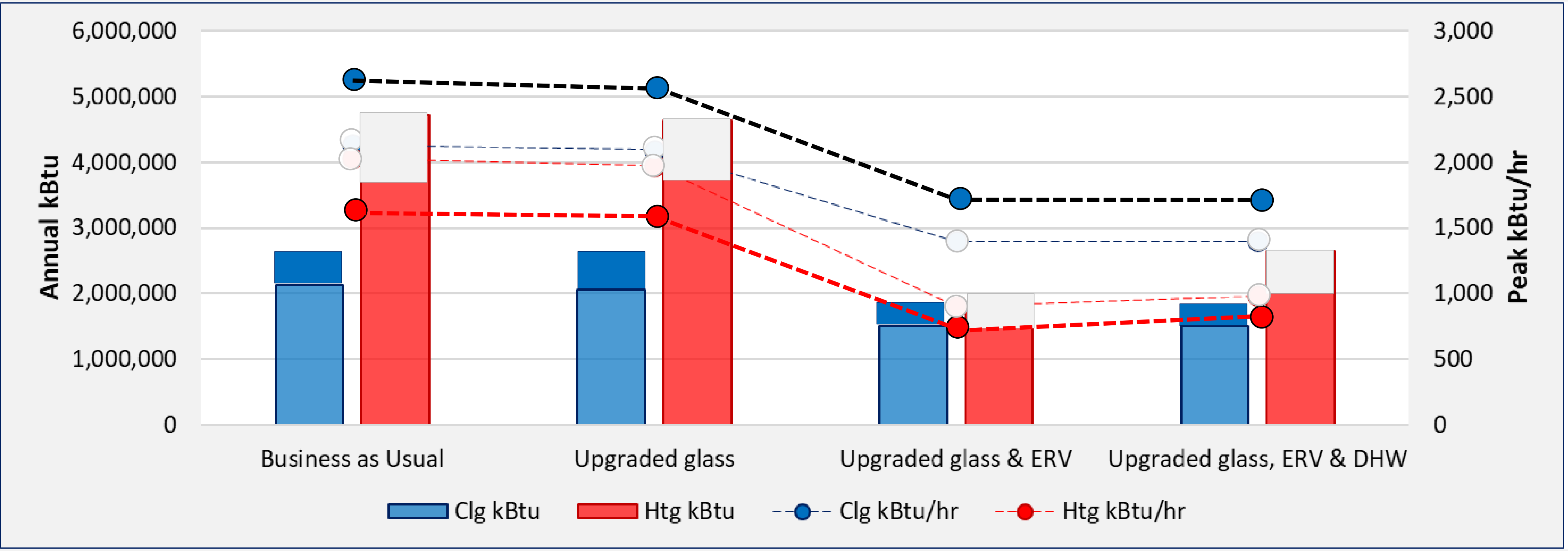



| | NY VA Home - Upgraded Glass, ERV & DHW Loads | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 12559 | 76 | 470443 | 985 |
| Feb | 12273 | 90 | 369807 | 937 |
| Mar | 28592 | 555 | 307043 | 867 |
| Apr | 49123 | 787 | 196549 | 674 |
| May | 157584 | 990 | 115326 | 435 |
| Jun | 239744 | 1210 | 89392 | 351 |
| Jul | 381615 | 1398 | 75747 | 215 |
| Aug | 326320 | 1394 | 81221 | 234 |
| Sep | 194205 | 1057 | 103306 | 406 |
| Oct | 67623 | 599 | 172766 | 619 |
| Nov | 24098 | 268 | 266146 | 724 |
| Dec | 16179 | 100 | 396543 | 883 |
| | 1,509,913 | 1,398 | 2,644,288 | 985 |
| | Tons | 117 | Tons | 82 |
| | EFLH | 1,080 | EFLH | 2,686 |

- 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%

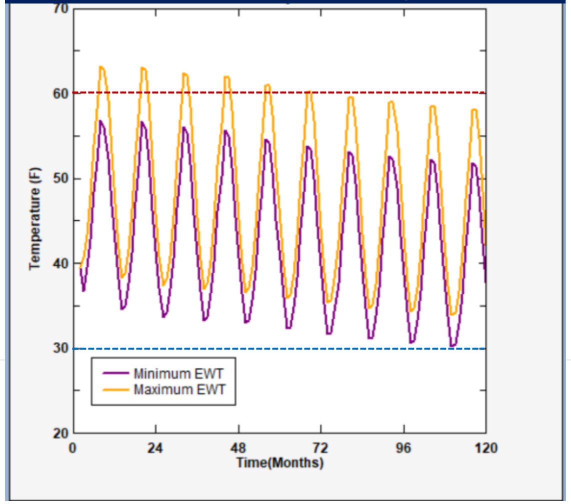
# Comparison of energy load profiles with & without compressor energy

- 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

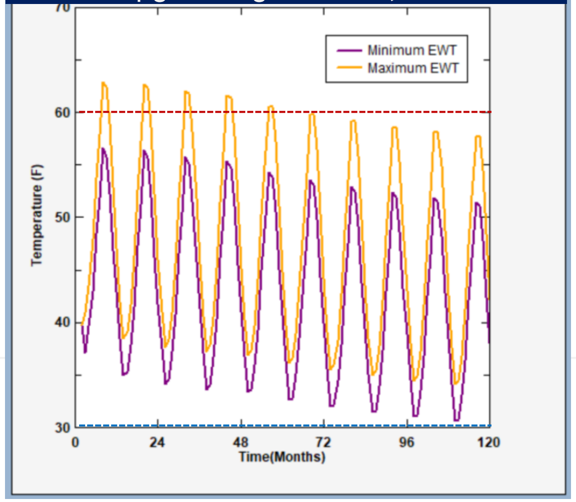


# Borehole required to meet four different building loads

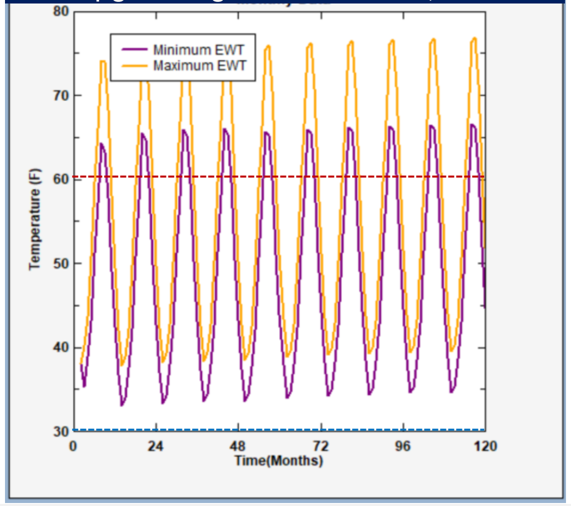
Business as usual – **54,000'**



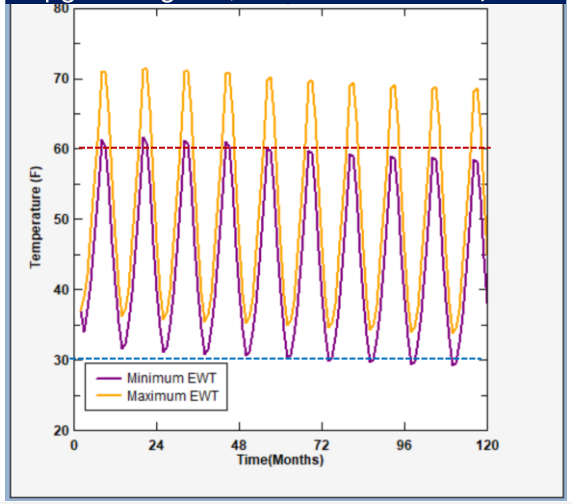

Upgraded glass – **54,000'**




Upgraded glass & ERV, **22,000'**

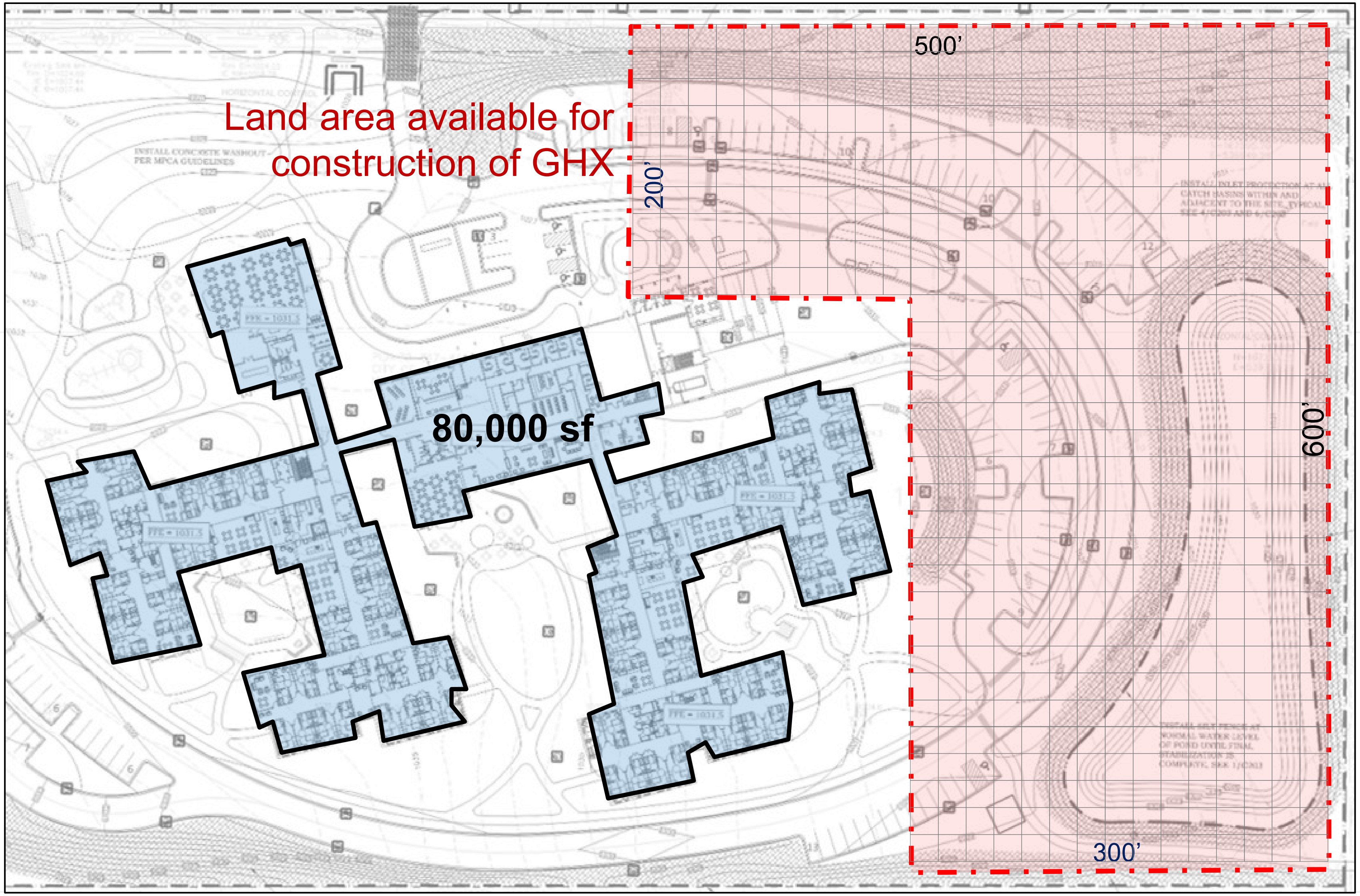



Upgraded glass, ERV & DHW – **22,000'**



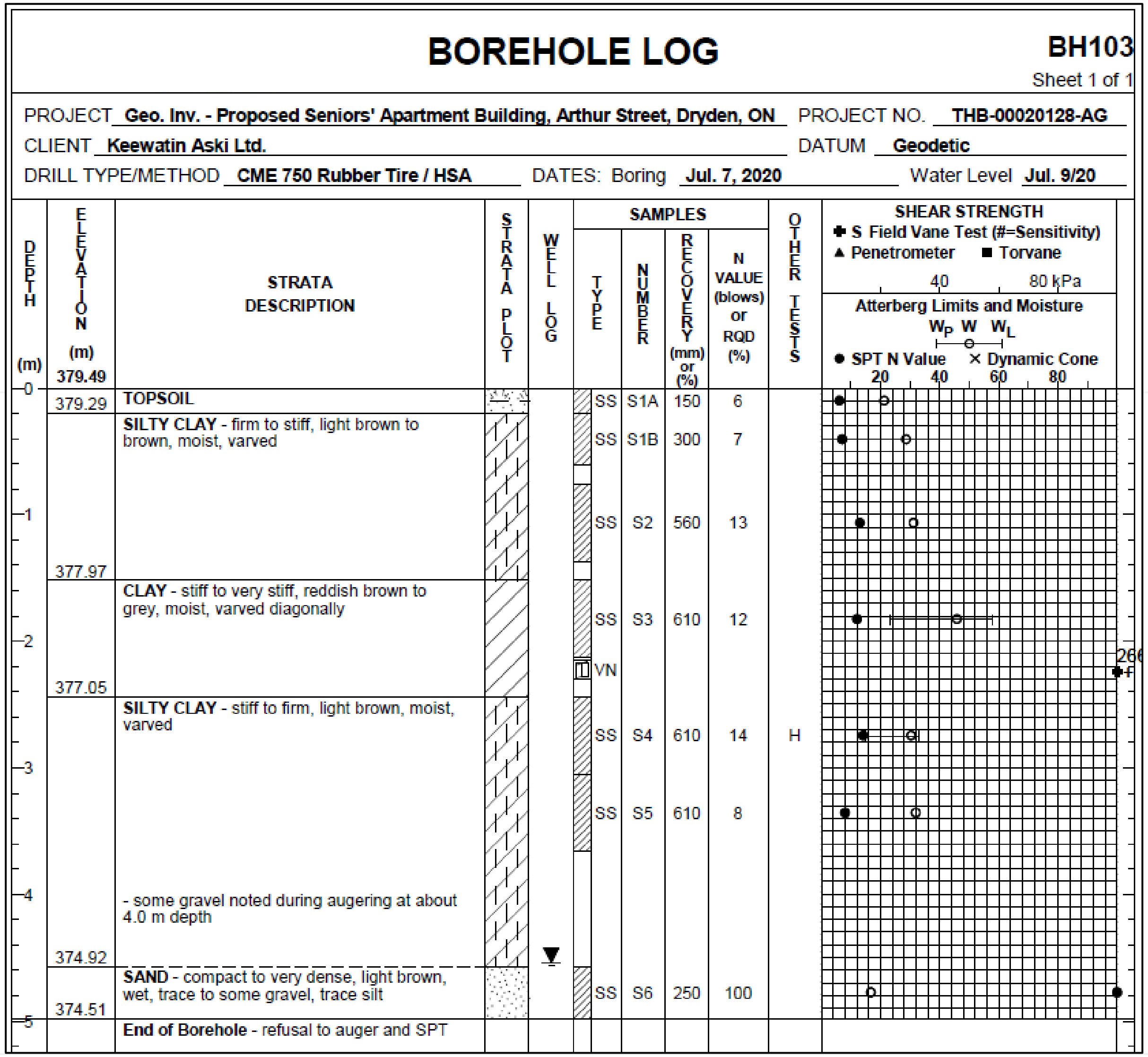

- The amount of borehole needed for the for each of the energy models changes significantly as efficiency measures or other loads are connected to the GHX. Loads change
  - Size and cost of GHX
  - Land are required to build GHX
  - Long-term performance
- Preliminary GHX models indicates quickly which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

# Land area available for construction of GHX



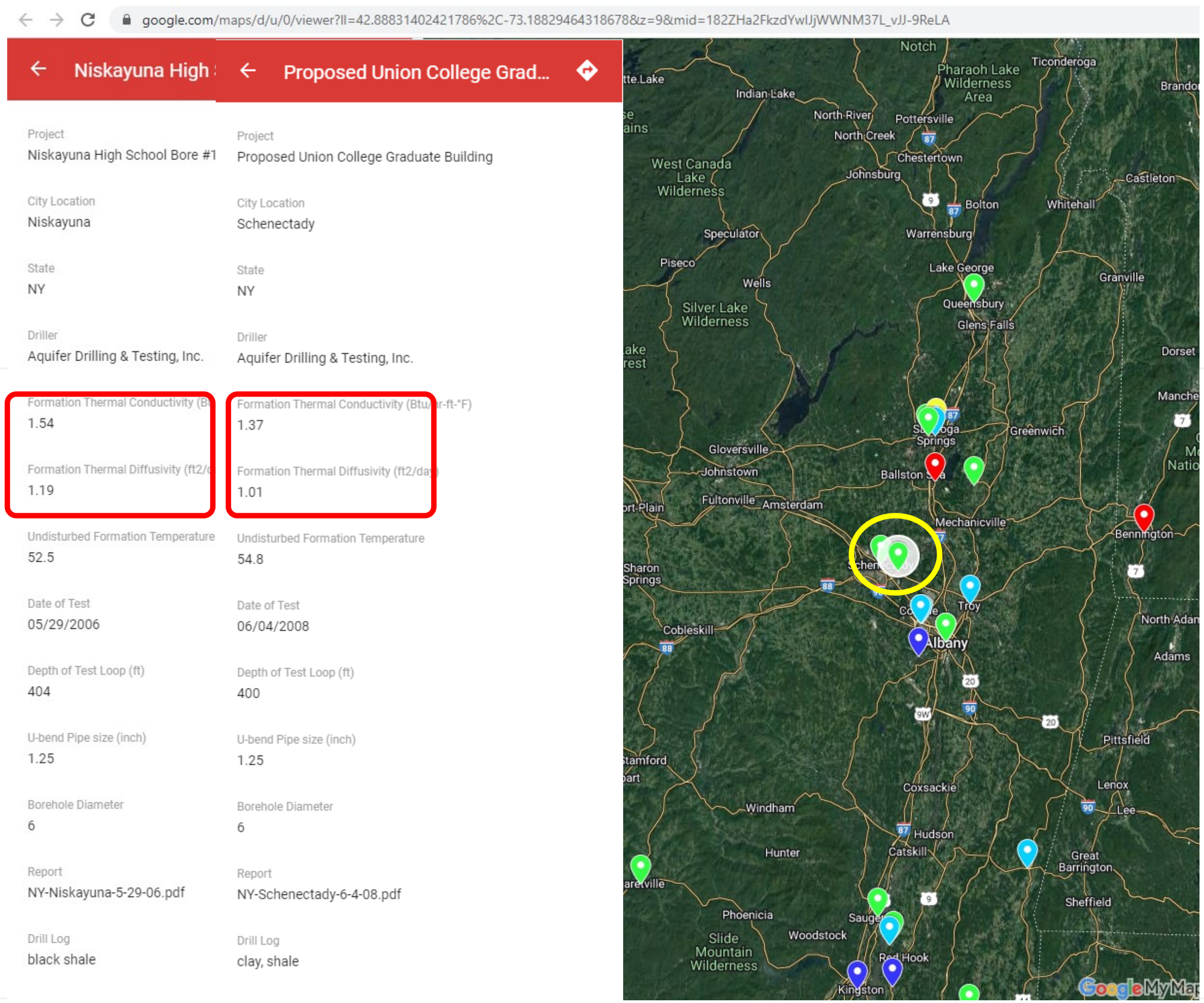

- Configuration & type of GHX is impacted by available land area
- Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

# 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

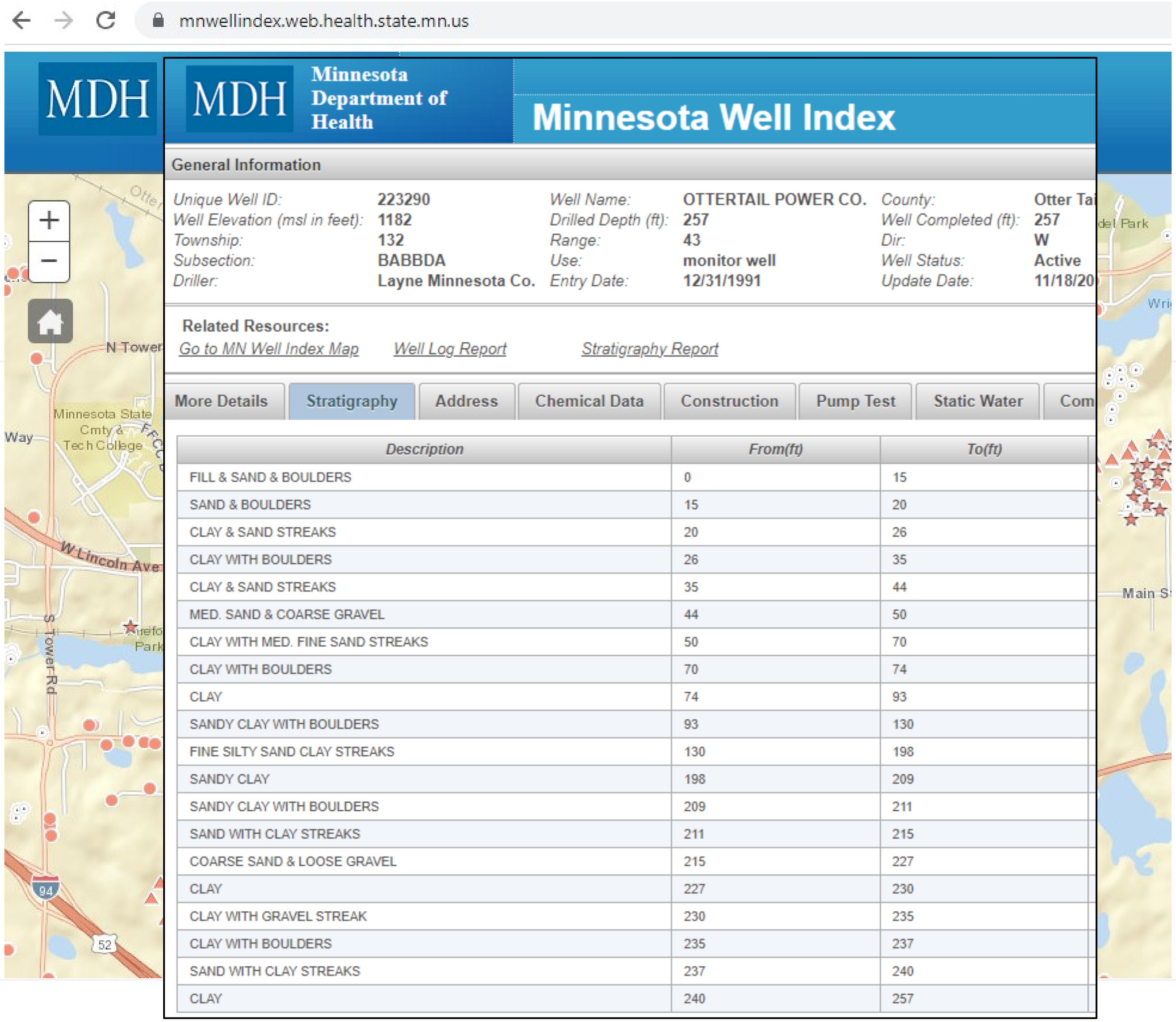



- In areas with significant numbers of commercial GSHP installations you may find databases with thermal response test results.

# 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



mnwellindex.web.health.state.mn.us

MDH Minnesota Department of Health

Minnesota Well Index

General Information

| | | | | | |
|---|---|---|---|---|---|
| Unique Well ID: | 223290 | Well Name: | OTTERTAIL POWER CO. | County: | Otter Tai |
| Well Elevation (msl in feet): | 1182 | Drilled Depth (ft): | 257 | Well Completed (ft): | 257 |
| Township: | 132 | Range: | 43 | Dir: | W |
| Subsection: | BABBDA | Use: | monitor well | Well Status: | Active |
| Driller: | Layne Minnesota Co. | Entry Date: | 12/31/1991 | Update Date: | 11/18/20 |

Related Resources:
Go to MN Well Index Map Well Log Report Stratigraphy Report

More Details | Stratigraphy | Address | Chemical Data | Construction | Pump Test | Static Water | Com

| Description | From(ft) | To(ft) |
|---|---|---|
| FILL & SAND & BOULDERS | 0 | 15 |
| SAND & BOULDERS | 15 | 20 |
| CLAY & SAND STREAKS | 20 | 26 |
| CLAY WITH BOULDERS | 26 | 35 |
| CLAY & SAND STREAKS | 35 | 44 |
| MED. SAND & COARSE GRAVEL | 44 | 50 |
| CLAY WITH MED. FINE SAND STREAKS | 50 | 70 |
| CLAY WITH BOULDERS | 70 | 74 |
| CLAY | 74 | 93 |
| SANDY CLAY WITH BOULDERS | 93 | 130 |
| FINE SILTY SAND CLAY STREAKS | 130 | 198 |
| SANDY CLAY | 198 | 209 |
| SANDY CLAY WITH BOULDERS | 209 | 211 |
| SAND WITH CLAY STREAKS | 211 | 215 |
| COARSE SAND & LOOSE GRAVEL | 215 | 227 |
| CLAY | 227 | 230 |
| CLAY WITH GRAVEL STREAK | 230 | 235 |
| CLAY WITH BOULDERS | 235 | 237 |
| SAND WITH CLAY 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

| | A | B | C |
|---|---|---|---|
| 1 | Chillers lo | Boilers load (kBtu/h) | |
| 2 | boston_of | boston_off.aps | |
| 3 | | | |
| 4 | | | |
| 5 | 0 | 1457.848 | |
| 6 | 0 | 1543.413 | |
| 7 | 0 | 1614.678 | |
| 8 | 0 | 1684.256 | |
| 9 | 5.54658 | 1763.168 | |
| 10 | 6.61337 | 1891.015 | |
| 11 | 5.748 | 1867.348 | |
| 12 | 11.17832 | 1710.941 | |
| 13 | 11.84287 | 1735.915 | |
| 14 | 28.19031 | 1703.237 | |
| 15 | 38.99178 | 1646.194 | |
| 16 | 32.54088 | 1579.55 | |
| 17 | 31.84263 | 1418.279 | |
| 18 | 33.22857 | 1374.319 | |
| 19 | 35.29769 | 1273.534 | |
| 20 | 51.46631 | 1128.692 | |
| 21 | 48.38217 | 1154.039 | |
| 22 | 34.67711 | 1094.363 | |
| 23 | 30.22018 | 957.4687 | |
| 24 | 29.79956 | 822.1762 | |
| 25 | 22.99127 | 812.6953 | |
| 26 | 14.42231 | 819.7145 | |
| 27 | 13.44765 | 776.6334 | |
| 28 | 12.62103 | 810.8748 | |
| 29 | 9.76974 | 911.3629 | |
| 30 | 10.13636 | 1053.87 | |
| 31 | 9.57984 | 1157.852 | |
| 32 | 9.09078 | 1249.956 | |
| 33 | 37.48852 | 1319.934 | |
| 34 | 21.10593 | 1481.956 | |
| 35 | 20.8102 | 1467.026 | |
| 36 | 22.03705 | 1383.609 | |
| 37 | 30.13111 | 1424.343 | |
| 38 | 47.99771 | 1364.315 | |
| 39 | 51.01344 | 1402.147 | |
| 40 | 46.02955 | 1398.741 | |
| 41 | 45.69978 | 1366.154 | |

Sheet 1

| | NY VA Home - Upgraged Glass, ERV & DHW | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 22954 | 132 | 1448778 | 2999 |
| Feb | 22853 | 180 | 1133406 | 2890 |
| Mar | 61668 | 1242 | 906178 | 2461 |
| Apr | 115275 | 2035 | 546207 | 1804 |
| May | 368089 | 2608 | 263785 | 1300 |
| Jun | 5751[illegible]8 | 3016 | 169508 | 1066 |
| Jul | 965[illegible] | 3493 | 107005 | 779 |
| Aug | 80[illegible]1 | 3530 | 130796 | 694 |
| Sep | 4[illegible]99 | 2793 | 231229 | 1078 |
| Oct | [illegible]782 | 1388 | 486886 | 1812 |
| No[illegible] | [illegible]0528 | 580 | 772720 | 2158 |
| D[illegible] | [illegible]30675 | 232 | 1174363 | 2573 |
| | [illegible]30,043 | 3,530 | 7,370,860 | 2,999 |
| | Tons | 294 | Tons | 250 |
| | EFLH | 1,028 | EFLH | 2,458 |

Total cooling kBtu in Jan

Peak cooling kBtu/hr in Jan

- 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

| | A | B | C |
|---|---|---|---|
| 1 | Chillers lo | Boilers load (kBtu/h) | |
| 2 | boston_of | boston_off.aps | |
| 3 | | | |
| 4 | | | |
| 5 | 0 | 1457.848 | |
| 6 | 0 | 1543.413 | |
| 7 | 0 | 1614.678 | |
| 8 | 0 | 1684.256 | |
| 9 | 5.54658 | 1763.168 | |
| 10 | 6.61337 | 1891.015 | |
| 11 | 5.748 | 1867.348 | |
| 12 | 11.17832 | 1710.941 | |
| 13 | 11.84287 | 1735.915 | |
| 14 | 28.19031 | 1703.237 | |
| 15 | 38.99178 | 1646.194 | |
| 16 | 32.54088 | 1579.55 | |
| 17 | 31.84263 | 1418.279 | |
| 18 | 33.22857 | 1374.319 | |
| 19 | 35.29769 | 1273.534 | |
| 20 | 51.46631 | 1128.692 | |
| 21 | 48.38217 | 1154.039 | |
| 22 | 34.67711 | 1094.363 | |
| 23 | 30.22018 | 957.4687 | |
| 24 | 29.79956 | 822.1762 | |
| 25 | 22.99127 | 812.6953 | |
| 26 | 14.42231 | 819.7145 | |
| 27 | 13.44765 | 776.6334 | |
| 28 | 12.62103 | 810.8748 | |
| 29 | 9.76974 | 911.3629 | |
| 30 | 10.13636 | 1053.87 | |
| 31 | 9.57984 | 1157.852 | |
| 32 | 9.09078 | 1249.956 | |
| 33 | 37.48852 | 1319.934 | |
| 34 | 21.10593 | 1481.956 | |
| 35 | 20.8102 | 1467.026 | |
| 36 | 22.03705 | 1383.609 | |
| 37 | 30.13111 | 1424.343 | |
| 38 | 47.99771 | 1364.315 | |
| 39 | 51.01344 | 1402.147 | |
| 40 | 46.02955 | 1398.741 | |
| 41 | 45.69978 | 1366.154 | |

Sheet1

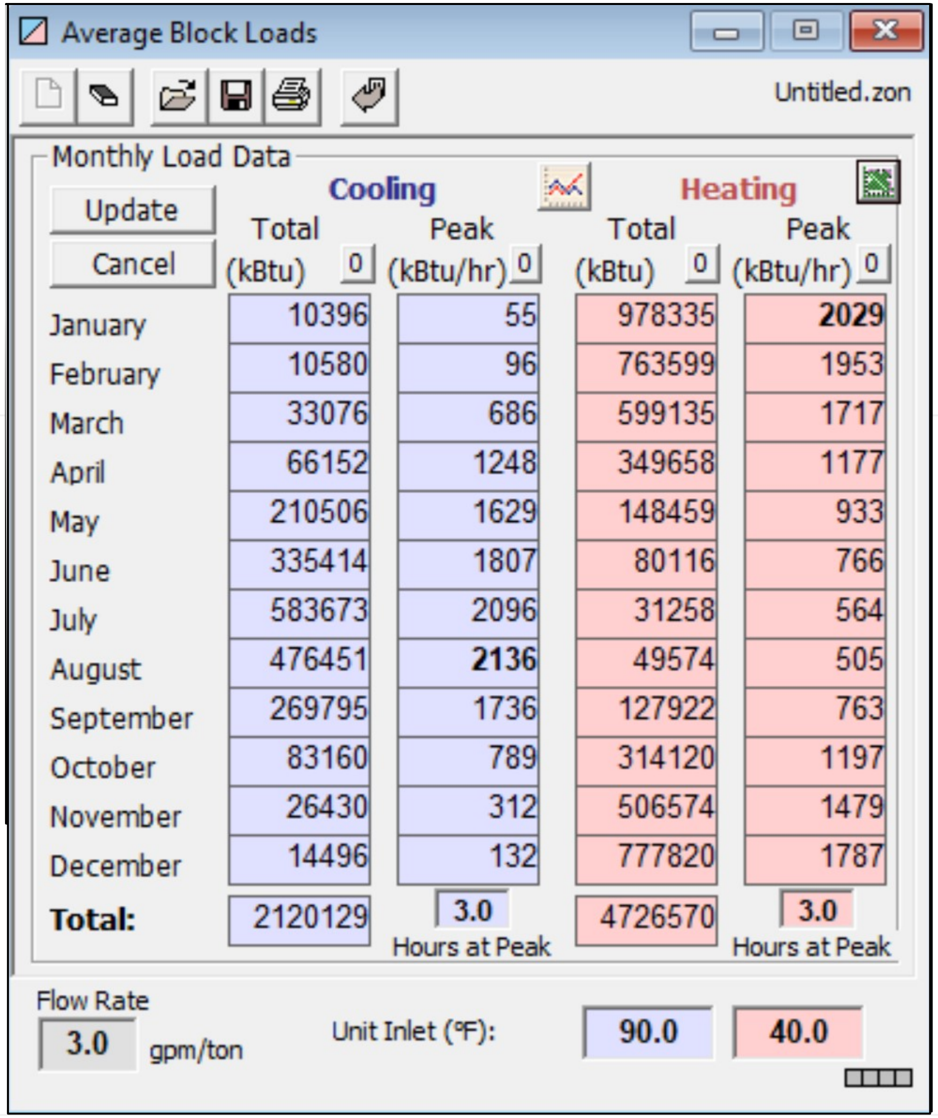
| | NY VA Home - Upgraged Glass, ERV & DHW | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 22954 | 132 | 1448778 | 2999 |
| Feb | 22853 | 180 | 1133406 | 2890 |
| Mar | 61668 | 1242 | 906178 | 2461 |
| Apr | 115275 | 2035 | 546207 | 1804 |
| May | 368089 | 2608 | 263785 | 1300 |
| Jun | 575158 | 3016 | 169508 | 1066 |
| Jul | 965289 | 3493 | [illegible]7005 | 779 |
| Aug | 802771 | 3530 | [illegible]0796 | 694 |
| Sep | 463999 | 2793 | 231229 | 1078 |
| Oct | 150782 | 1388 | 486886 | 1812 |
| Nov | 50528 | 58[illegible] | 772720 | 2158 |
| Dec | 30675 | [illegible] | 1174363 | 2573 |
| | 3,630,0[illegible] | [illegible]0 | 7,370,860 | 2,999 |
| | [illegible] | [illegible]94 | Tons | 250 |
| | [illegible]LH | 1,028 | EFLH | 2,458 |

Total heating kBtu in Jan

Peak heating kBtu/hr in Jan

- 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

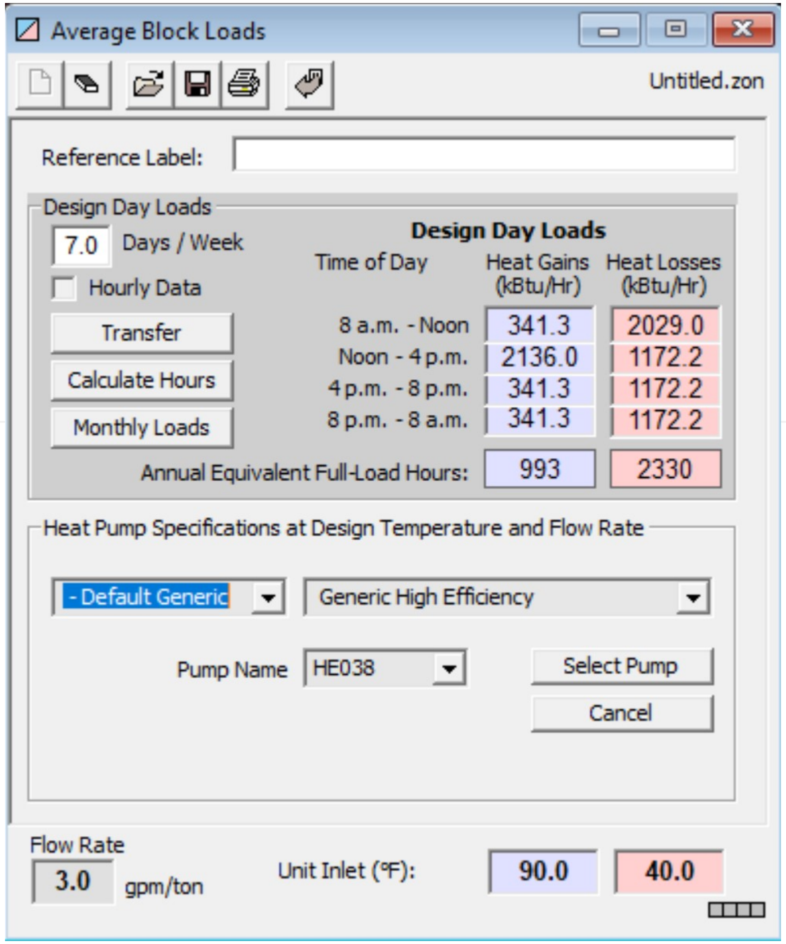
# Importing monthly loads into GHX design software




| | Cooling Total (kBtu) | Cooling Peak (kBtu/hr) | Heating Total (kBtu) | Heating Peak (kBtu/hr) |
|---|---|---|---|---|
| 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 Hours at Peak |

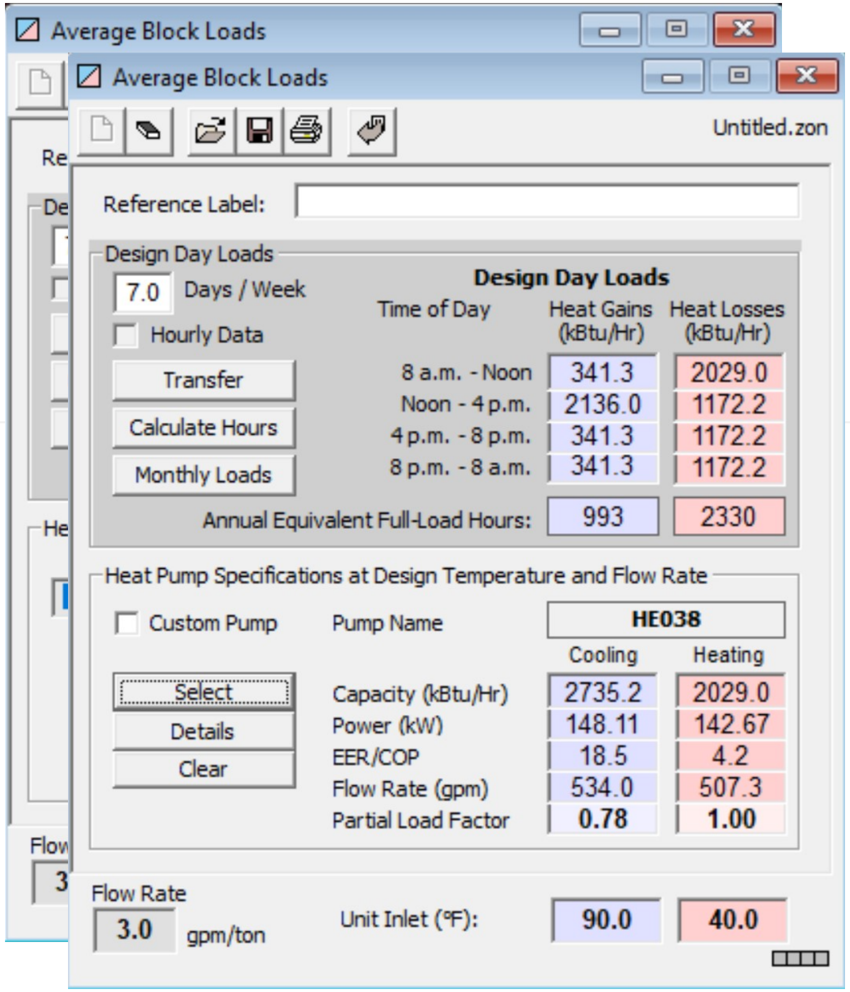
- Monthly energy loads are the minimum required to calculate the size and performance of a GHX
- Some GHX design software can import hourly energy loads and calculate the size and performance of a GHX with greater granularity

# Heat pump selection has an impact on loads to GHX



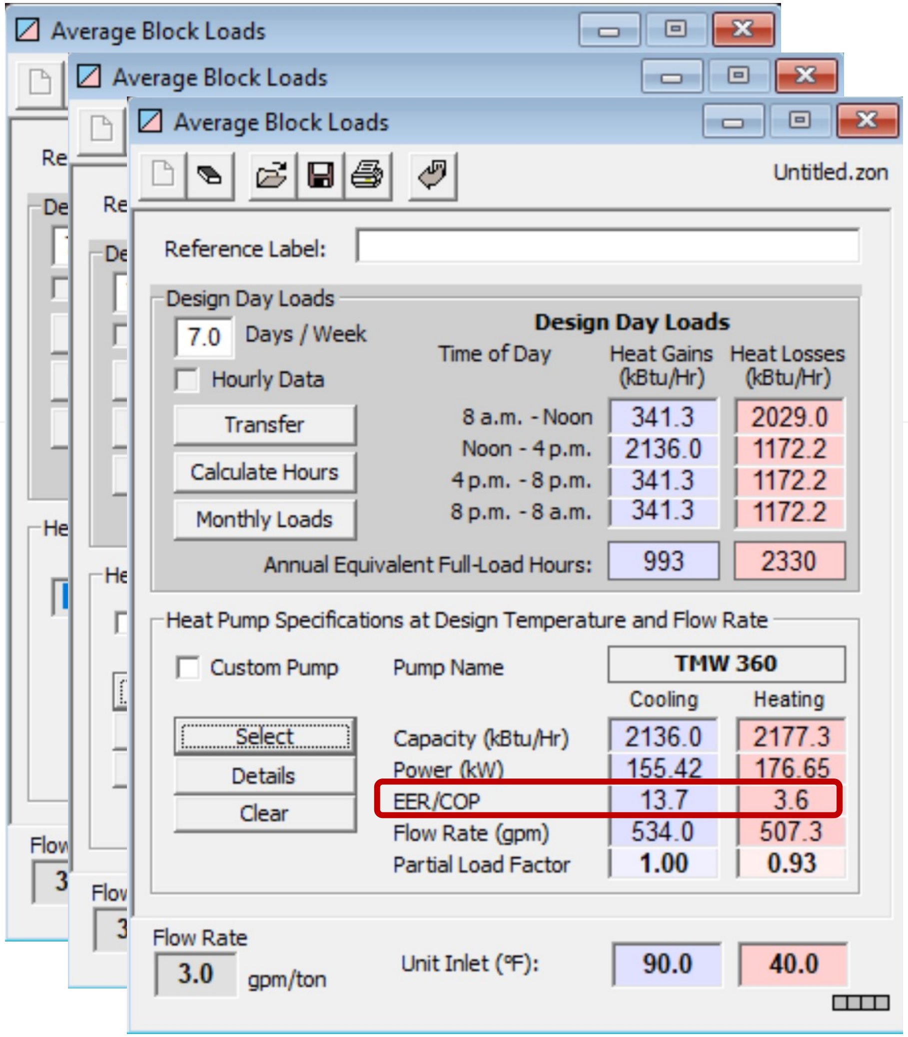

- Equipment selection determines compressor energy to / from GHX
  - Electric motors in heat pump compressors are cooled by refrigerant flowing through the compressor
  - Compressor energy is rejected to the GHX in addition to heat removed from the building
  - Compressor energy contributes heat to the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

# More efficient heat pumps have less impact on the GHX



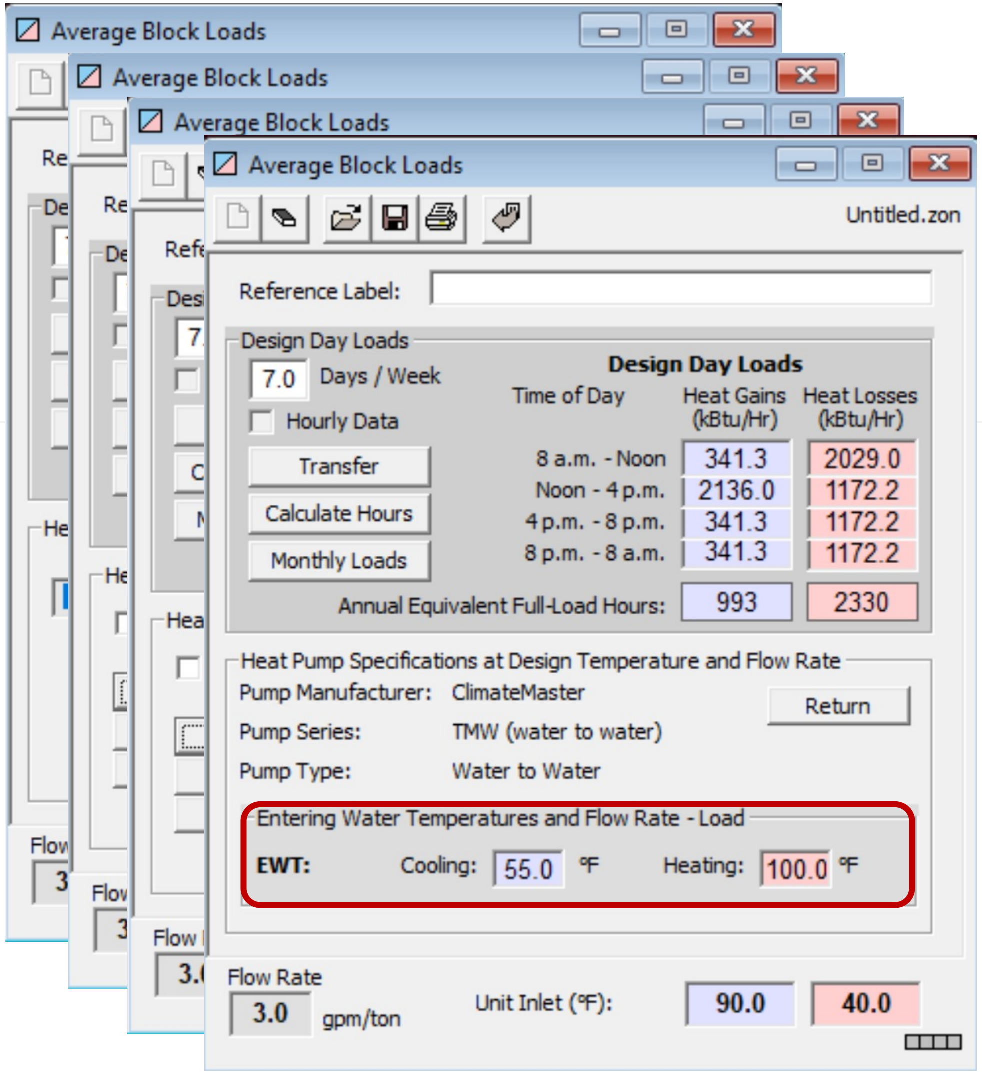

- More efficient heat pumps:
  - Add less heat to building when heating
  - Reject less heat to GHX when cooling
- Changing heat pump efficiency can have an impact on the energy balance and affect the size, cost and performance of a GHX

# Default parameters built into GHX software



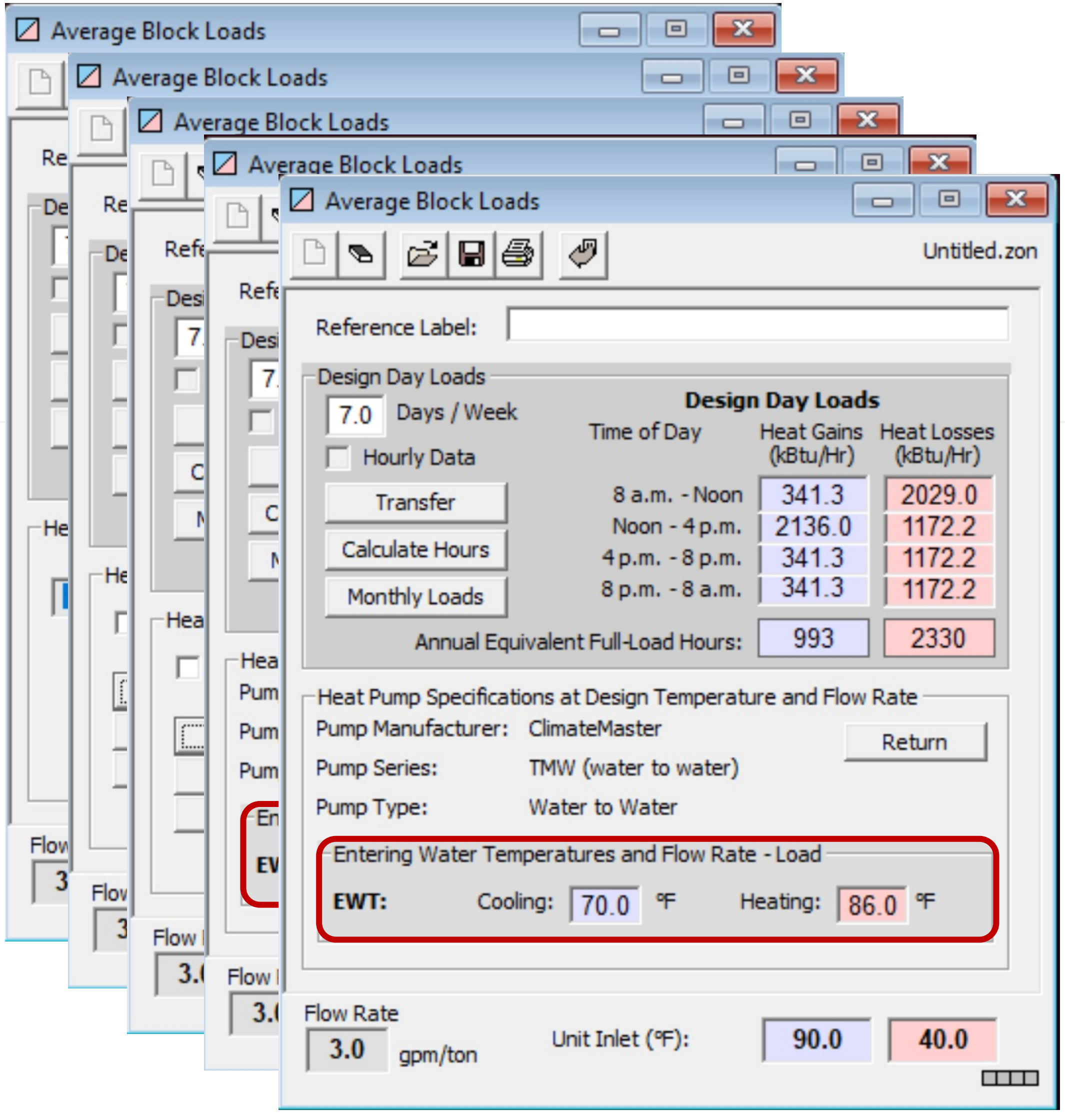

- Mechanical system design can have an impact on heat pump efficiency:
  - The default settings for water to water heat pumps shows heat pump efficiency for typical operation with air handling units selected with 45°F chilled water in cooling and 110°F water in heating
  - COPh = 3.6
  - EER = 13.7

# Adjusting heat pump operating parameters to match design



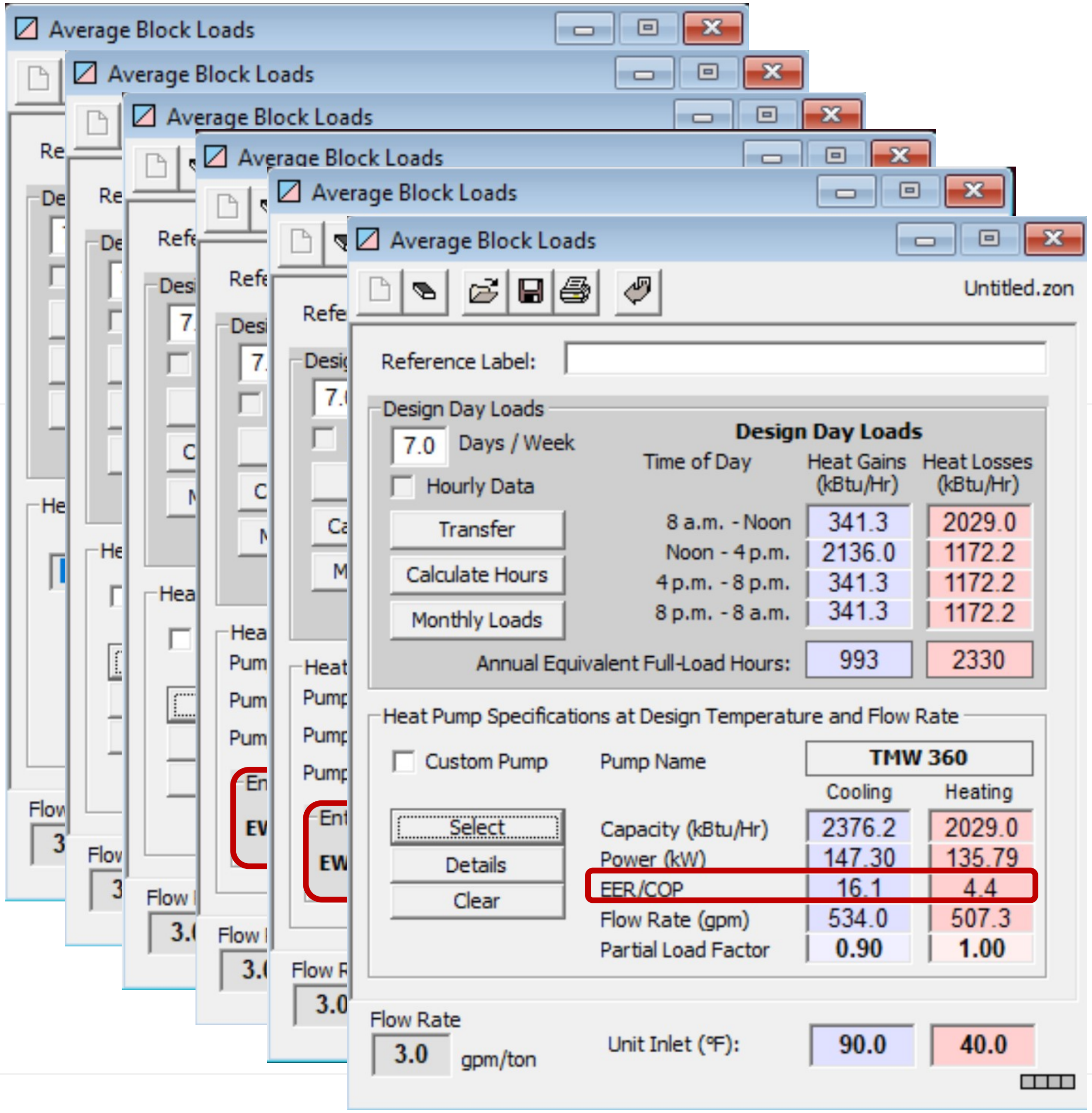

- Selecting heat pump output temperatures to match requirements for a radiant floor heating and cooling or chilled beams changes heat pump efficiency

# Adjusting heat pump parameters for more efficient performance




- 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

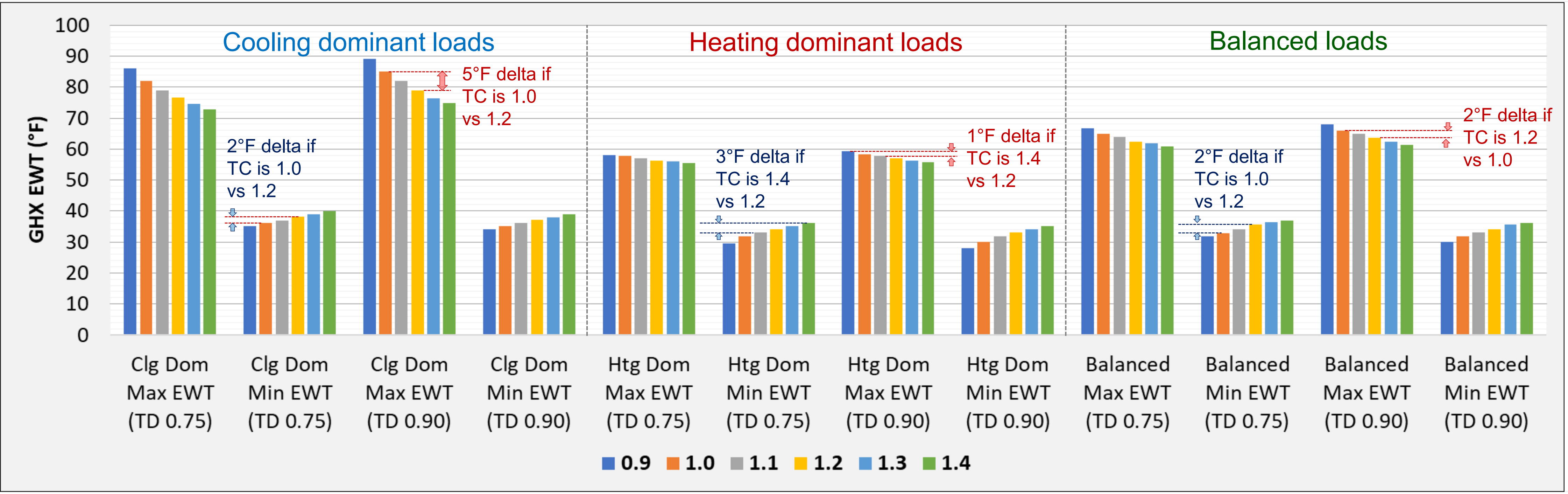
# Estimating thermal properties of from a borehole log

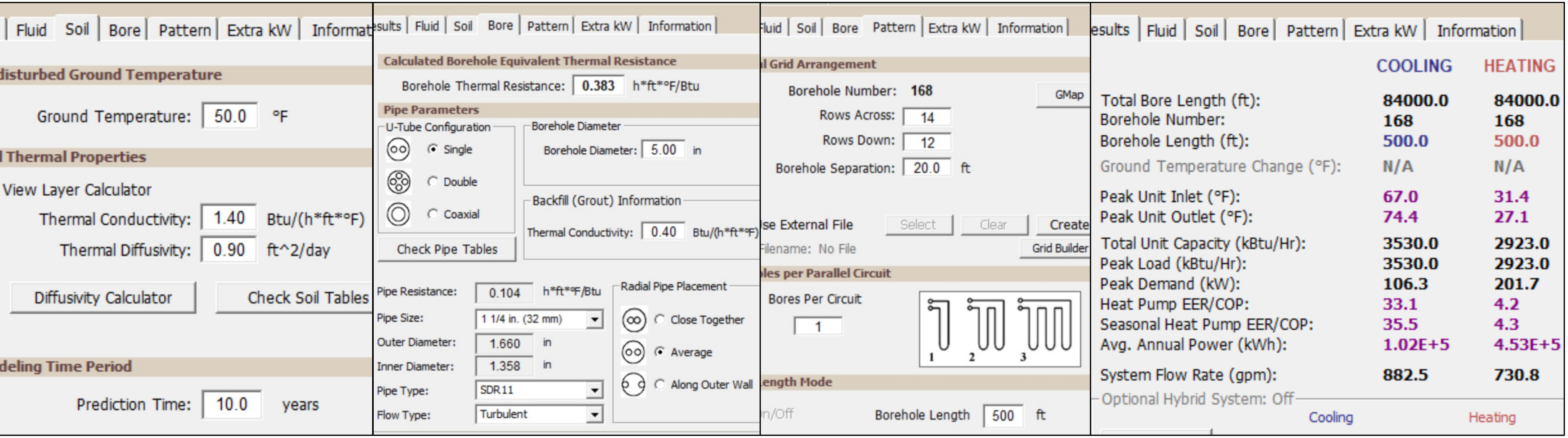
- Creating a weighted average of the stratigraphy of a borehole log provides preliminary information needed to model GHX

| Depth | | Layer | Lithology | Layer Conductivity | | | Layer Diffusivity | | | Weighted TC | | | Weighted TD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | | | 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** | **Average Estimated Thermal Conductivity & Diffusivity of Borehole** | | | | | | | | 0.96 | **1.19** | 1.42 | 0.58 | **0.68** | 0.78 |

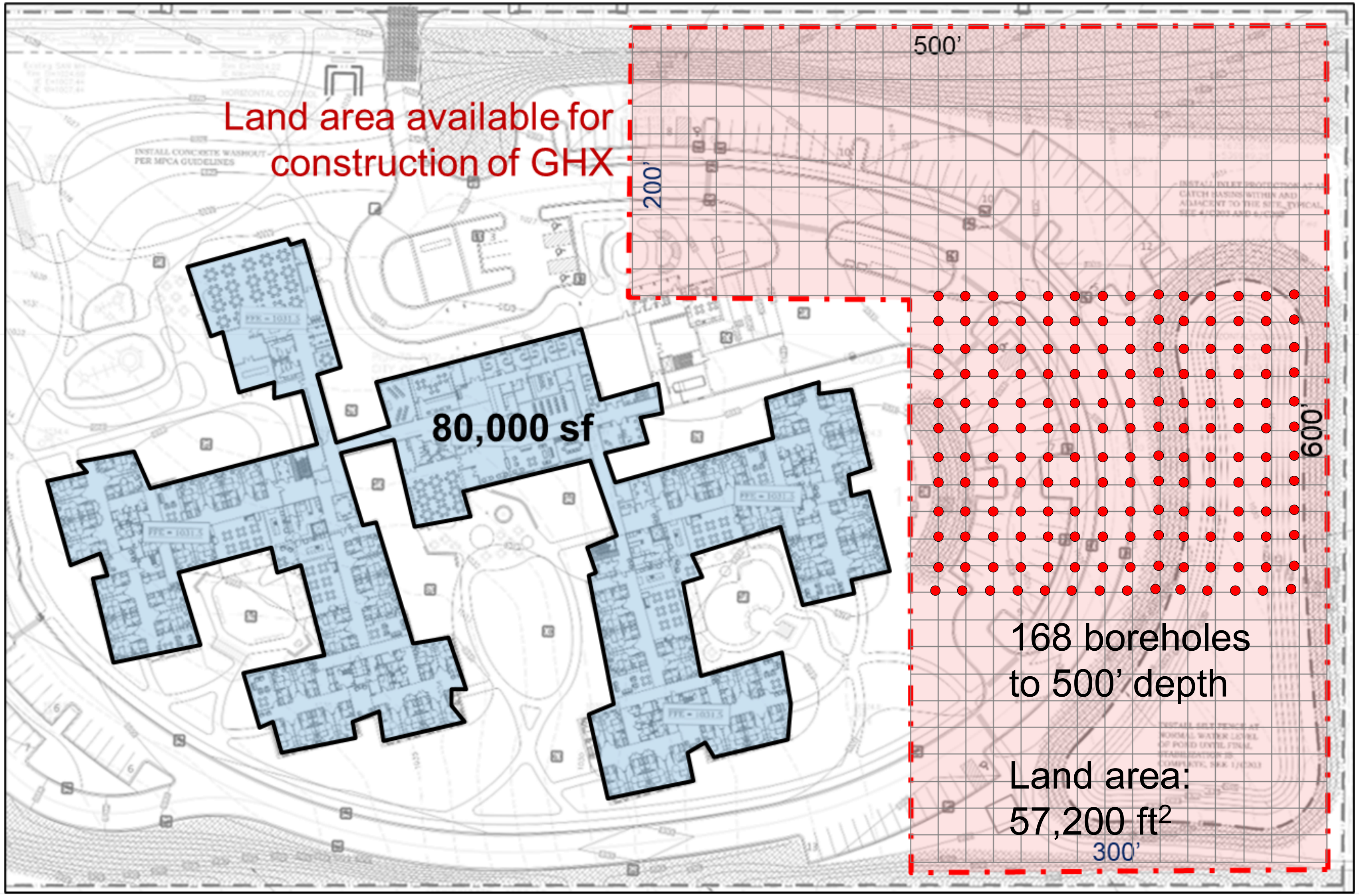
# Thermal conductivity and diffusivity estimates for vertical GHX

- 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



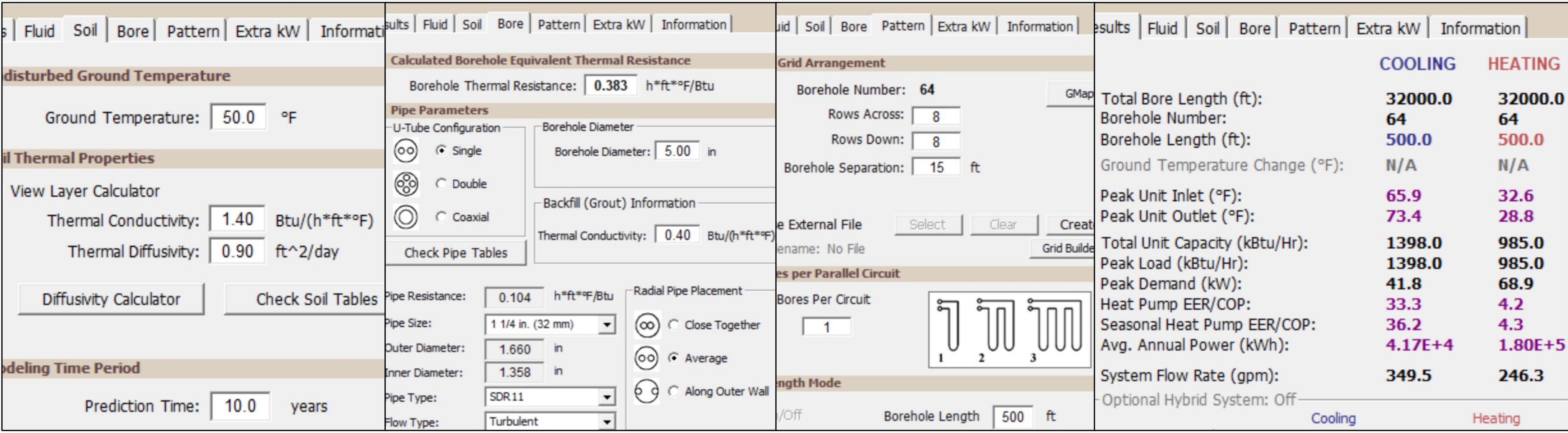

Fluid Soil Bore Pattern Extra kW Informat
disturbed Ground Temperature
Ground Temperature: 50.0 °F
l Thermal Properties
View Layer Calculator
Thermal Conductivity: 1.40 Btu/(h*ft*°F)
Thermal Diffusivity: 0.90 ft^2/day
Diffusivity Calculator
Check Soil Tables
deling Time Period
Prediction Time: 10.0 years
sults Fluid Soil Bore Pattern Extra kW Information
Calculated Borehole Equivalent Thermal Resistance
Borehole Thermal Resistance: 0.383 h*ft*°F/Btu
Pipe Parameters
U-Tube Configuration
Single
Double
Coaxial
Check Pipe Tables
Borehole Diameter
Borehole Diameter: 5.00 in
Backfill (Grout) Information
Thermal Conductivity: 0.40 Btu/(h*ft*°F)
Pipe Resistance: 0.104 h*ft*°F/Btu
Pipe Size: 1 1/4 in. (32 mm)
Outer Diameter: 1.660 in
Inner Diameter: 1.358 in
Pipe Type: SDR11
Flow Type: Turbulent
Radial Pipe Placement
Close Together
Average
Along Outer Wall
luid Soil Bore Pattern Extra kW Information
l Grid Arrangement
Borehole Number: 168
GMap
Rows Across: 14
Rows Down: 12
Borehole Separation: 20.0 ft
se External File
Select
Clear
Create
ilename: No File
Grid Builder
les per Parallel Circuit
Bores Per Circuit
1
1 2 3
ength Mode
n/Off
Borehole Length 500 ft
esults Fluid Soil Bore Pattern Extra kW Information
COOLING HEATING
Total Bore Length (ft): 84000.0 84000.0
Borehole Number: 168 168
Borehole Length (ft): 500.0 500.0
Ground Temperature Change (°F): N/A N/A
Peak Unit Inlet (°F): 67.0 31.4
Peak Unit Outlet (°F): 74.4 27.1
Total Unit Capacity (kBtu/Hr): 3530.0 2923.0
Peak Load (kBtu/Hr): 3530.0 2923.0
Peak Demand (kW): 106.3 201.7
Heat Pump EER/COP: 33.1 4.2
Seasonal Heat Pump EER/COP: 35.5 4.3
Avg. Annual Power (kWh): 1.02E+5 4.53E+5
System Flow Rate (gpm): 882.5 730.8
Optional Hybrid System: Off
Cooling
Heating

# Vertical GHX for standard building or building with upgraded glass

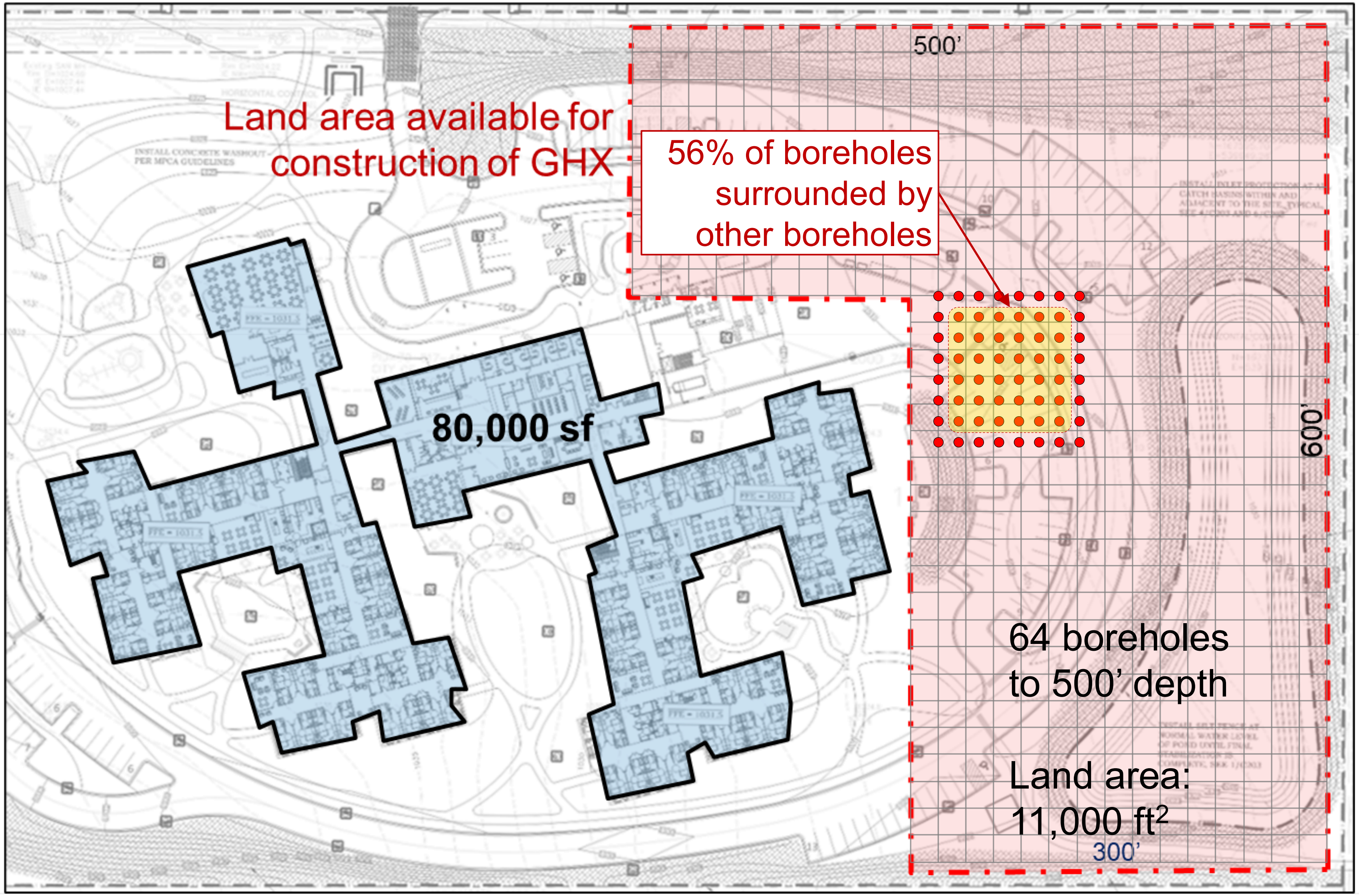



- Configuration & type of GHX is impacted by available land area
- Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

# Modeling for vertical borehole GHX

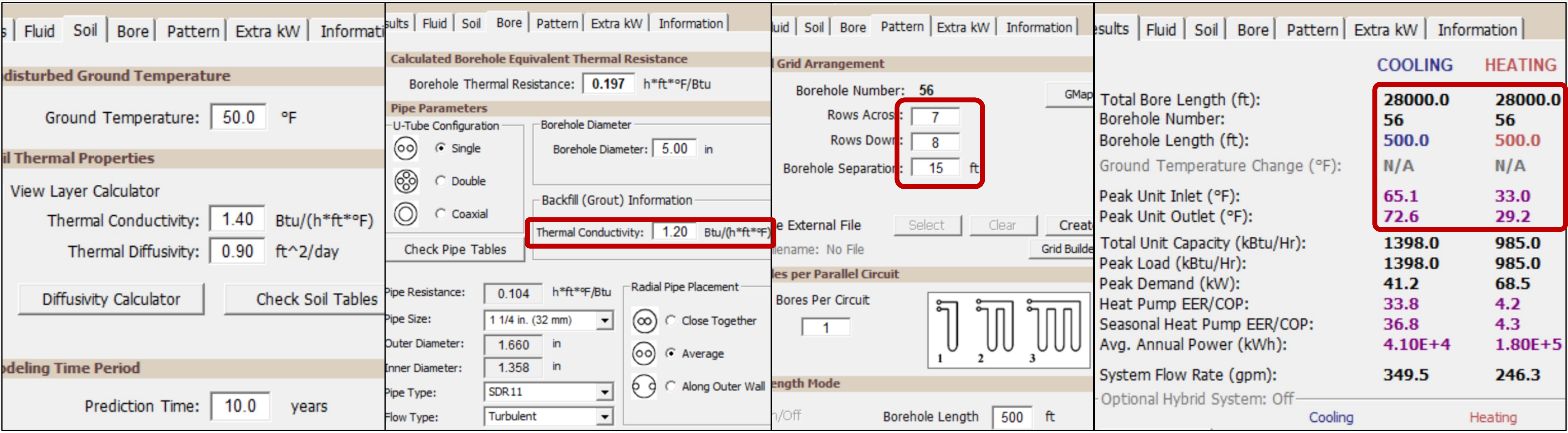


# Vertical GHX for building with upgraded glass, ERV & DHW

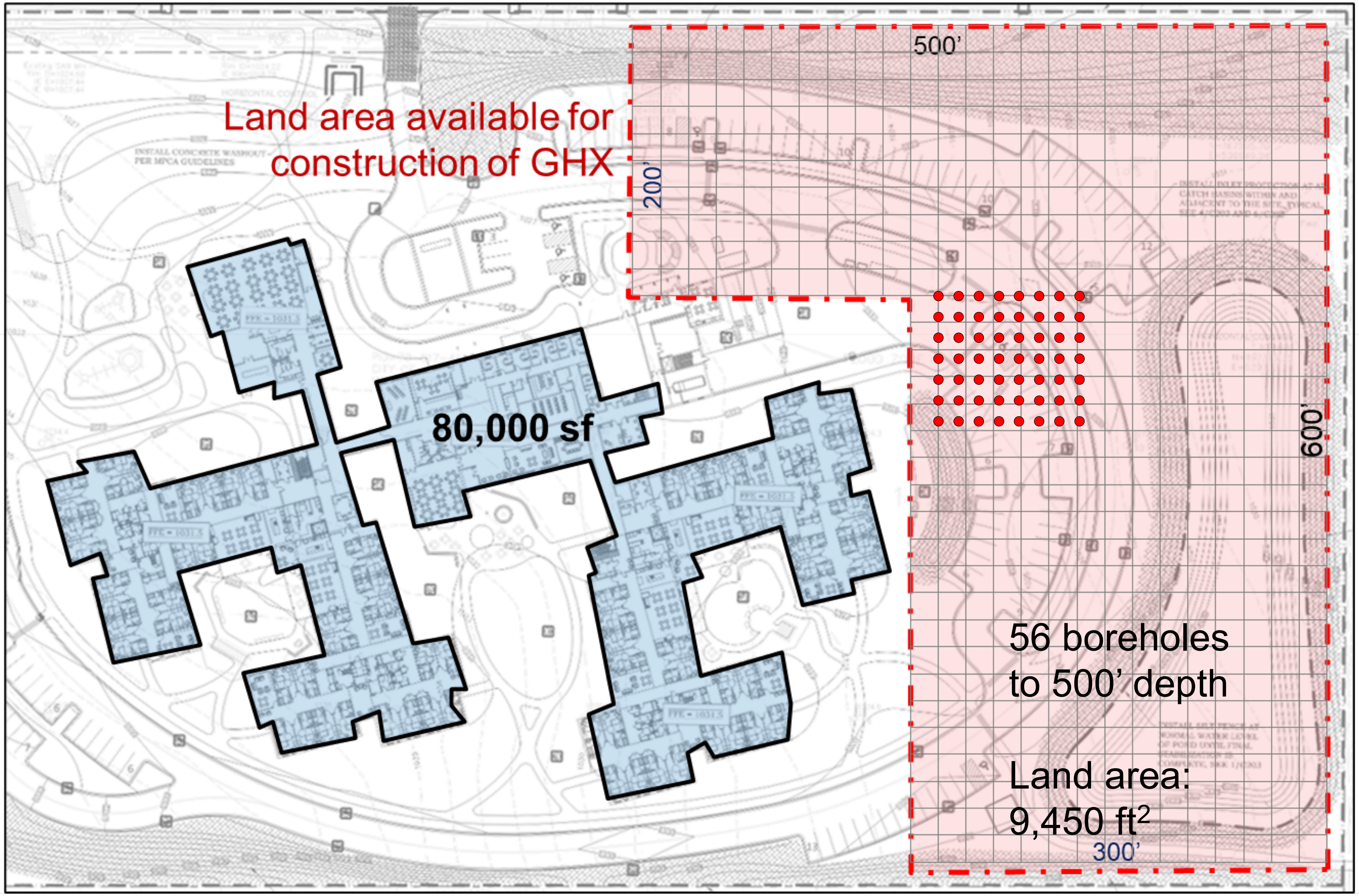



- Configuration & type of GHX is impacted by available land area
- Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

# Modeling for vertical borehole GHX

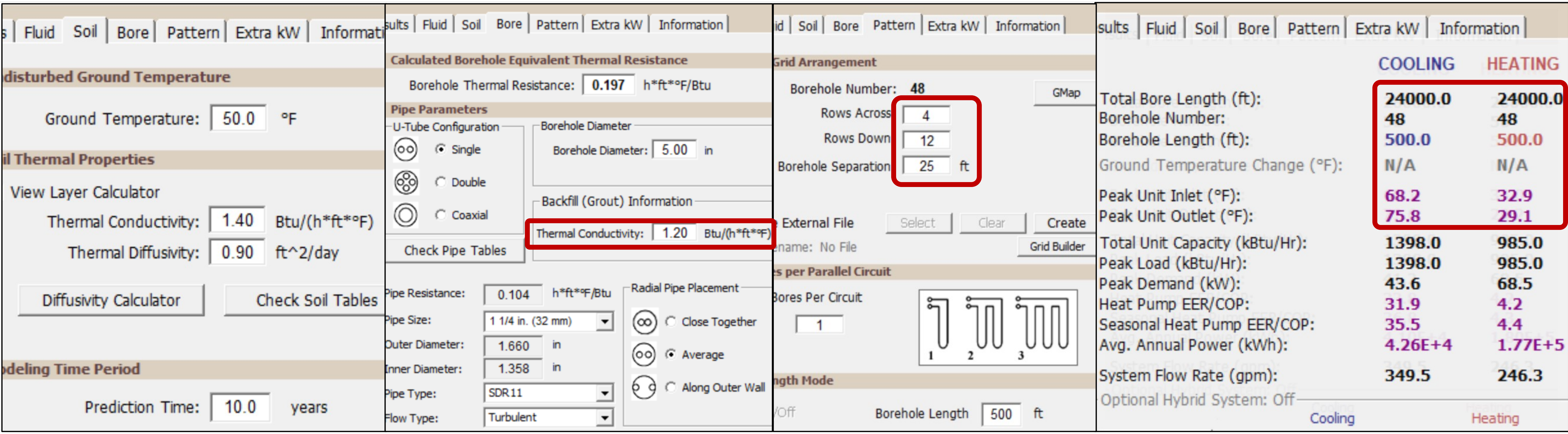


# Vertical GHX for building with upgraded glass, ERV & DHW

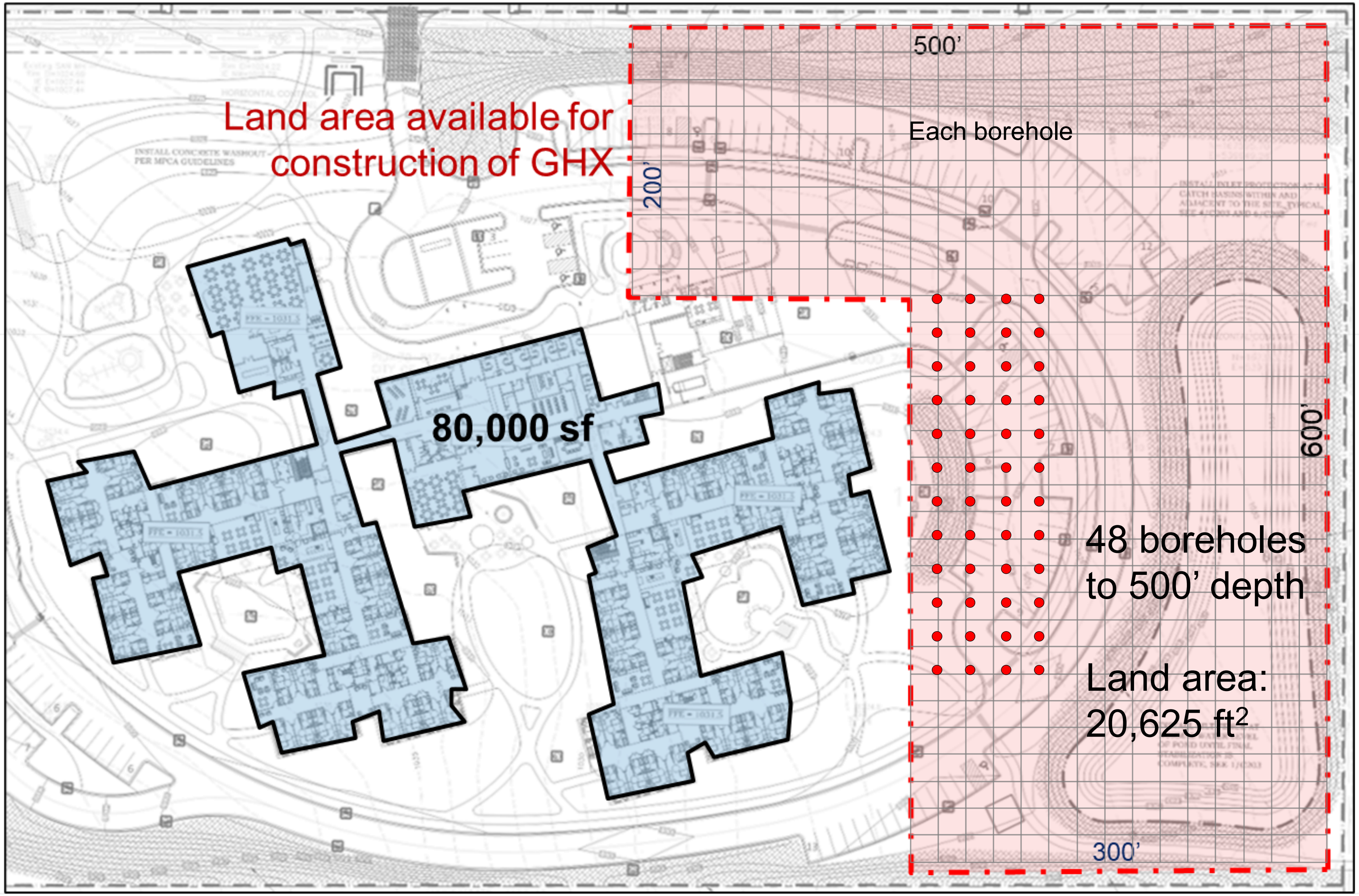



- Configuration & type of GHX is impacted by available land area
- Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

# Modeling for vertical borehole GHX



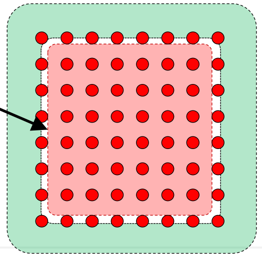
# Vertical GHX for building with upgraded glass, ERV & DHW




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

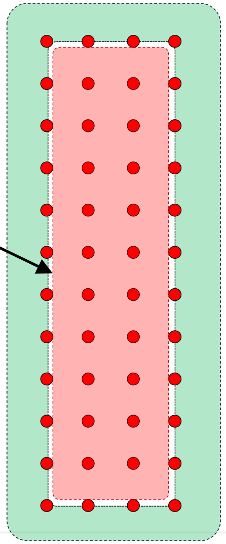
## 7 x 8 grid - 15' spacing

56% of boreholes surrounded by other boreholes

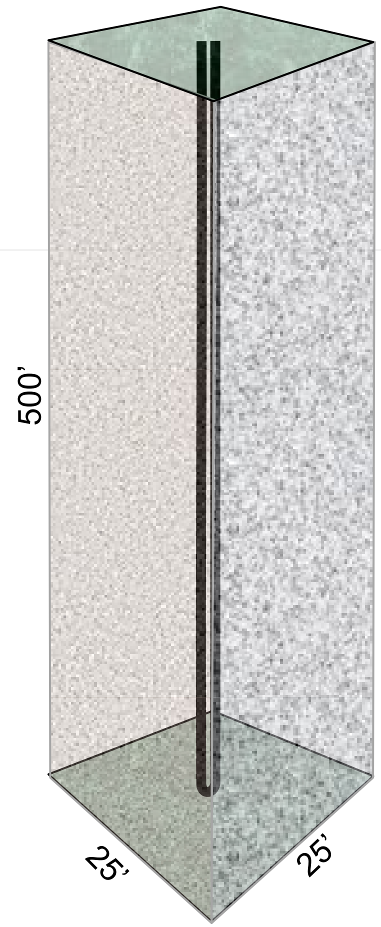


## 4 x 12 grid - 20' spacing

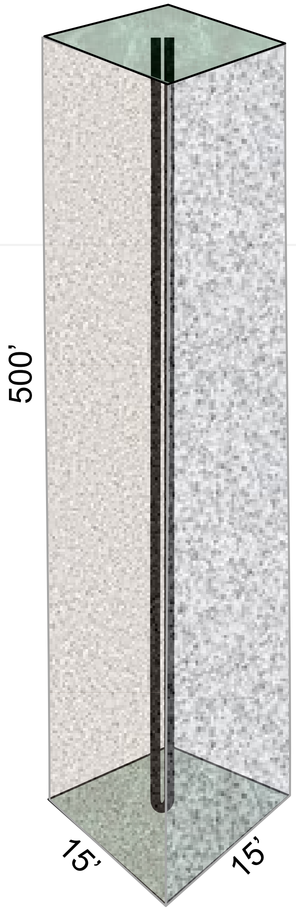
42% of boreholes surrounded by other boreholes



$312,500\ ft^3$

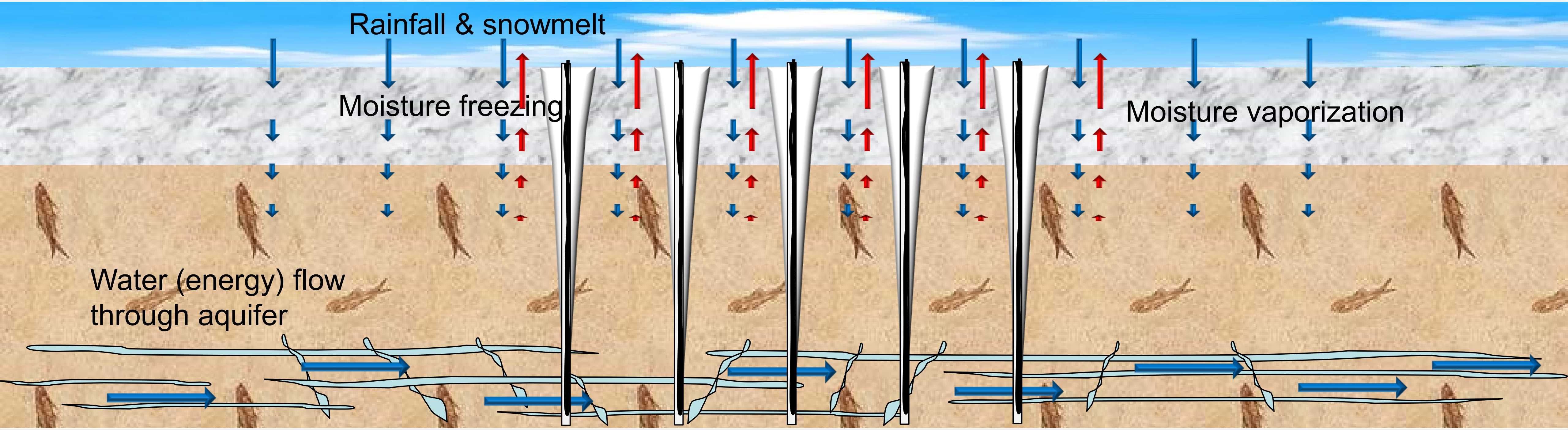



$112,500\ ft^3$



# 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



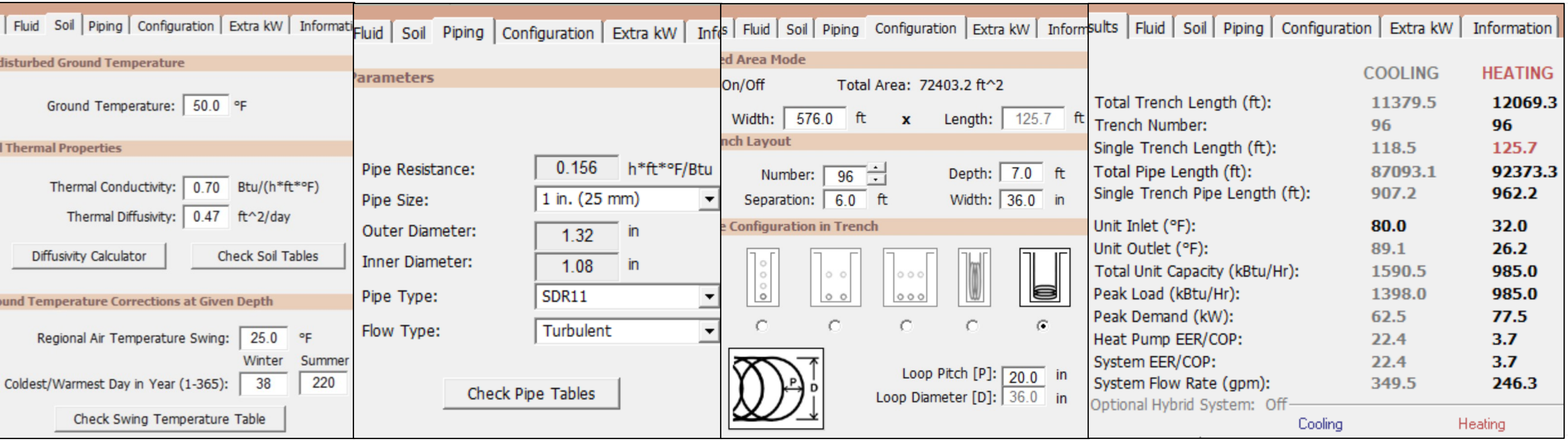
# Horizontal excavation for slinky GHX

# Thermal properties estimated for excavated horizontal GHX

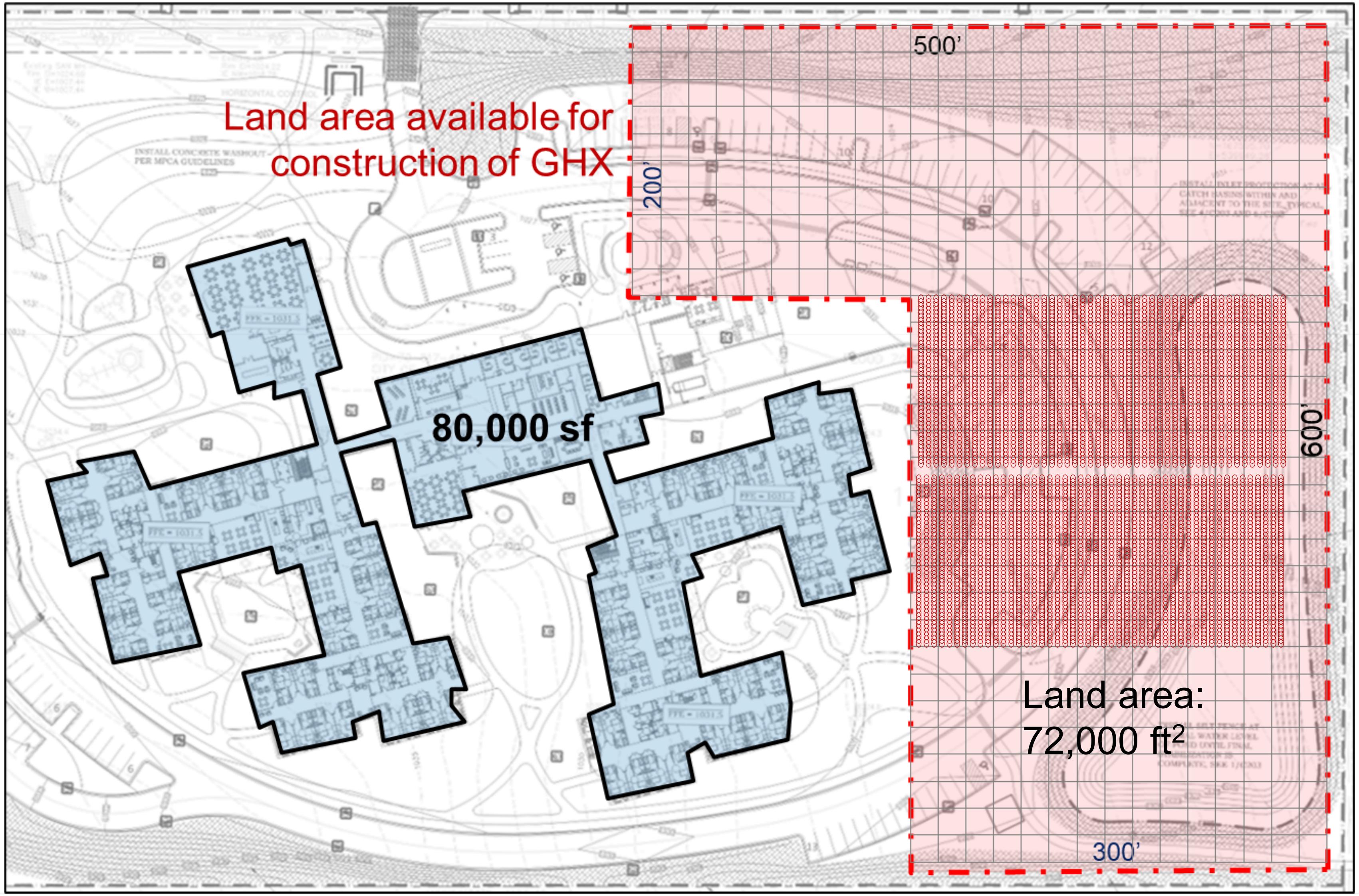
- Horizontal excavated GHX typically installed 5-10' below grade. Thermal conductivity and diffusivity can be estimated with geo-tech borehole logs
- Select the TC and TD of the strata in which the GHX will be embedded

| Depth | | Layer | Lithology | Layer Conductivity | | | Layer Diffusivity | | | Weighted TC | | | Weighted TD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | | | 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 |
| 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** | **Average Estimated Thermal Conductivity & Diffusivity of Borehole** | | | | | | | | 0.68 | **0.78** | 0.88 | 0.52 | **0.69** | 0.87 |

# Modeling horizontal slinky GHX



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

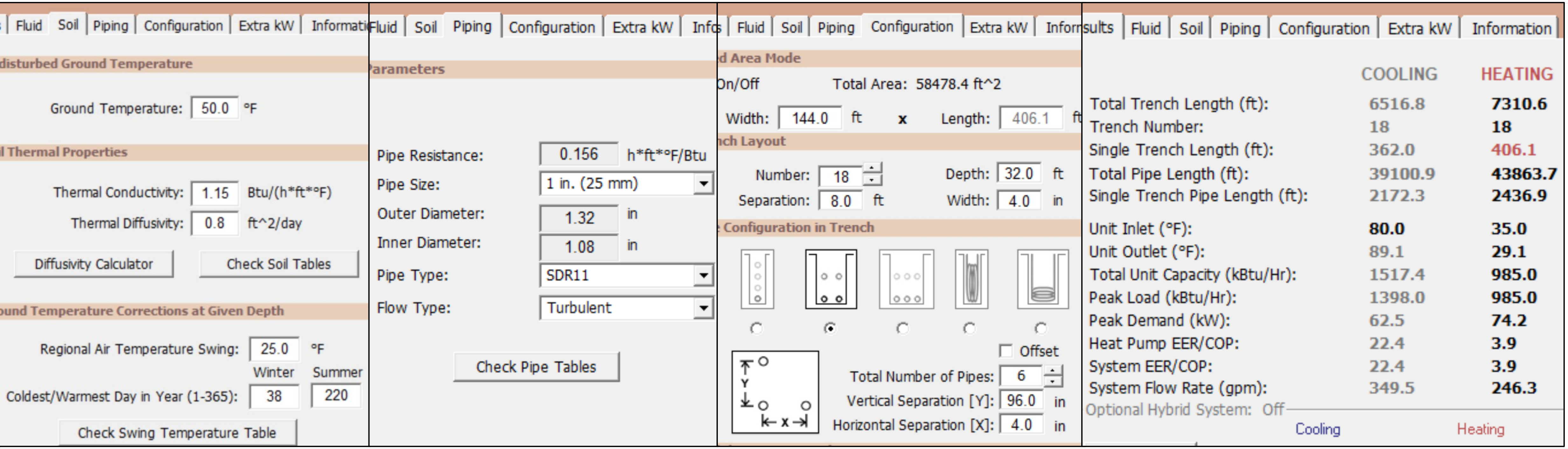



- Configuration & type of GHX is impacted by available land area
- Preliminary review suggests vertical, excavated horizontal or horizontal directionally drilled GHX might be considered

# Thermal properties for horizontal directionally drilled GHX

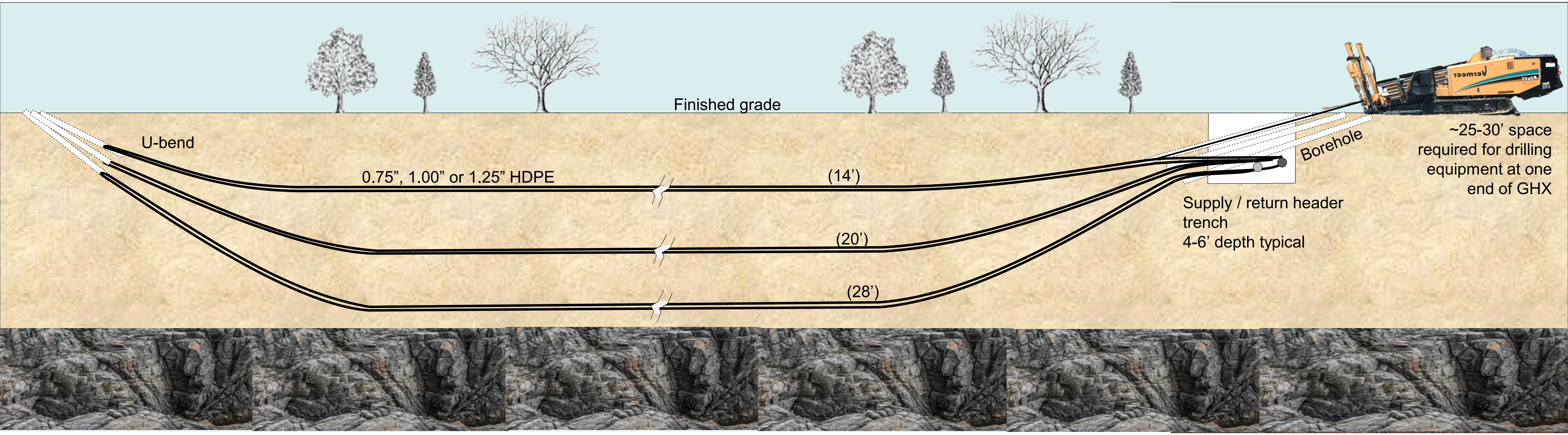
| Depth | | Layer | Lithology | Layer Conductivity | | | Layer Diffusivity | | | Weighted TC | | | Weighted TD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | | | Low | Avg | High | Low | Avg | High | Low | Avg | High | Low | Avg | High |
| 0 | 4 | 4 | Silty clay 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** | **Average Estimated Thermal Conductivity & Diffusivity of Borehole** | | | | | | | | 0.84 | **1.02** | 1.21 | 0.61 | **0.77** | 0.92 |

# Modeling horizontal directionally drilled GHX

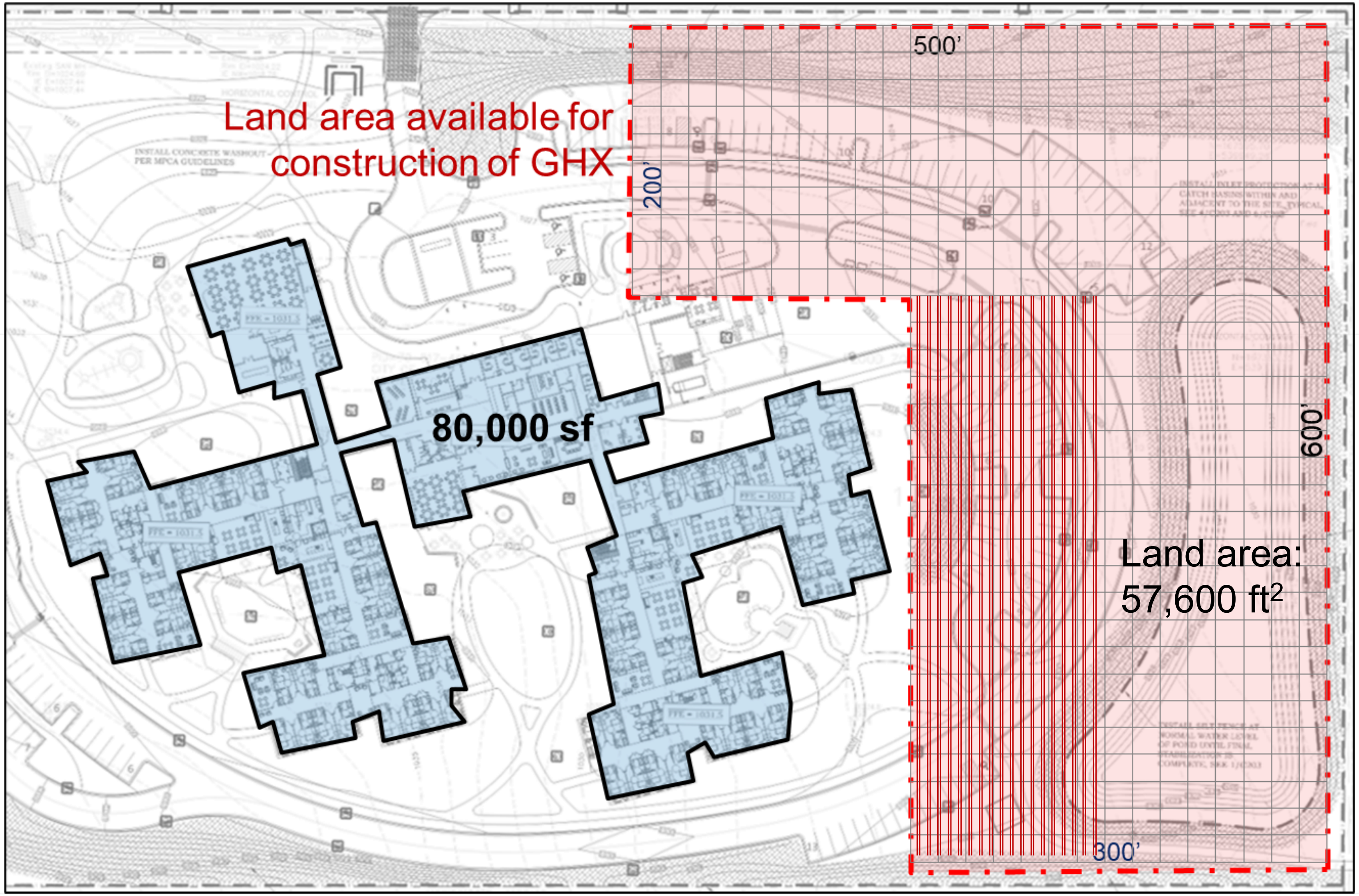


# Horizontal directional drilling GHX

- 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



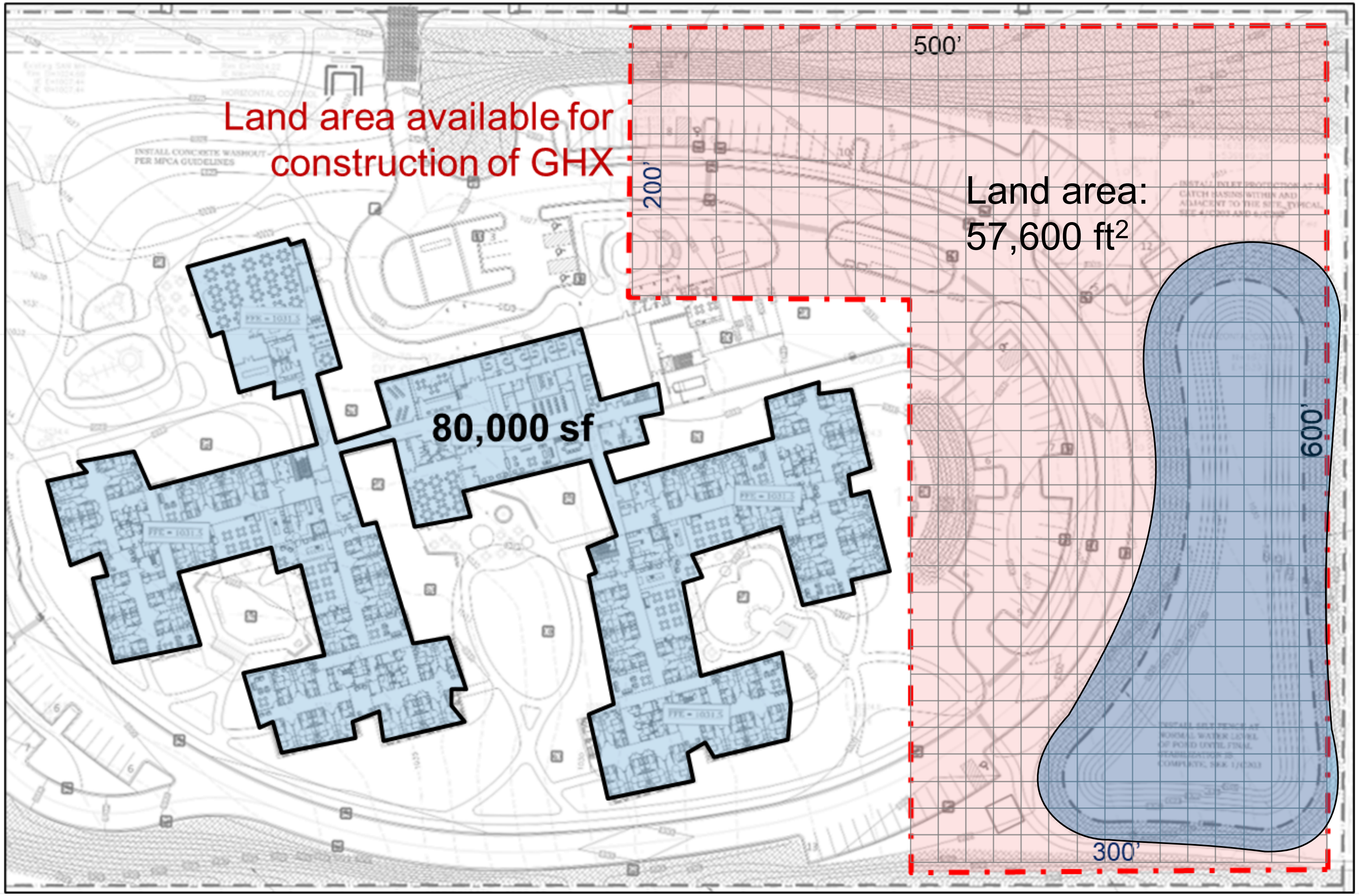
# Horizontal drilled boreholes - building with upgraded glass, ERV & DHW




- 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

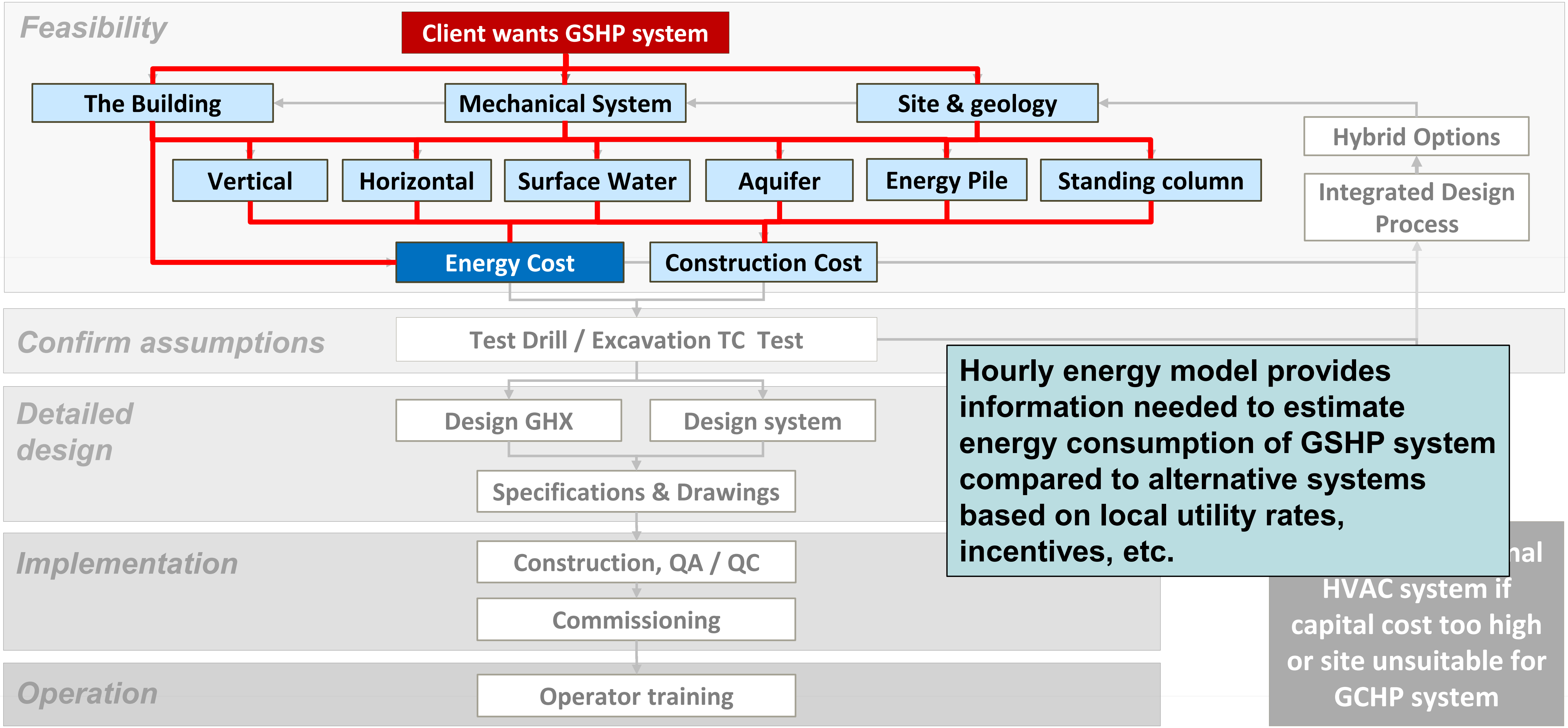
# Surface water heat exchanger




- 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



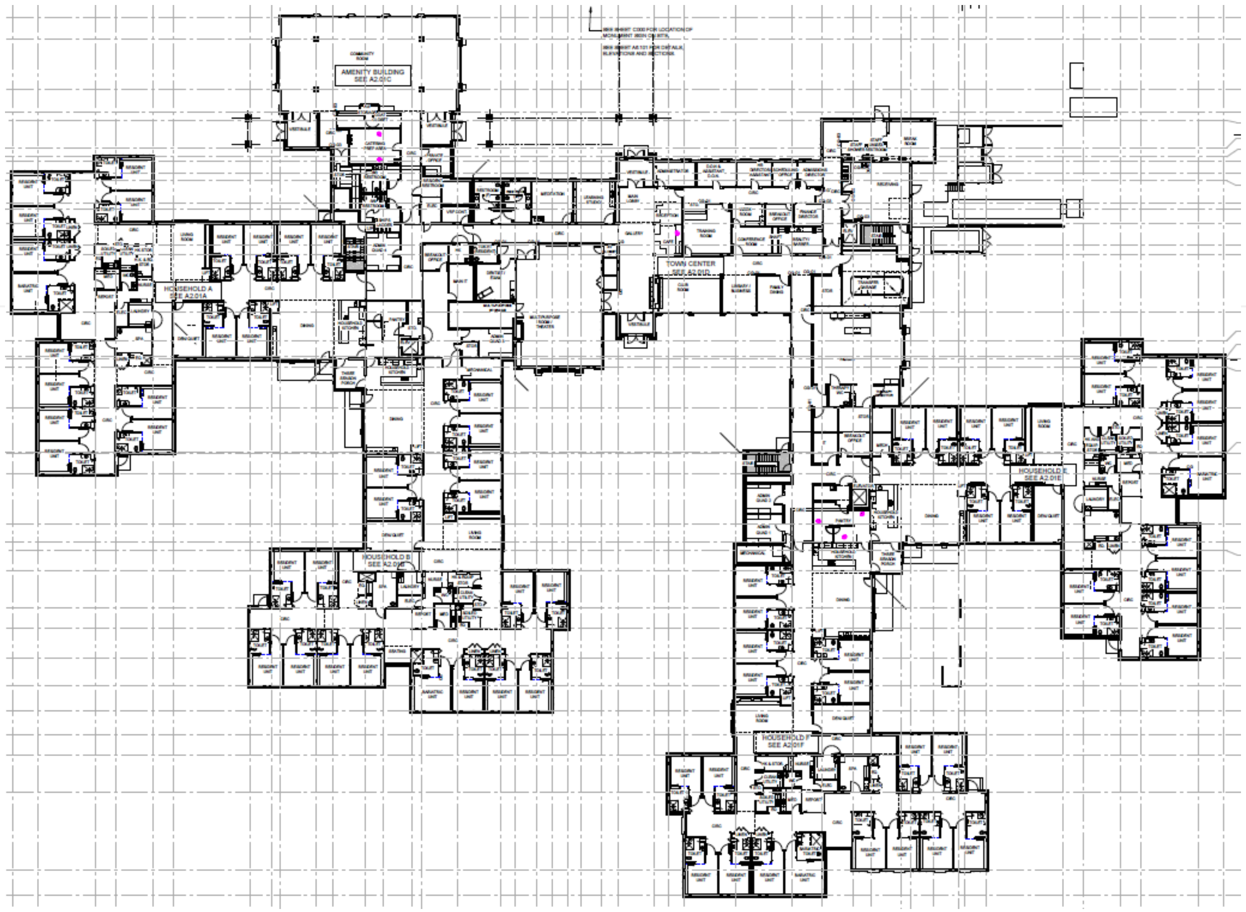

**Hourly energy model provides information needed to estimate energy consumption of GSHP system compared to alternative systems based on local utility rates, incentives, etc.**

| Depth | | Layer | Lithology | Layer Conductivity | | | Layer Diffusivity | | | Weighted TC | | | Weighted TD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | | | 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** | **Average Estimated Thermal Conductivity & Diffusivity of Borehole** | | | | | | | | 0.98 | **1.22** | 1.45 | 0.59 | **0.69** | 0.80 |

# Energy piles

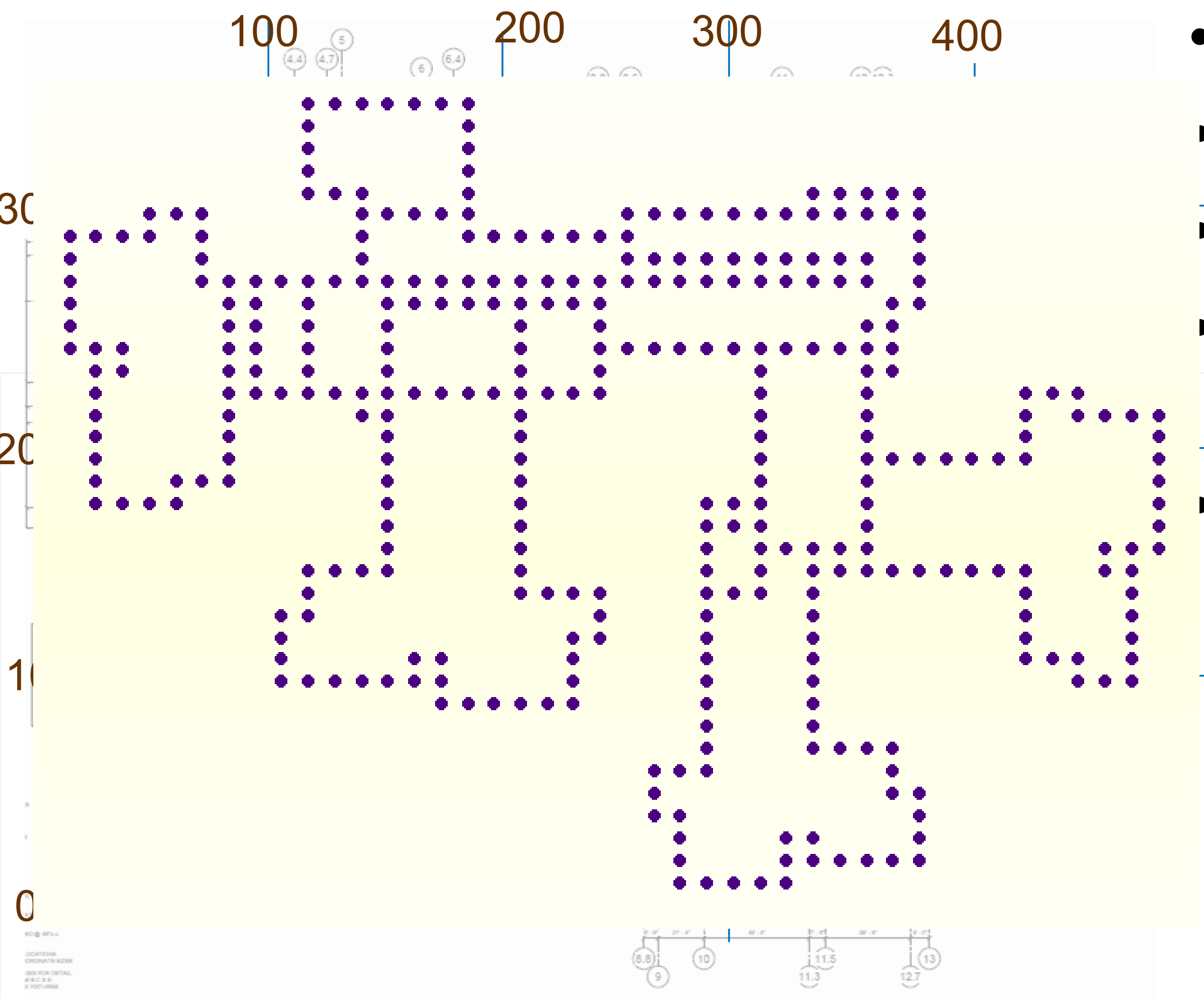
- HDPE U-tubes can be installed in driven tubular steel piles, helical piles, small or large diameter poured concrete piles and can transfer energy to and from the earth

# Energy piles foundation

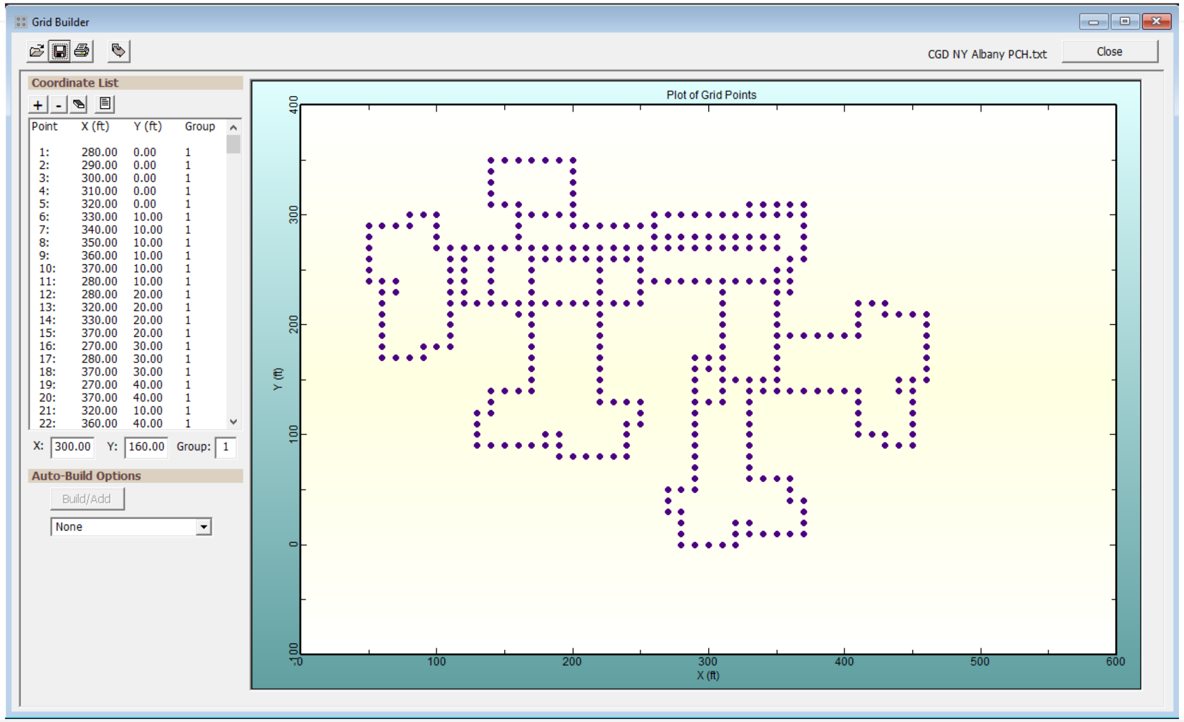


- 352 helical steel piles proposed for this project to a depth of approximately 55’

# Energy piles

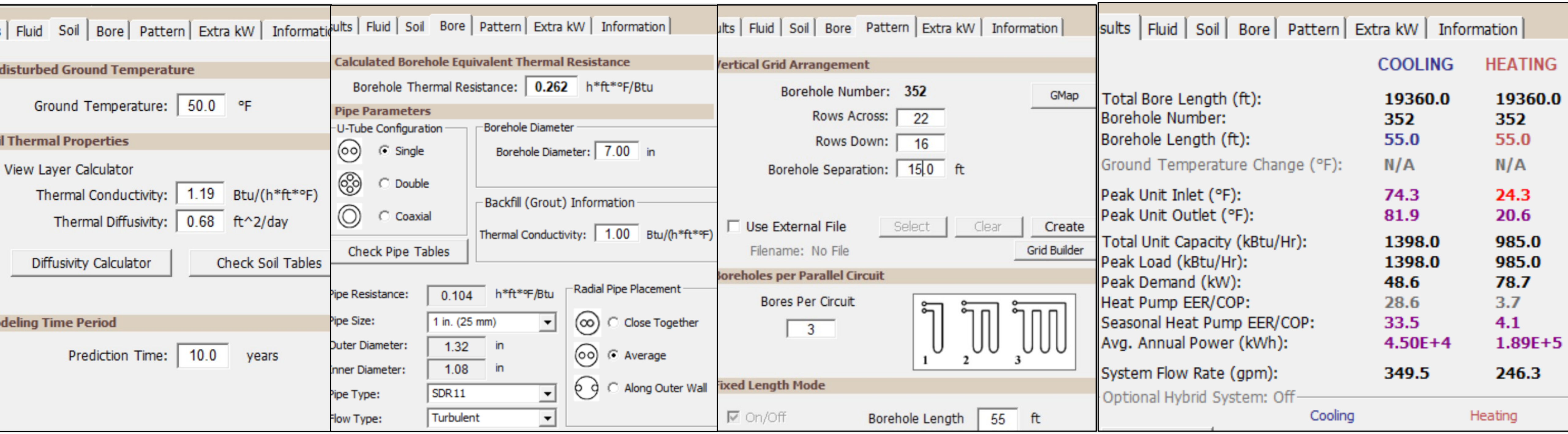



- Pile diameter: 7.00”
- Pile depth: 55’
- Average spacing: 15;
- Concrete grout installed with tremie line after U-tube insertion
- Foundation plan needed to create a grid file for GHX design software to model interaction between U-tubes accurately



Grid Builder
CGD NY Albany PCH.txt
Close
Coordinate List
Point X (ft) Y (ft) Group
1: 280.00 0.00 1
2: 290.00 0.00 1
3: 300.00 0.00 1
4: 310.00 0.00 1
5: 320.00 0.00 1
6: 330.00 10.00 1
7: 340.00 10.00 1
8: 350.00 10.00 1
9: 360.00 10.00 1
10: 370.00 10.00 1
11: 280.00 10.00 1
12: 280.00 20.00 1
13: 320.00 20.00 1
14: 330.00 20.00 1
15: 370.00 20.00 1
16: 270.00 30.00 1
17: 280.00 30.00 1
18: 370.00 30.00 1
19: 270.00 40.00 1
20: 370.00 40.00 1
21: 320.00 10.00 1
22: 360.00 40.00 1
X: 300.00 Y: 160.00 Group: 1
Auto-Build Options
Build/Add
None
Plot of Grid Points
Y (ft)
X (ft)
400
300
200
100
0
-100
100
200
300
400
500
600

# Modeling energy pile GHX



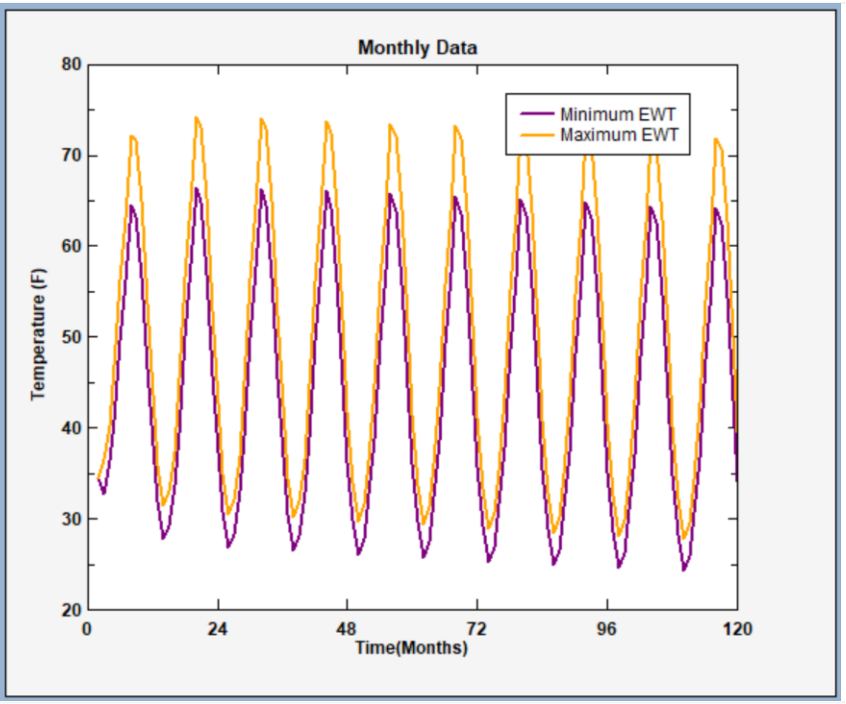
| | NY VA Home - Upgraded Glass, ERV & DHW Loads | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 12559 | 76 | 470443 | 985 |
| Feb | 12273 | 90 | 369807 | 937 |
| Mar | 28592 | 555 | 307043 | 867 |
| Apr | 49123 | 787 | 196549 | 674 |
| May | 157584 | 990 | 115326 | 435 |
| Jun | 239744 | 1210 | 89392 | 351 |
| Jul | 381615 | 1398 | 75747 | 215 |
| Aug | 326320 | 1394 | 81221 | 234 |
| Sep | 194205 | 1057 | 103306 | 406 |
| Oct | 67623 | 599 | 172766 | 619 |
| Nov | 24098 | 268 | 266146 | 724 |
| Dec | 16179 | 100 | 396543 | 883 |
| | 1,509,913 | 1,398 | 2,644,288 | 985 |
| | Tons | 117 | Tons | 82 |
| | EFLH | 1,080 | EFLH | 2,686 |

sults | Fluid | Soil | Bore | Pattern | Extra kW | Information

| | COOLING | HEATING |
|---|---|---|
| Total Bore Length (ft): | 19360.0 | 19360.0 |
| Borehole Number: | 352 | 352 |
| Borehole Length (ft): | 55.0 | 55.0 |
| Ground Temperature Change (°F): | N/A | N/A |
| Peak Unit Inlet (°F): | 74.3 | 24.3 |
| Peak Unit Outlet (°F): | 81.9 | 20.6 |
| Total Unit Capacity (kBtu/Hr): | 1398.0 | 985.0 |
| Peak Load (kBtu/Hr): | 1398.0 | 985.0 |
| Peak Demand (kW): | 48.6 | 78.7 |
| Heat Pump EER/COP: | 28.6 | 3.7 |
| Seasonal Heat Pump EER/COP: | 33.5 | 4.1 |
| Avg. Annual Power (kWh): | 4.50E+4 | 1.89E+5 |
| System Flow Rate (gpm): | 349.5 | 246.3 |

Optional Hybrid System: Off

Cooling Heating



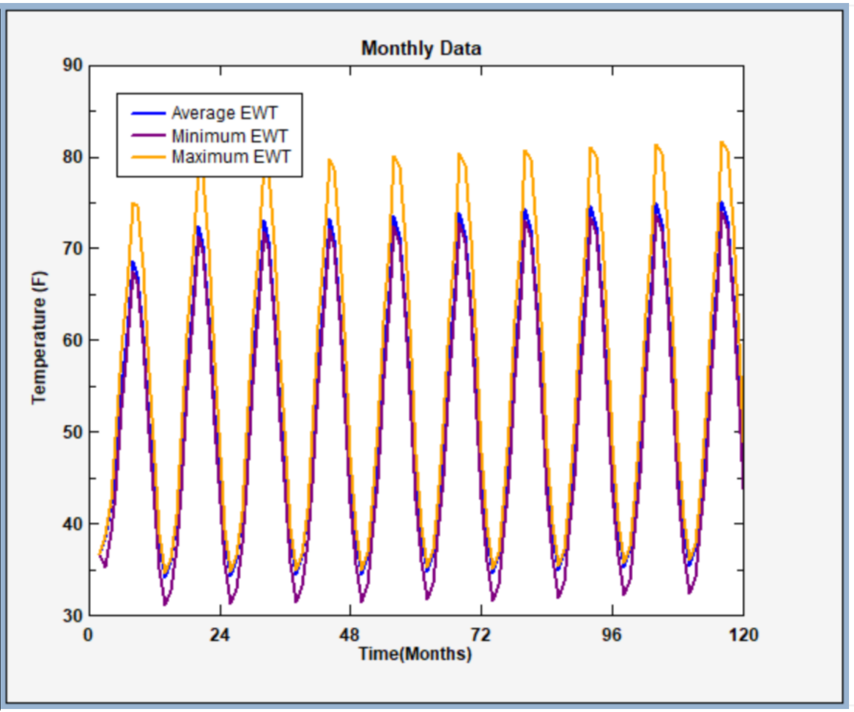
| | NY VA Home - Upgraded Glass & ERV | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 12559 | 76 | 404253 | 905 |
| Feb | 12273 | 90 | 310023 | 843 |
| Mar | 28592 | 555 | 240854 | 794 |
| Apr | 49123 | 787 | 132495 | 591 |
| May | 157584 | 990 | 49136 | 363 |
| Jun | 239744 | 1210 | 25337 | 294 |
| Jul | 381615 | 1398 | 9557 | 211 |
| Aug | 326320 | 1394 | 15032 | 183 |
| Sep | 194205 | 1057 | 39252 | 306 |
| Oct | 67623 | 599 | 106576 | 512 |
| Nov | 24098 | 268 | 202091 | 662 |
| Dec | 16179 | 100 | 330354 | 838 |
| | **1,509,913** | **1,398** | **1,864,960** | **905** |
| | Tons | 117 | Tons | 75 |
| | EFLH | 1,080 | EFLH | 2,061 |

sults | Fluid | Soil | Bore | Pattern | Extra kW | Information

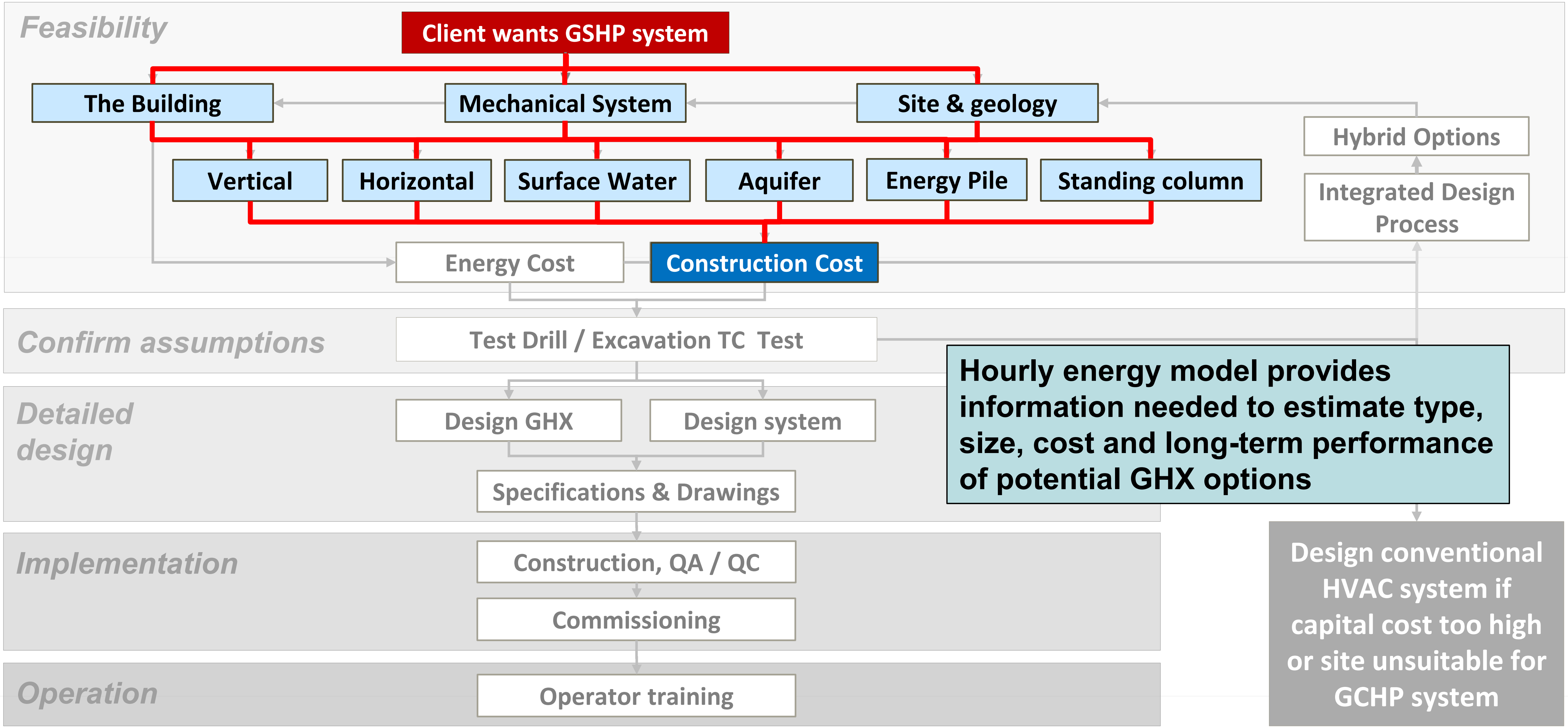
| | COOLING | HEATING |
|---|---|---|
| Total Bore Length (ft): | 19360.0 | 19360.0 |
| Borehole Number: | 352 | 352 |
| Borehole Length (ft): | 55.0 | 55.0 |
| Ground Temperature Change (°F): | N/A | N/A |
| Peak Unit Inlet (°F): | 81.7 | 31.0 |
| Peak Unit Outlet (°F): | 89.4 | 27.5 |
| Total Unit Capacity (kBtu/Hr): | 1398.0 | 905.0 |
| Peak Load (kBtu/Hr): | 1398.0 | 905.0 |
| Peak Demand (kW): | 55.9 | 66.9 |
| Heat Pump EER/COP: | 24.9 | 3.9 |
| Seasonal Heat Pump EER/COP: | 30.1 | 4.3 |
| Avg. Annual Power (kWh): | 5.02E+4 | 1.27E+5 |
| System Flow Rate (gpm): | 349.5 | 226.3 |

Optional Hybrid System: Off

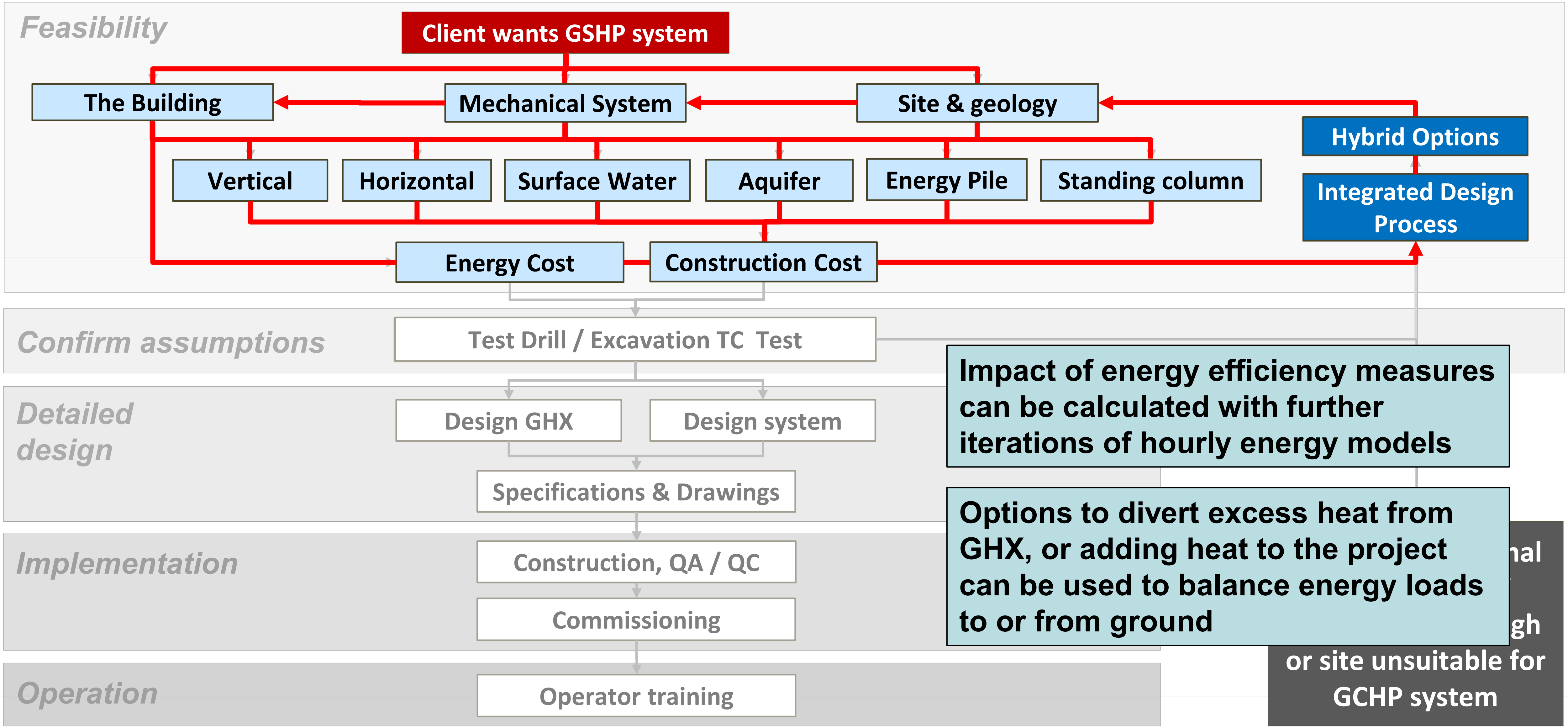
Cooling Heating



# Contractor capabilities, geology, site constraints



# Iterative process to achieve energy load balance to GHX




**Impact of energy efficiency measures can be calculated with further iterations of hourly energy models**

**Options to divert excess heat from GHX, or adding heat to the project can be used to balance energy loads to or from ground**

# 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

**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

# 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

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


- 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

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



- 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

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


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