# Keeping Ground Source Heat Pump Projects on the Table

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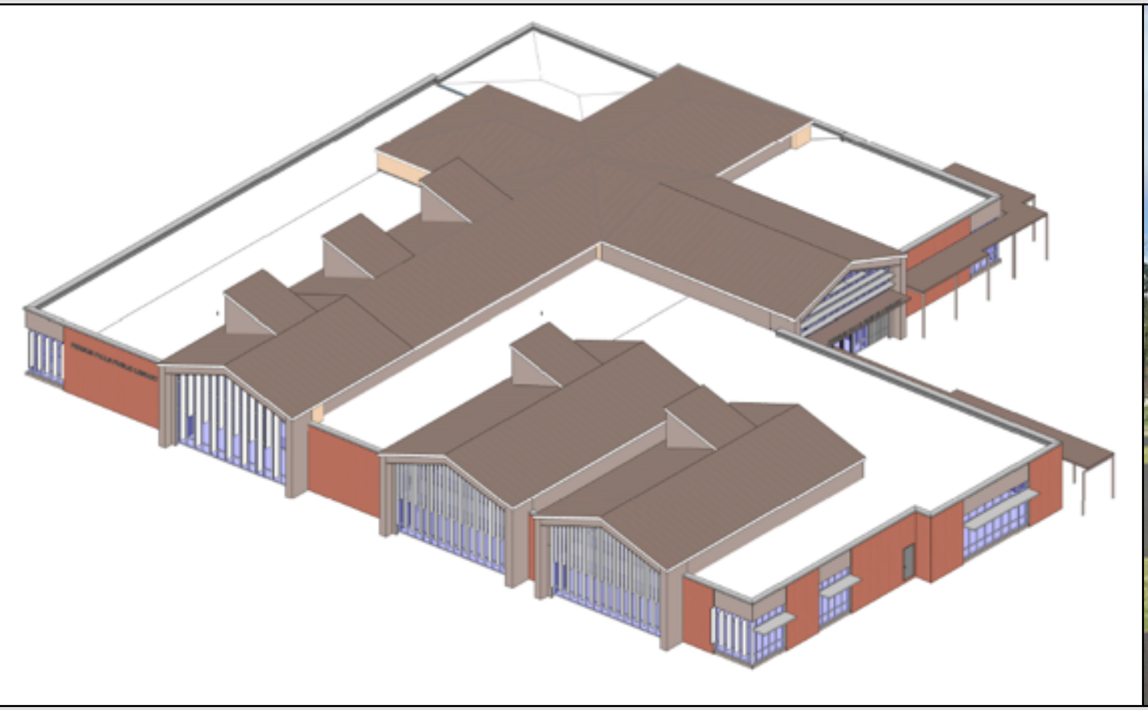
# Feasibility assessments for GSHP systems

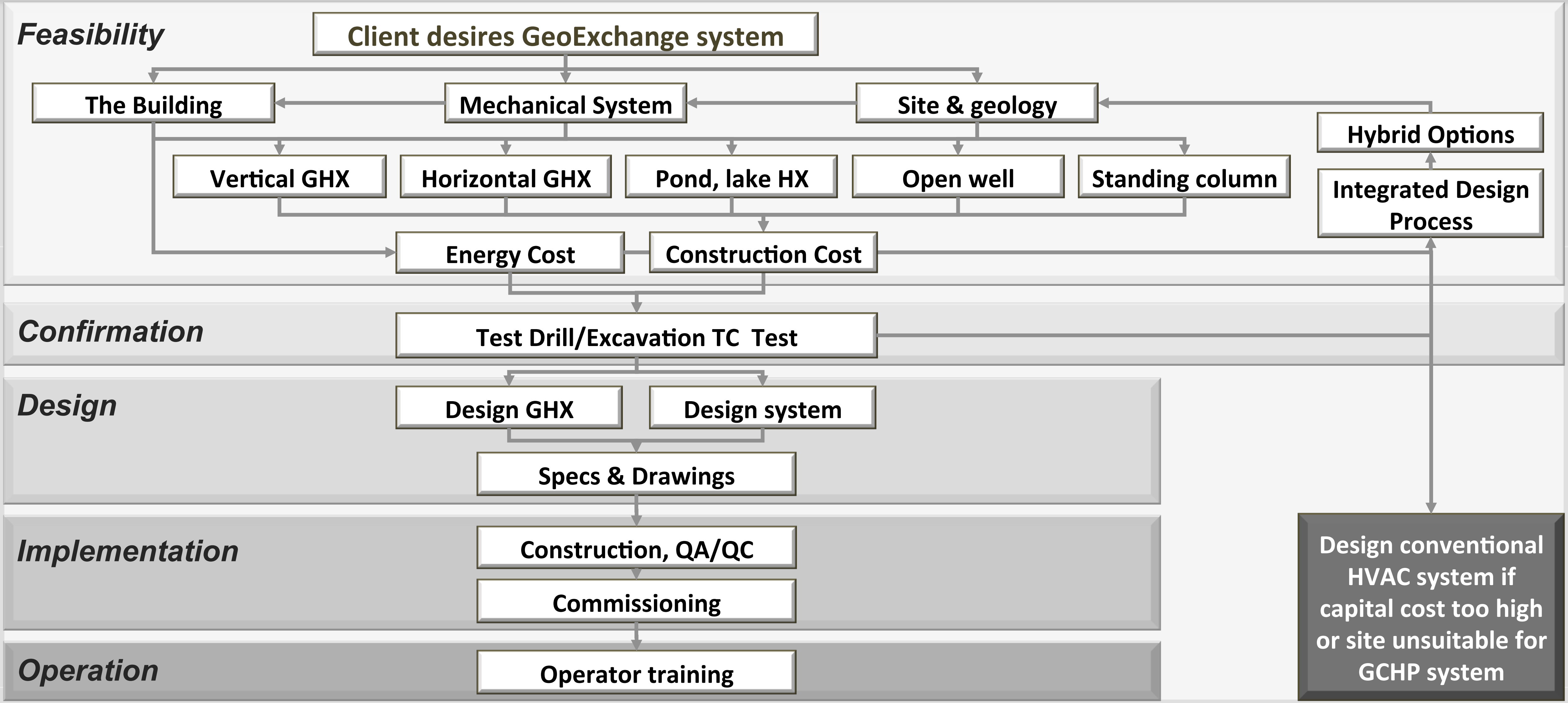
- **High percentage of potential GSHP projects scrapped at feasibility study stage. Rules of thumb are used to:**
  - Building peak loads are estimated – 400 $ft^2$ per ton or 20 Btu/hr per $ft^2$
  - Estimate amount of drilling required – 200' of borehole per ton
  - Land area required is based on 20' spacing between boreholes
  - GHX configuration is not considered
  - Accurate hourly energy models are seldom developed at feasibility stage and are seldom used to influence building heating and cooling loads
- **This results in a GSHP system that does not provide a good return on investment and potential GSHP project is discarded as too expensive**
- **Presentation reviews one project in Minnesota that was pulled back into consideration – a 24,000 $ft^2$ new library building**

# Preliminary "feasibility assessment"

- 24,000 square feet / 400 = 60 tons capacity required
- 60 tons X 200' = 12,000' of borehole
- 12,000' X $18 = $216,000
- Geothermal vault = $40,000
- **Total extra cost of GSHP system = $256,000**



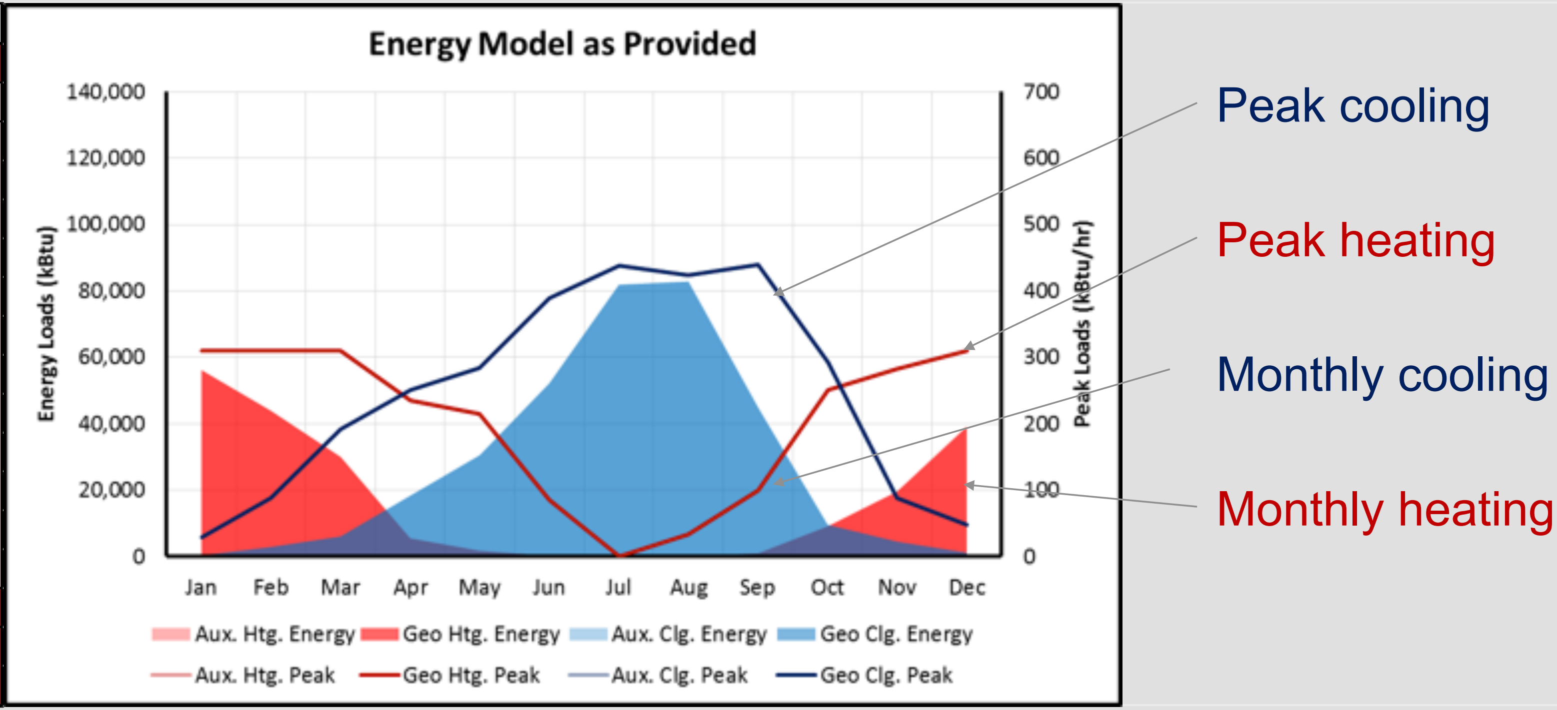
# Design process for a GCHP system



# Preliminary energy model

*Preliminary* energy model developed using Trane Trace 700 software created by ABC Engineering. Minor changes were made to the systems described in the model to allow it to run. Hourly loads converted to monthly energy loads (kBtu) and monthly peak loads (kBtu/hr)

| Energy Model as Provided | | | | |
|---|---|---|---|---|
| Month | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 416 | 29 | 56198 | 310 |
| Feb | 2926 | 88 | 43909 | 310 |
| Mar | 6093 | 192 | 30052 | 310 |
| Apr | 18365 | 251 | 5516 | 236 |
| May | 30564 | 284 | 1796 | 215 |
| Jun | 52232 | 389 | 228 | 85 |
| Jul | 81898 | 438 | 0 | 0 |
| Aug | 82856 | 424 | 58 | 34 |
| Sep | 44956 | 440 | 1013 | 100 |
| Oct | 9619 | 293 | 9132 | 252 |
| Nov | 4532 | 89 | 19641 | 283 |
| Dec | 1205 | 48 | 39172 | 310 |
| Annual | **335,661** | **440** | **206,716** | **310** |
| | Tons | 37 | Tons | 26 |
| | EFLH | 763 | EFLH | 668 |



# Occupancy schedule in energy model

Building occupancy schedules reviewed to reflect building use as accurately as possible. Current Library Director consulted to provide estimated occupancy schedule for the proposed building. Schedule input to energy model.

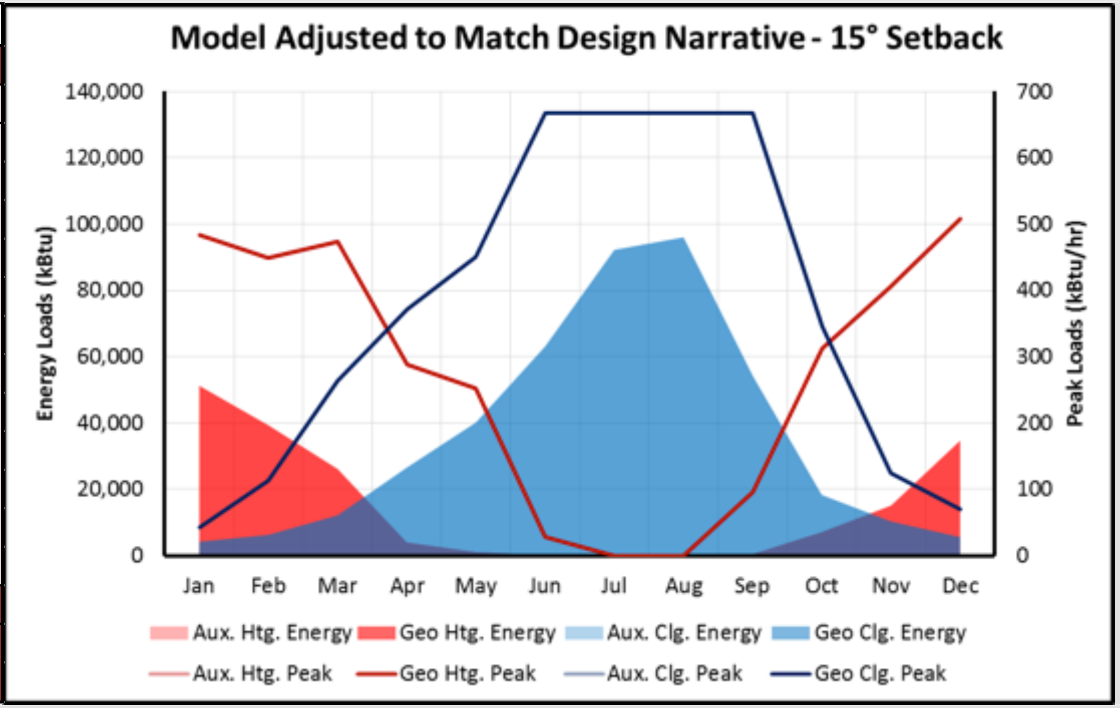
| | | September to May | | | | | | | | June to August | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max | 320 | Mon - Thurs | | Fri | | Sat | | Sun | | Mon - Thurs | | Fri | | Sat | | Sun | |
| Start Time | End Time | % | # | % | # | % | # | % | # | % | # | % | # | % | # | % | # |
| 0 | 1 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 1 | 2 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 2 | 3 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 3 | 4 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 4 | 5 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 5 | 6 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 6 | 7 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 7 | 8 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 8 | 9 | 1% | 3 | 1% | 3 | 1% | 3 | 0% | 0 | 1% | 3 | 1% | 3 | 1% | 3 | 0% | 0 |
| 9 | 10 | 5% | 16 | 5% | 16 | 5% | 16 | 0% | 0 | 5% | 16 | 5% | 16 | 5% | 16 | 0% | 0 |
| 10 | 11 | 10% | 32 | 10% | 32 | 10% | 32 | 0% | 0 | 10% | 32 | 10% | 32 | 10% | 32 | 0% | 0 |
| 11 | 12 | 15% | 48 | 20% | 64 | 12% | 38 | 0% | 0 | 20% | 64 | 20% | 64 | 12% | 38 | 0% | 0 |
| 12 | 13 | 12% | 38 | 15% | 48 | 14% | 45 | 0% | 0 | 15% | 48 | 15% | 48 | 14% | 45 | 0% | 0 |
| 13 | 14 | 10% | 32 | 12% | 38 | 16% | 51 | 0% | 0 | 12% | 38 | 12% | 38 | 16% | 51 | 0% | 0 |
| 14 | 15 | 10% | 32 | 10% | 32 | 14% | 45 | 0% | 0 | 10% | 32 | 10% | 32 | 14% | 45 | 0% | 0 |
| 15 | 16 | 12% | 38 | 15% | 48 | 12% | 38 | 0% | 0 | 15% | 48 | 15% | 48 | 12% | 38 | 0% | 0 |
| 16 | 17 | 15% | 48 | 20% | 64 | 0% | 1 | 0% | 0 | 20% | 64 | 20% | 64 | 0% | 1 | 0% | 0 |
| 17 | 18 | 18% | 58 | 25% | 80 | 0% | 0 | 0% | 0 | 25% | 80 | 25% | 80 | 0% | 0 | 0% | 0 |
| 18 | 19 | 15% | 48 | 1% | 3 | 0% | 0 | 0% | 0 | 15% | 48 | 1% | 3 | 0% | 0 | 0% | 0 |
| 19 | 20 | 10% | 32 | 0% | 0 | 0% | 0 | 0% | 0 | 12% | 38 | 0% | 0 | 0% | 0 | 0% | 0 |
| 20 | 21 | 1% | 3 | 0% | 0 | 0% | 0 | 0% | 0 | 8% | 26 | 0% | 0 | 0% | 0 | 0% | 0 |
| 21 | 22 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 22 | 23 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |
| 23 | 24 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% | 0 |

# Energy model changes to match design narrative - 15°F setback

Energy model adjusted to match design narrative as closely as possible. Design narrative includes 15°F night setback for heating and cooling from daytime setpoint.

**Model Adjusted to Match Narrative - 15° Setback**

| Month | Geo Cooling | | Geo Heating | |
|---|---|---|---|---|
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 4155 | 43 | 51214 | 484 |
| Feb | 6248 | 113 | 39271 | 448 |
| Mar | 12127 | 263 | 26095 | 474 |
| Apr | 26543 | 371 | 3939 | 288 |
| May | 40149 | 451 | 1066 | 252 |
| Jun | 63092 | 667 | 29 | 29 |
| Jul | 92197 | 667 | 0 | 0 |
| Aug | 95980 | 667 | 0 | 0 |
| Sep | 54203 | 667 | 431 | 96 |
| Oct | 18253 | 346 | 7081 | 313 |
| Nov | 10278 | 125 | 15067 | 405 |
| Dec | 5544 | 69 | 34659 | 507 |
| Annual | 428,768 | 667 | 178,852 | 507 |
| | Tons | 56 | Tons | 42 |
| | EFLH | 643 | EFLH | 353 |

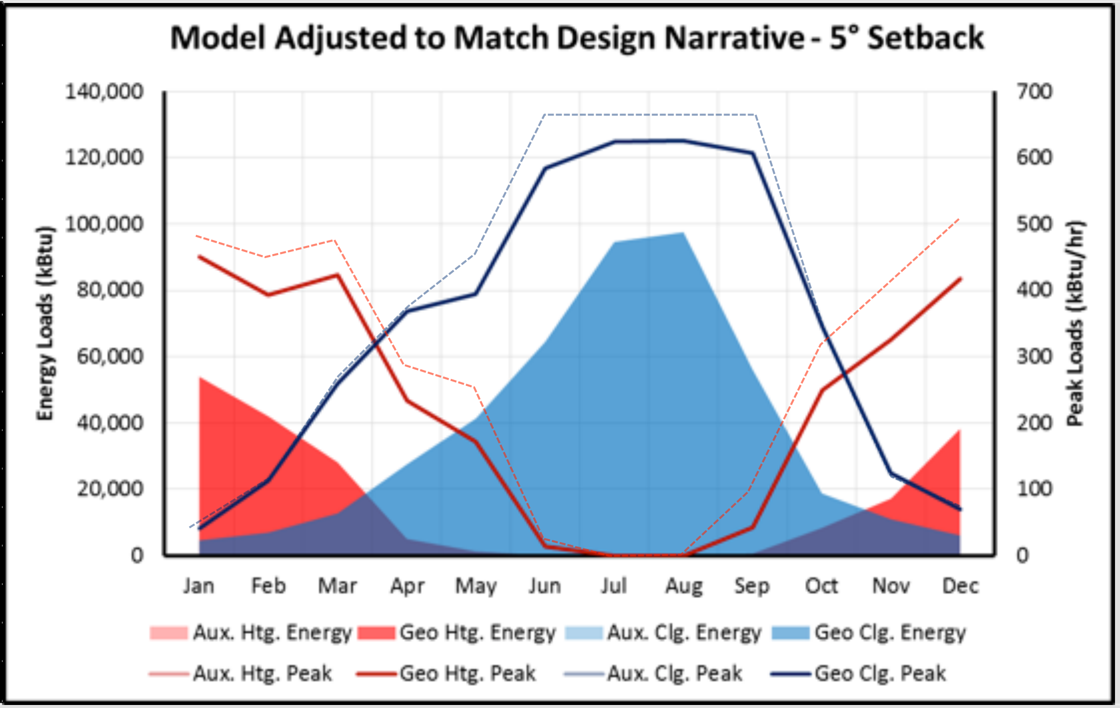


# Night setback reduced to 5°F

Night setback adjusted to 5°F. Peak cooling load drops from 667 to 625 kBtu/hr and peak heating load drops from 507 to 450 kBtu/hr.

**Model Adjusted to Match Narrative - 5° Setback**

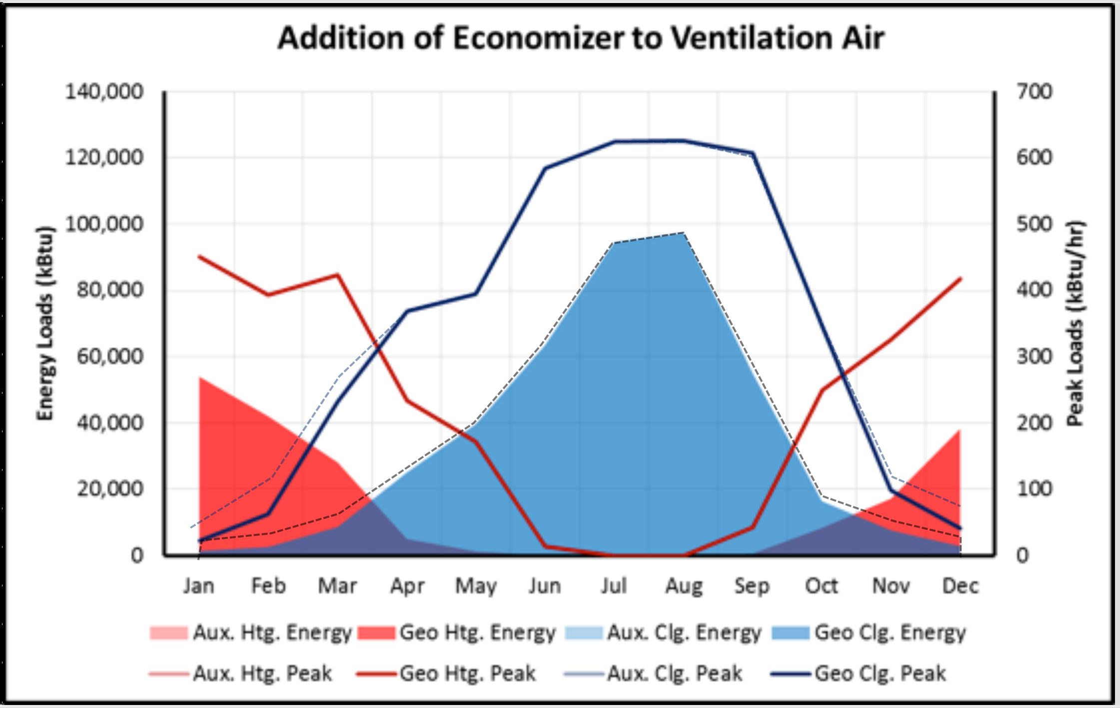
| Month | Geo Cooling | | Geo Heating | |
|---|---|---|---|---|
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 4569 | 41 | 53926 | 450 |
| Feb | 6935 | 113 | 41942 | 392 |
| Mar | 12710 | 259 | 28063 | 424 |
| Apr | 27485 | 369 | 4990 | 234 |
| May | 41345 | 395 | 1229 | 171 |
| Jun | 64436 | 584 | 39 | 13 |
| Jul | 94593 | 624 | 0 | 0 |
| Aug | 97517 | 625 | 0 | 0 |
| Sep | 56003 | 607 | 572 | 42 |
| Oct | 18736 | 346 | 8315 | 249 |
| Nov | 10942 | 125 | 17173 | 326 |
| Dec | 6054 | 69 | 38211 | 417 |
| Annual | **441,324** | **625** | **194,460** | **450** |
| | Tons | 52 | Tons | 37 |
| | EFLH | 706 | EFLH | 432 |



# Economizer added to heat recovery ventilation system

Economizer dampers added to heat recovery ventilation system to take advantage of cool outdoor air to provide cooling when possible. Peak cooling & monthly energy loads reduced in winter and shoulder seasons.

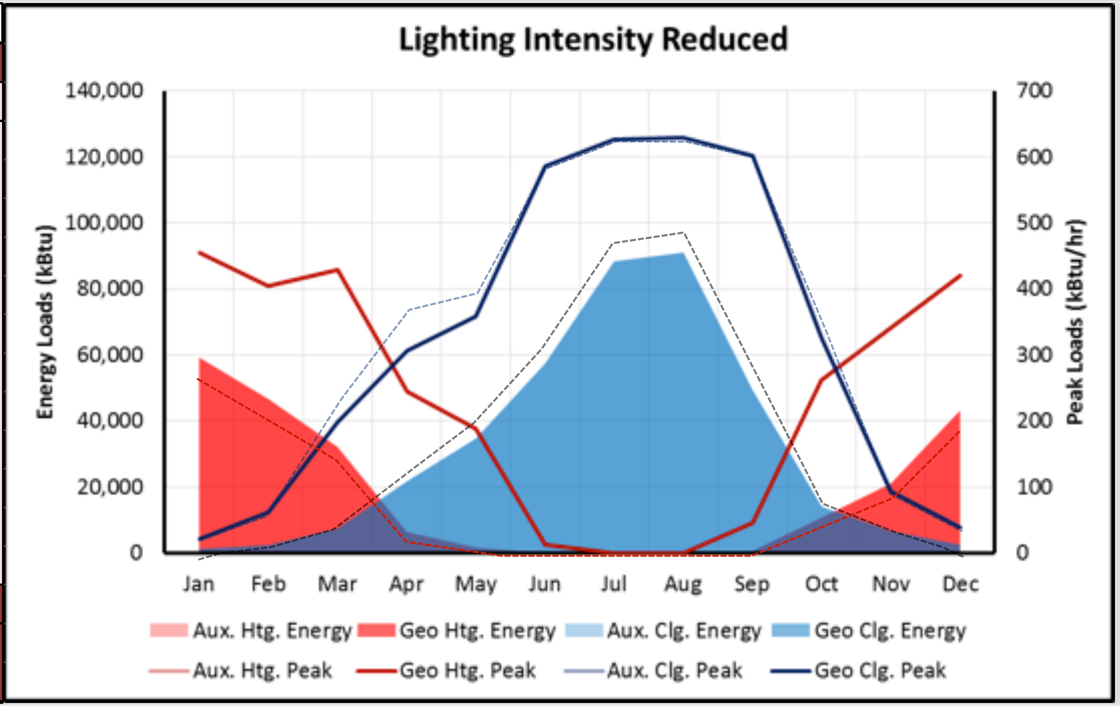
| Addition of Economizer to Ventilation Air | | | | |
|---|---|---|---|---|
| Month | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 1388 | 22 | 53926 | 450 |
| Feb | 2594 | 63 | 41942 | 392 |
| Mar | 8627 | 232 | 28063 | 424 |
| Apr | 25037 | 369 | 4990 | 234 |
| May | 39640 | 395 | 1229 | 171 |
| Jun | 63482 | 584 | 39 | 13 |
| Jul | 94499 | 624 | 0 | 0 |
| Aug | 97462 | 625 | 0 | 0 |
| Sep | 54938 | 607 | 572 | 42 |
| Oct | 16393 | 346 | 8315 | 249 |
| Nov | 7589 | 99 | 17173 | 326 |
| Dec | 2846 | 41 | 38211 | 417 |
| Annual | 414,495 | 625 | 194,459 | 450 |
| | Tons | 52 | Tons | 37 |
| | EFLH | 663 | EFLH | 432 |



# Lighting intensity reduced and CO2 sensors added to fresh air supply

Reducing lighting intensity reduced using occupancy sensors and daylighting sensors reduces annual energy consumption from lighting (but doesn't reduce peak gains). CO2 sensors used to control fresh air supply to facility reduces heating and cooling energy loads. NOTE that reduced lighting gains *increases* heat required from GCHP system.

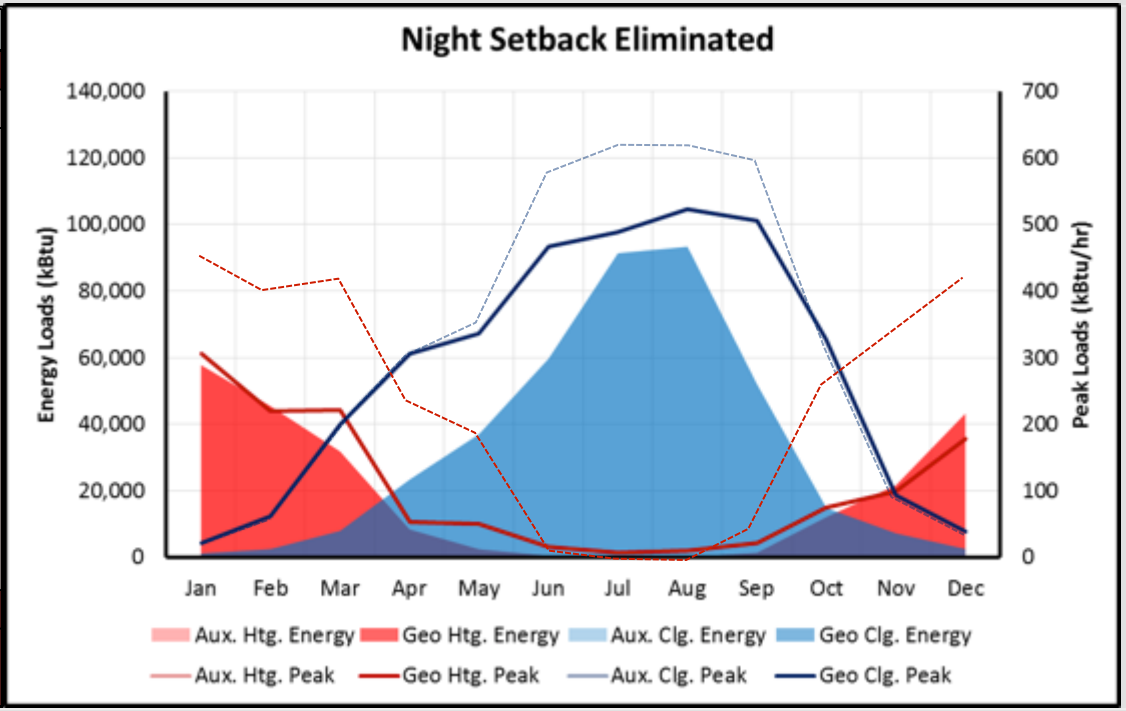
| Lighying Intensity Reduced | | | | |
|---|---|---|---|---|
| Month | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 1275 | 22 | 59212 | 455 |
| Feb | 2434 | 61 | 46633 | 405 |
| Mar | 7437 | 198 | 32107 | 429 |
| Apr | 21683 | 306 | 6390 | 244 |
| May | 34720 | 358 | 1678 | 188 |
| Jun | 57393 | 587 | 49 | 13 |
| Jul | 88349 | 627 | 0 | 0 |
| Aug | 91023 | 628 | 0 | 0 |
| Sep | 49366 | 602 | 658 | 46 |
| Oct | 14060 | 327 | 10751 | 262 |
| Nov | 6633 | 93 | 21079 | 341 |
| Dec | 2505 | 38 | 43174 | 420 |
| Annual | 376,879 | 628 | 221,730 | 455 |
| | Tons | 52 | Tons | 38 |
| | EFLH | 600 | EFLH | 487 |



# Night setback eliminated in energy model

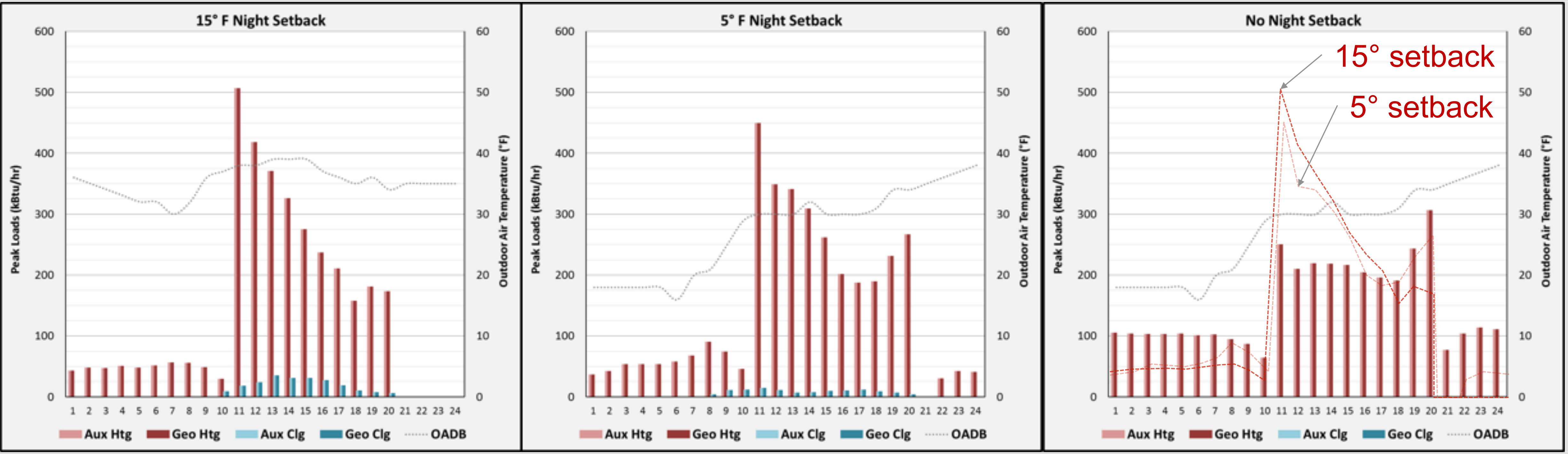
Warming or cooling a building to reach daytime setpoints forces full heat pump capacity for an extended time, especially to help mass in building to regain temperature. This greatly increases peak heat extraction from and heat rejection to the GHX during morning recovery period.

| Night Setback Eliminated | | | | |
|---|---|---|---|---|
| Month | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 1191 | 22 | 57760 | 307 |
| Feb | 2515 | 61 | 45430 | 219 |
| Mar | 7956 | 199 | 31817 | 222 |
| Apr | 23359 | 306 | 8401 | 53 |
| May | 37031 | 337 | 2467 | 50 |
| Jun | 59677 | 466 | 485 | 16 |
| Jul | 91371 | 489 | 28 | 8 |
| Aug | 93328 | 522 | 77 | 10 |
| Sep | 52033 | 506 | 1387 | 22 |
| Oct | 14836 | 327 | 12125 | 74 |
| Nov | 7236 | 93 | 21661 | 99 |
| Dec | 2556 | 40 | 43202 | 178 |
| Annual | 393,088 | 522 | 224,840 | 307 |
| | Tons | 44 | Tons | 26 |
| | EFLH | 753 | EFLH | 733 |



# Impact of night setback on design day heating load profile

Heating the building after allowing the temperature to drop creates a peak heating requirement…and peak heat extraction from the GHX for several hours. Overnight energy loads increased to maintain temperature, but overall effect on energy cost is not large.



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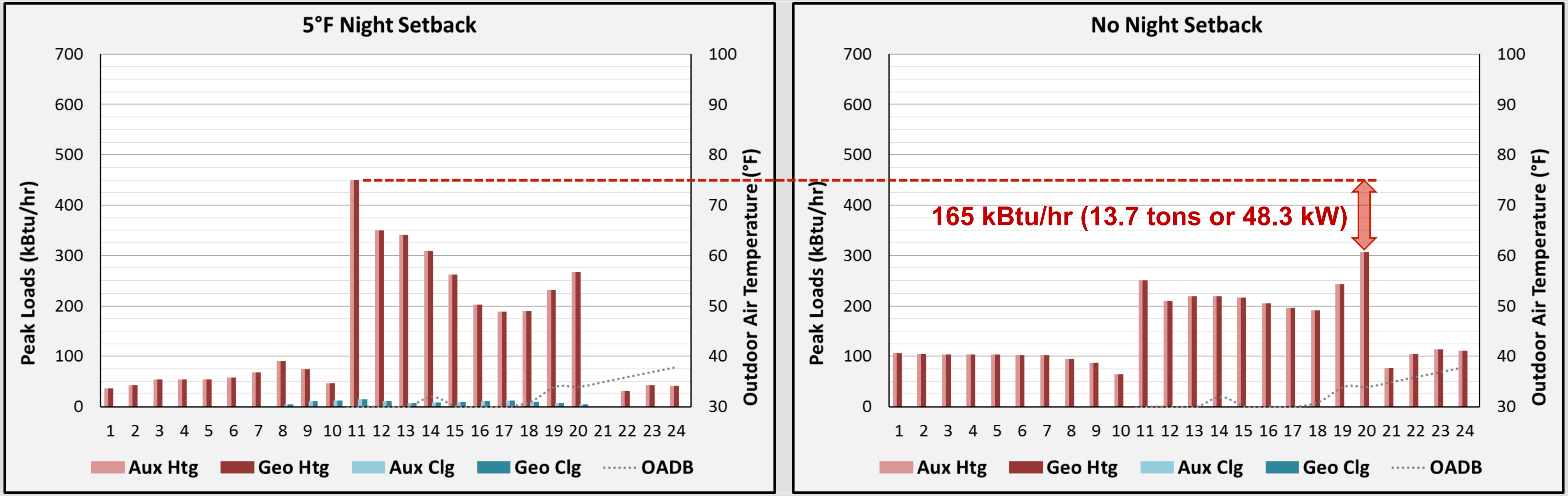
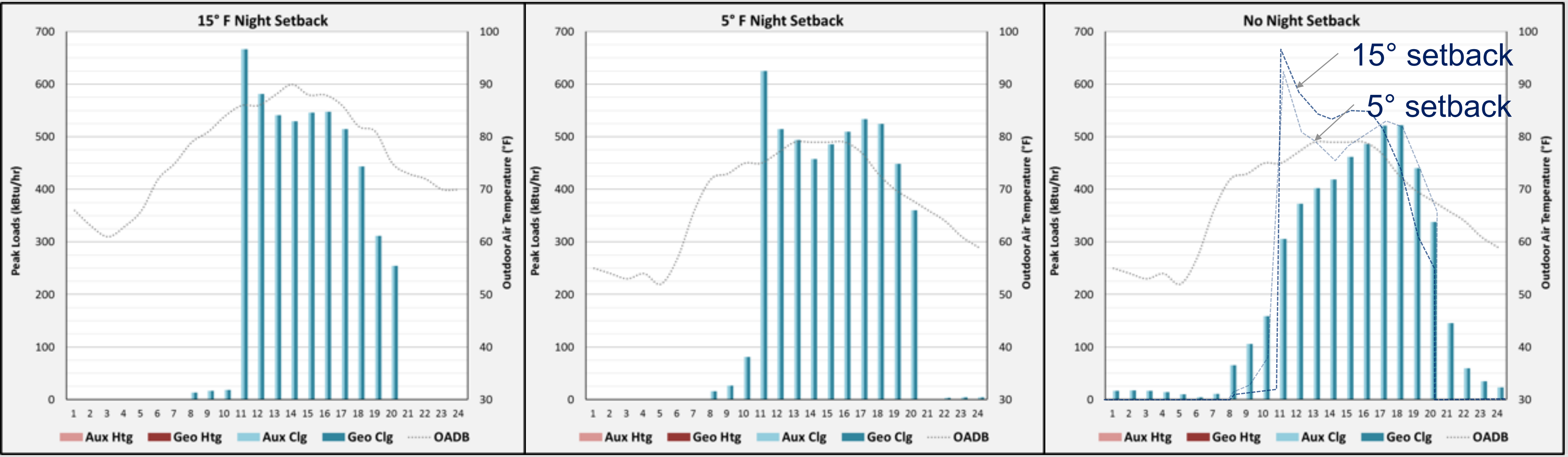


# Impact of night setback on design day cooling load profile

Cooling the building to reach setpoint when the building is occupied in the morning significantly increases peak heat rejection to the GHX. Note that the load profiles only indicate the building loads…compressor loads add approximately 20% more heat to the GHX.



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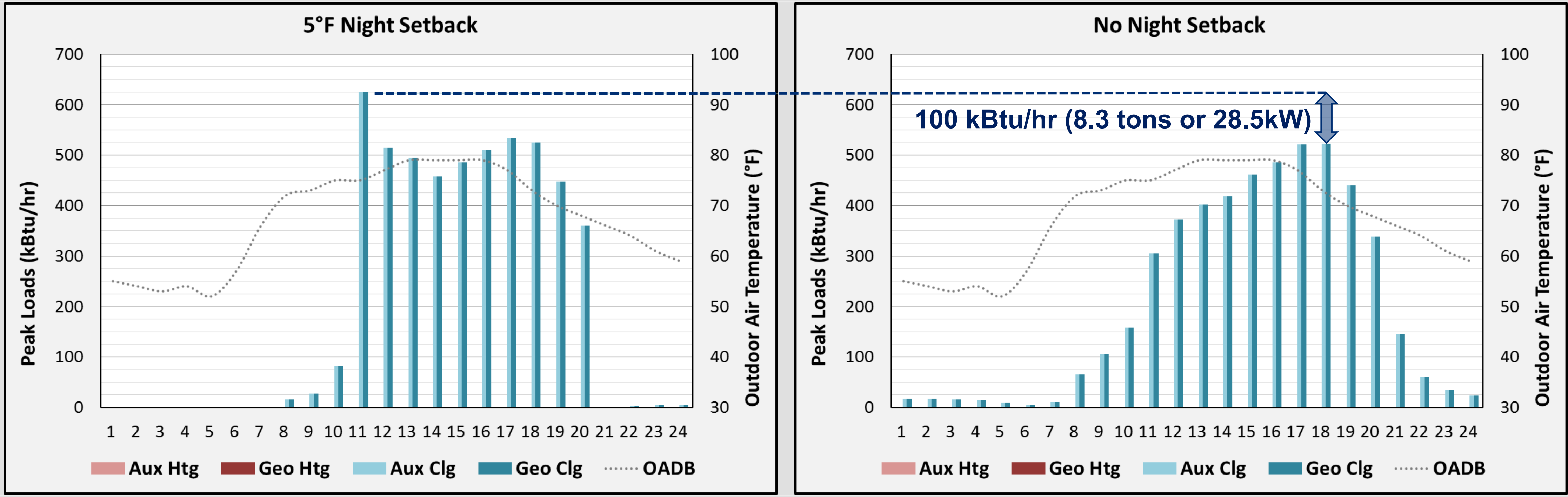
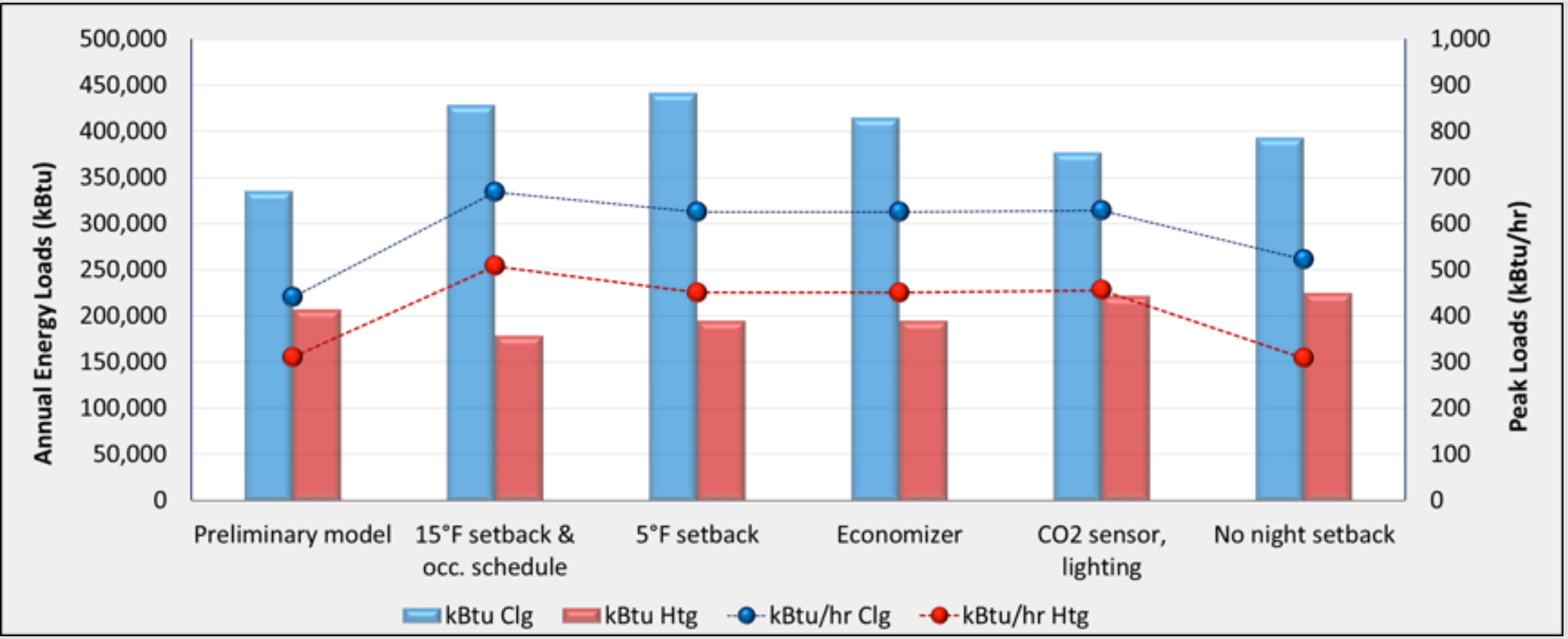


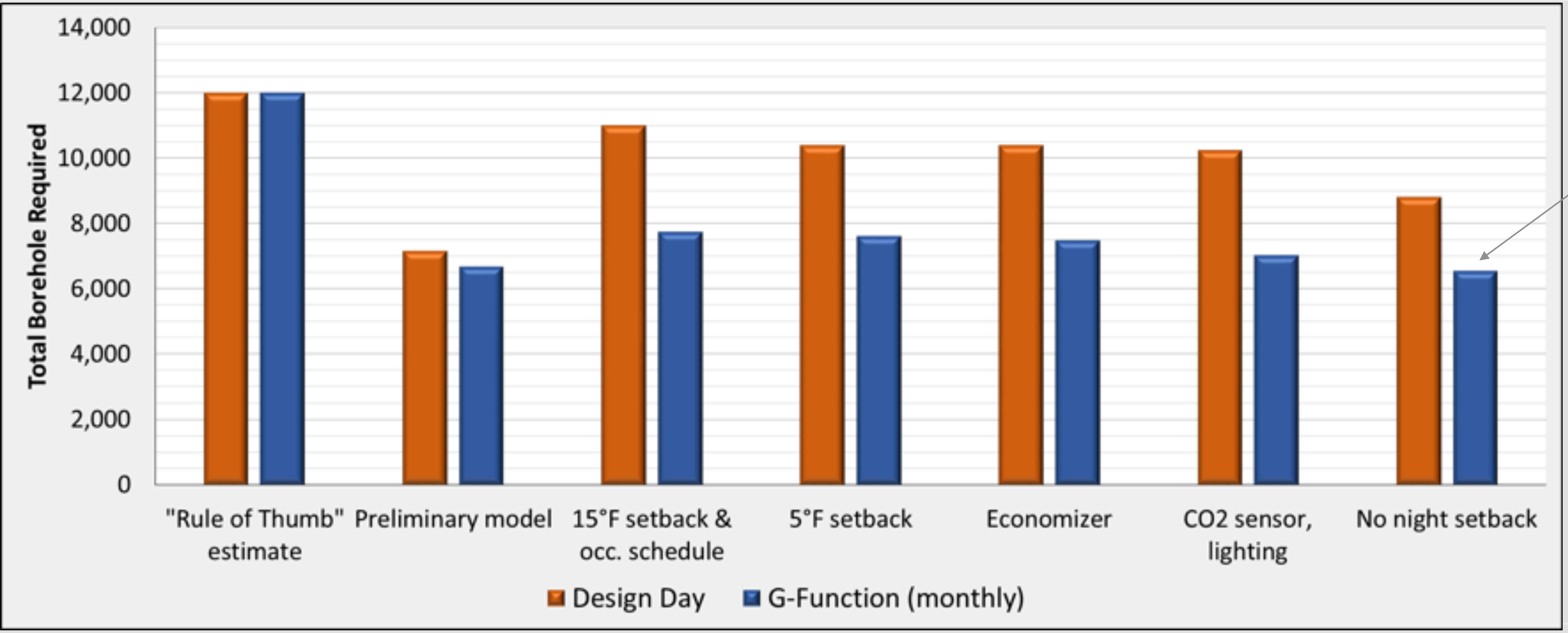
# Energy model iterations

Each iteration of the energy model was changed in an attempt to reduce the peak or annual cooling loads and balance energy loads to the GHX.



# Impact of energy model iterations on GHX size

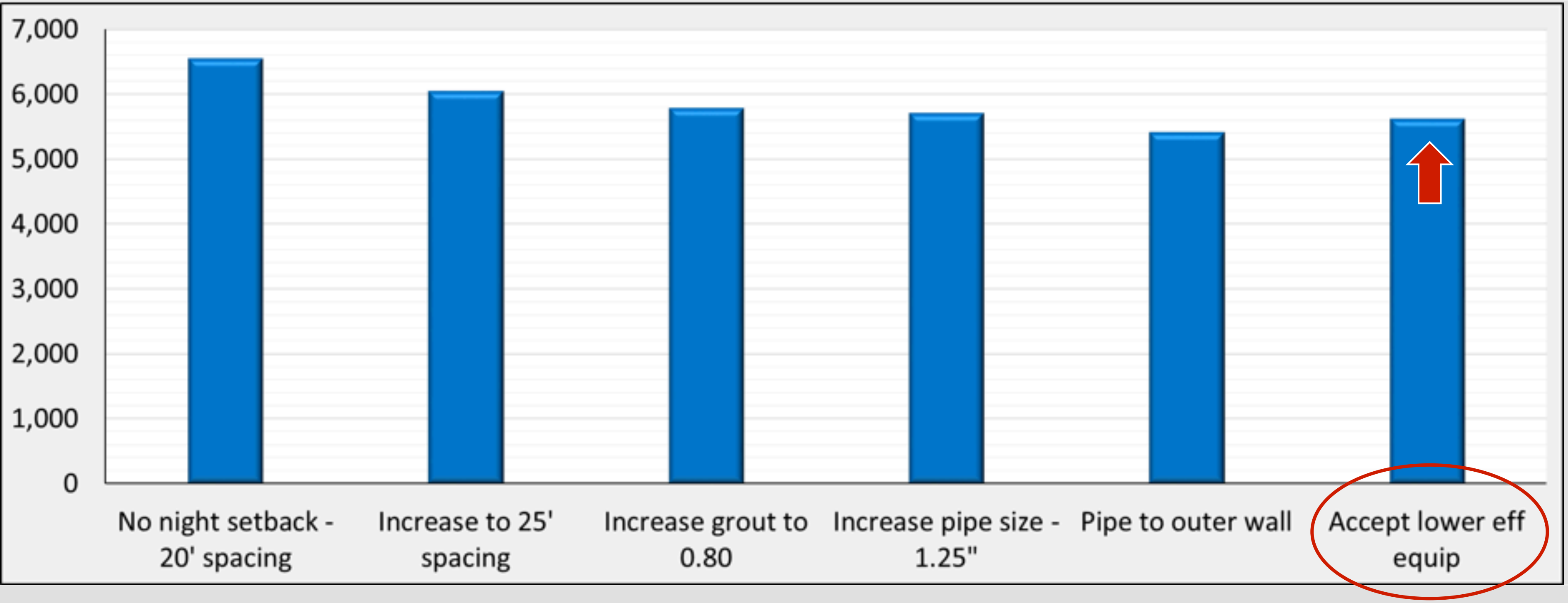
GHX modeling software was used to calculate the size of GHX required for this project based on the successive energy models. Two commonly used GHX modeling algorithms were used to determine the total amount of borehole. For larger commercial projects the G-function algorithms are considered more accurate.




Final energy model used to refine GHX layout and borehole configuration

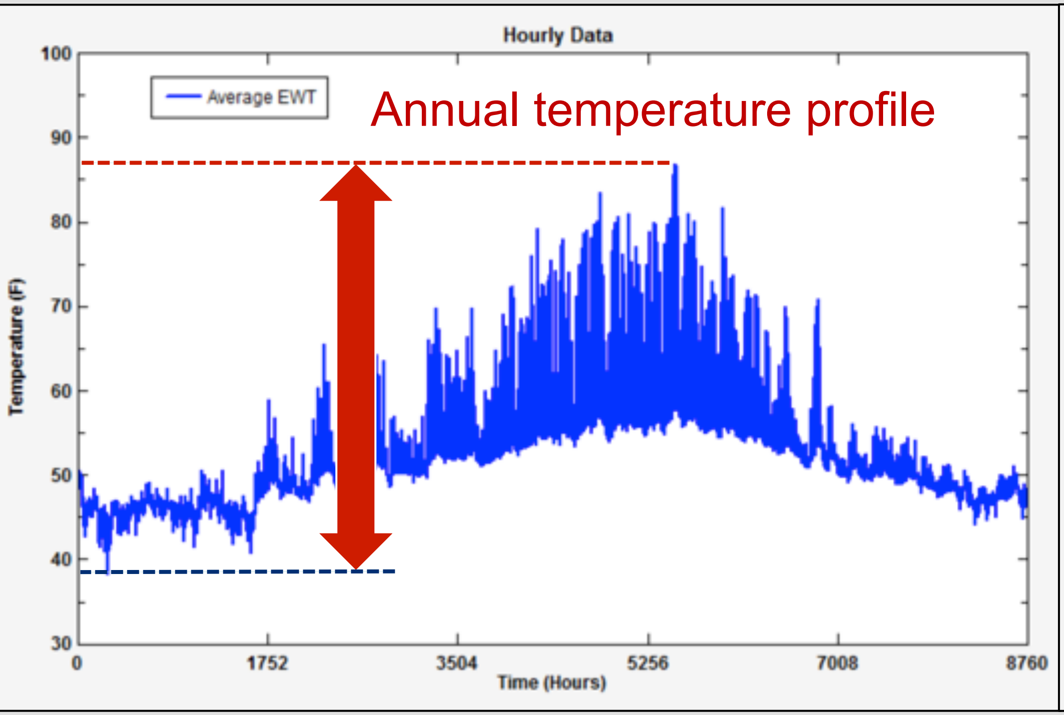
# Changes to GHX layout and borehole configuration affect borehole length

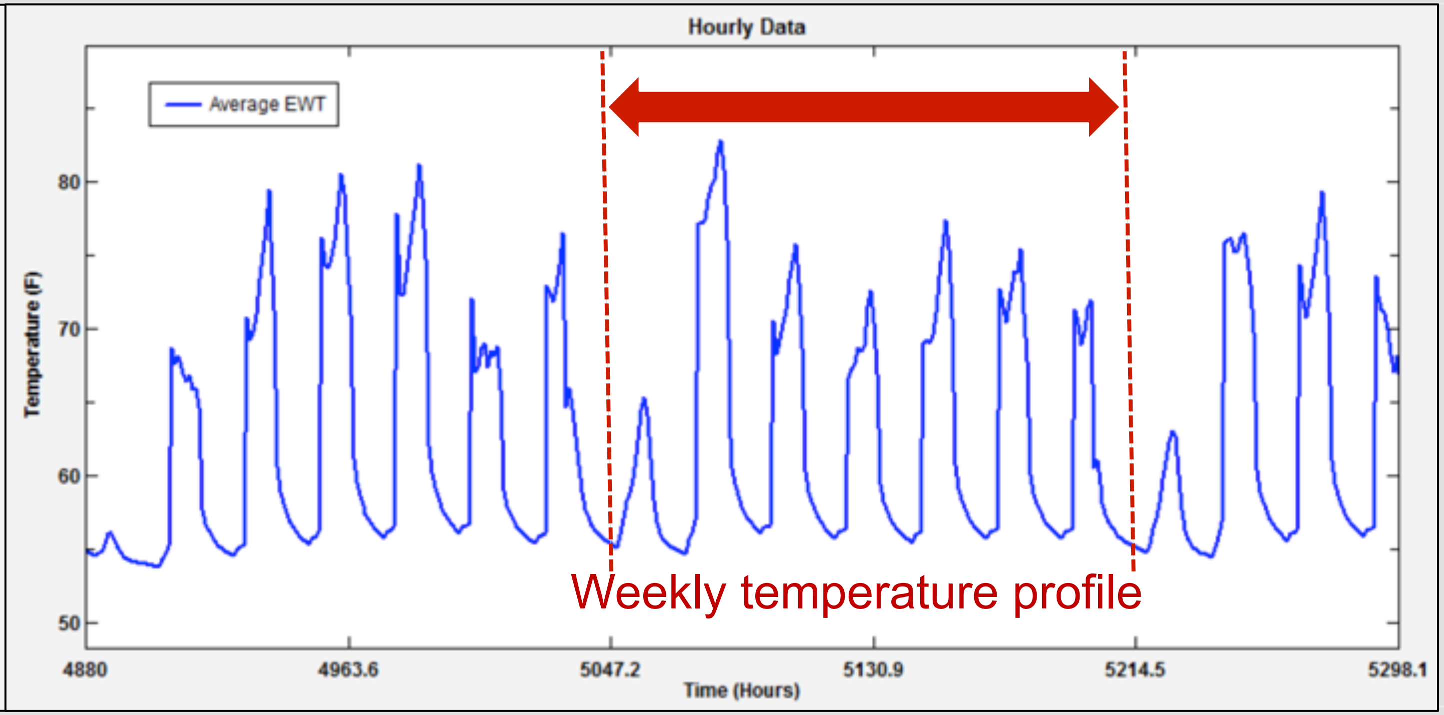
The final iteration of the energy model was used to refine the GHX layout and borehole configuration to further reduce the total amount of borehole required. Note that allowing less efficient heat pump equipment on a cooling dominant building will *increase* the amount of drilling required.



# GHX model using hourly loads

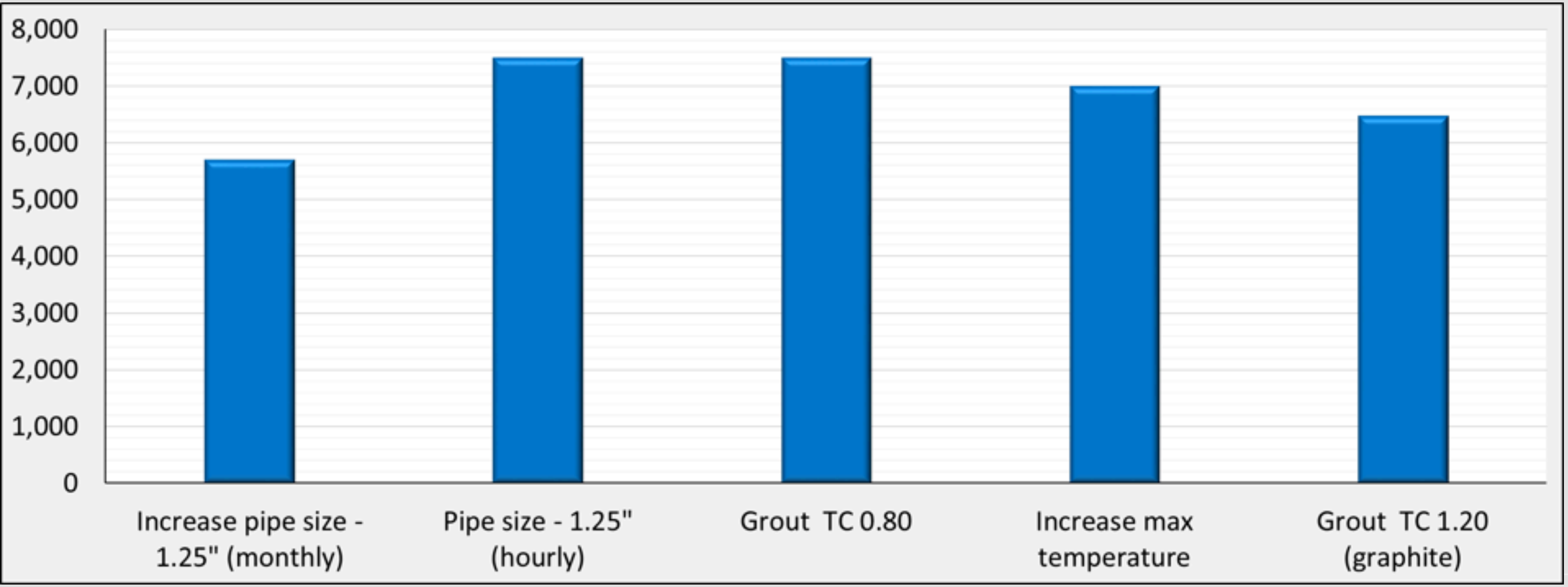
Hourly energy model loads provide greater detail in how the GHX will perform. Monitoring the GHX allows the building operator to determine if the system is operating as designed and helps validate the design process.



# GHX model using hourly loads

Hourly energy model loads provides more detailed information to calculate the GHX more accurately. Final design is typically based on information from test borehole log, results from thermal conductivity test, estimated construction cost (based on discussions with local drilling contractors) and land area constraints.



# Geological information

Local water well logs and discussions with GHX drilling contractors indicated that a borehole depth of 200’ to 275’ would be the most cost-effective depth for this project. Tables were used to estimate thermal properties of the soil based on the drill logs to calculate the borehole required.

**Well Name**

| Township | Range | Dir | Section | Subsections | Elevation |
|---|---|---|---|---|---|
| 132 | 43 | W | 3 | BABBDA | 1182 ft. |
| | | | | Elevation Method | 7.5 minute topographic map (+/- 5 feet) |

**Well Address**

MN

| Geological Material | Color | Hardness | From | To |
|---|---|---|---|---|
| FILL & SAND & BOULDERS | | | 0 | 15 |
| SAND & BOULDERS | BROWN | | 15 | 20 |
| CLAY & SAND STREAKS | BLUE | | 20 | 28 |
| CLAY WITH BOULDERS | BLUE | | 28 | 35 |
| CLAY & SAND STREAKS | BLUE | | 35 | 44 |
| MED. SAND & COARSE GRAVEL | BROWN | | 44 | 50 |
| CLAY WITH MED. FINE SAND STREAKS | GRAY | | 50 | 70 |
| CLAY WITH BOULDERS | GRAY | | 70 | 74 |
| CLAY | GRAY | HARD | 74 | 93 |
| SANDY CLAY WITH BOULDERS | YELLOW | | 93 | 130 |
| FINE SILTY SAND CLAY STREAKS | | | 130 | 198 |
| SANDY CLAY | BLUE | | 198 | 209 |
| SANDY CLAY WITH BOULDERS | | | 209 | 211 |
| SAND WITH CLAY STREAKS | | | 211 | 215 |
| COARSE SAND & LOOSE GRAVEL | | | 215 | 227 |
| CLAY | GRAY | HARD | 227 | 230 |
| CLAY WITH GRAVEL STREAK | GRAY | | 230 | 235 |
| CLAY WITH BOULDERS | GRAY | | 235 | 237 |
| SAND WITH CLAY STREAKS | | | 237 | 240 |
| CLAY | GRAY | | 240 | 257 |

| Well Depth | Depth Completed | Date Well Completed |
|---|---|---|
| 257 ft. | 257 ft. | 04/30/1971 |

**Drilling Method** --

**Drilling Fluid** --

**Well Hydrofractured?** ☐ Yes ☐ No
From Ft. to Ft.

**Use** Monitor well

**Casing Type** **Joint** No Information **Drive Shoe?** ☐ Yes ☐ No **Above/Below** ft.

**Casing Diameter** **Weight** **Hole Diameter**

**Open Hole** from ft. to ft.

**Screen** **Make** **Type**

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

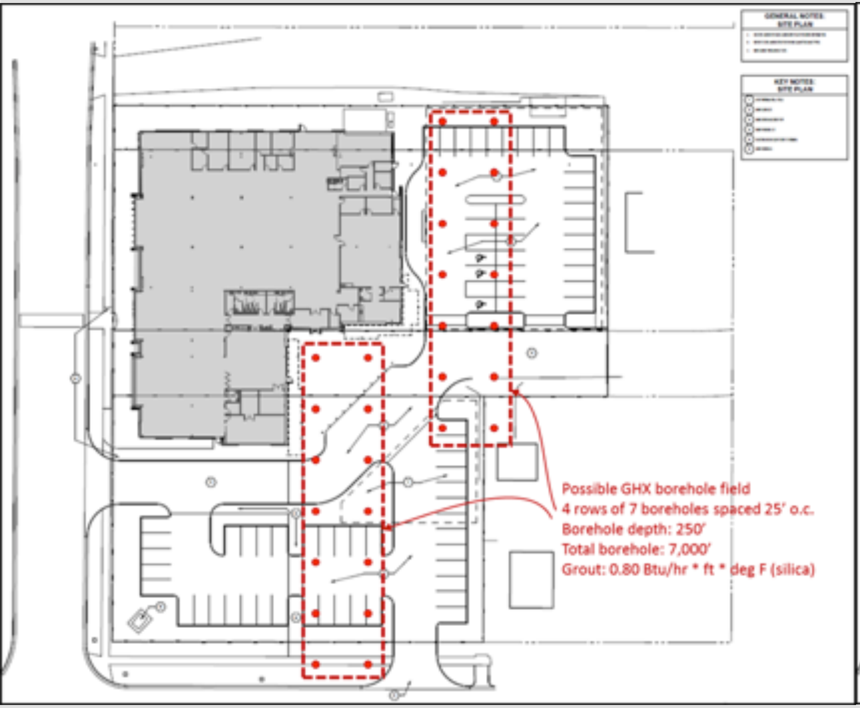
**Static Water Level**
ft. from Date Measured

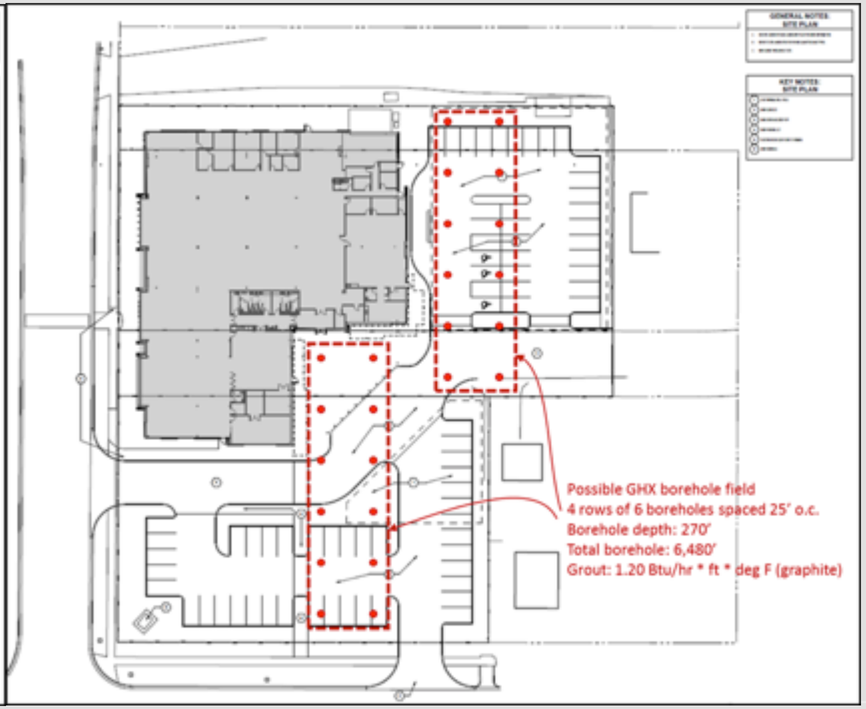
**PUMPING LEVEL (below land surface)**
ft. after hrs. pumping g.p.m.

**Well Head Completion**
Pitless adapter manufacturer Model
☐ Casing Protection ☐ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

# Preliminary GHX layout on site

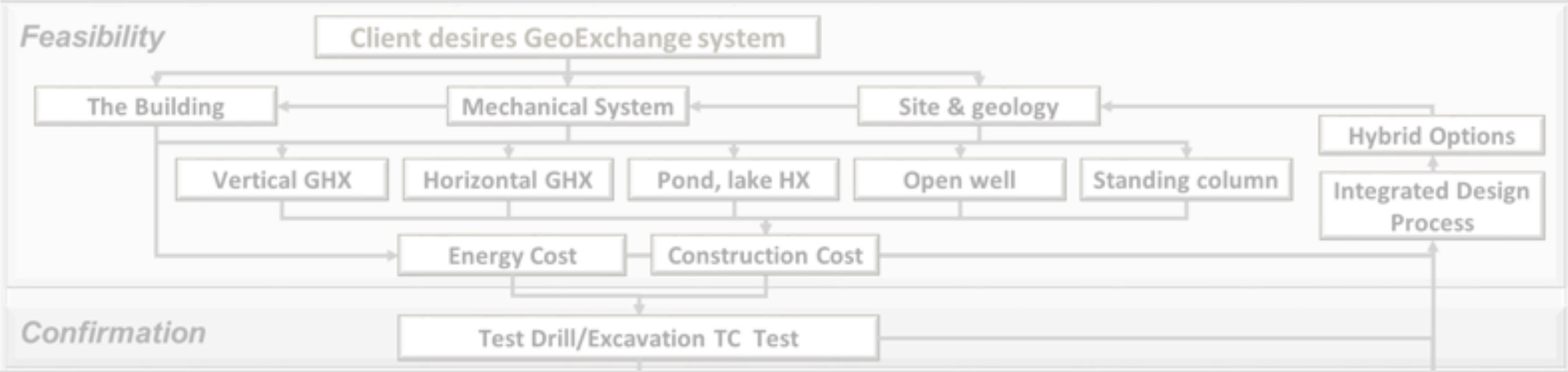
Hourly energy model loads provides more detailed information to calculate the GHX more accurately. Final design is typically based on information from test borehole log, results from thermal conductivity test, estimated construction cost (based on discussions with local drilling contractors) and land area constraints.



# From feasibility to design & implementation

The initial report estimated the approximate cost of installing a GSHP system in the Library. Soil properties were estimated, an hourly energy model was created, and a GHX model was created based on the initial findings. The estimated cost of installing a GHX was $105,000. The next step is detailed design and implementation.




# Initial & updated energy load profile

Several iterations of an hourly energy model were developed to determine the feasibility of installing a GSHP system. As building plans finalized, building occupancy schedules were refined and mechanical system designs were developed, initial energy model was updated based on most recent information.

| Night Setback Eliminated | | | | |
|---|---|---|---|---|
| Month | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 1191 | 22 | 57760 | 307 |
| Feb | 2515 | 61 | 45430 | 219 |
| Mar | 7956 | 199 | 31817 | 222 |
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| Oct | 14836 | 327 | 12125 | 74 |
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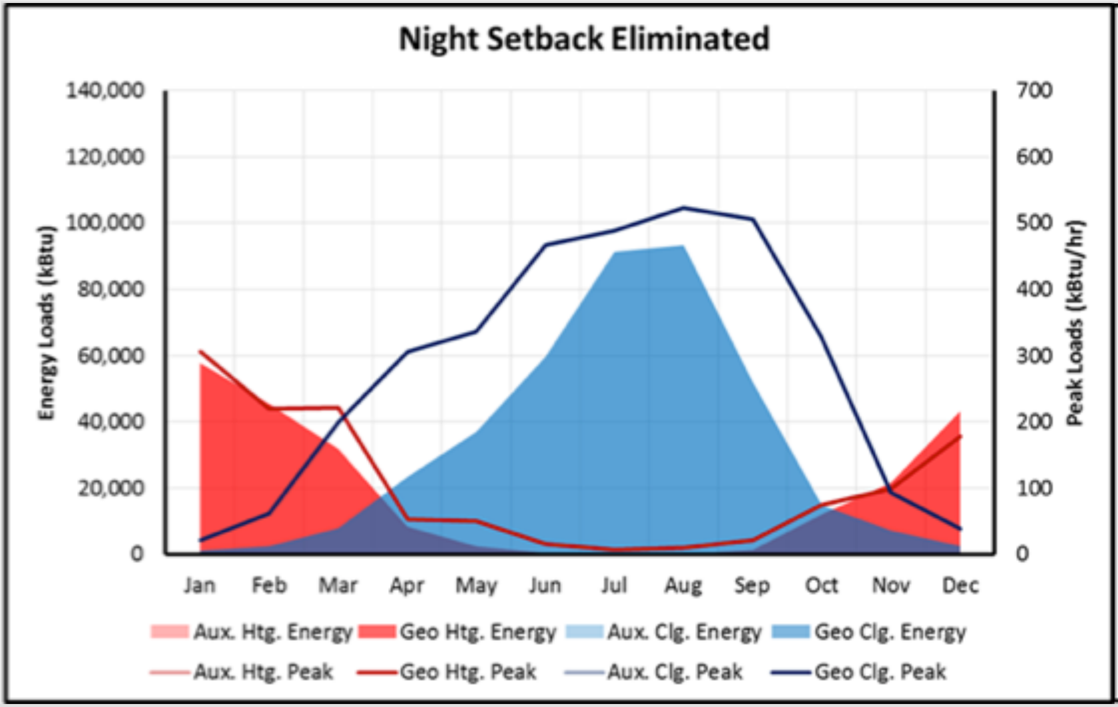
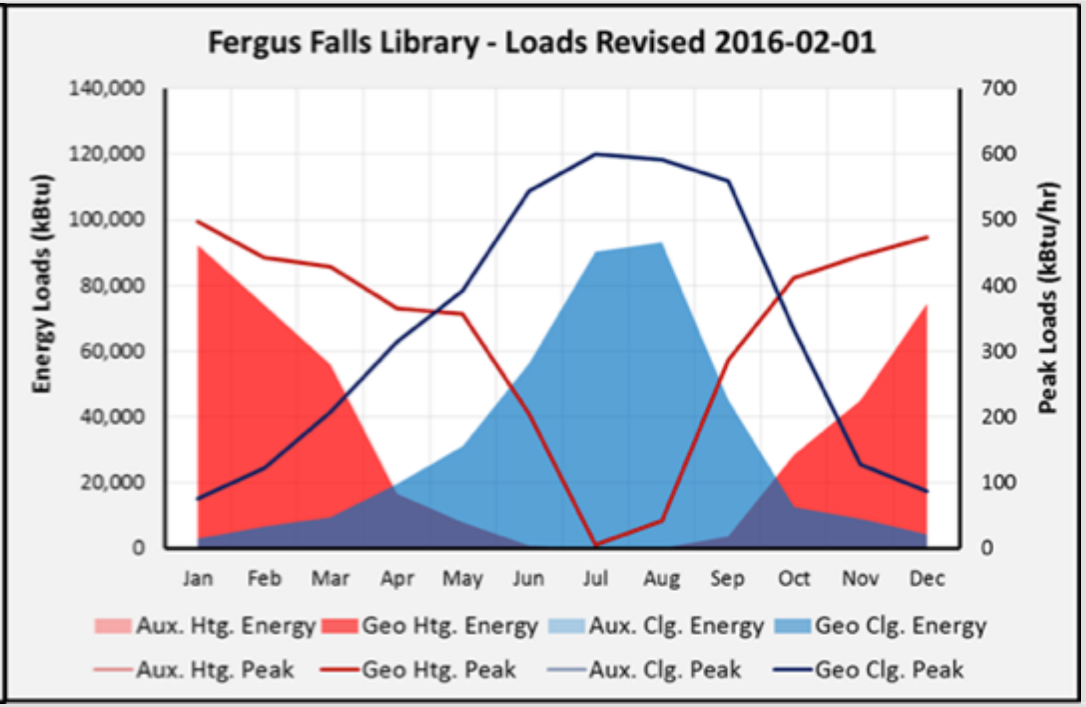
| Annual | 393,088 | 522 | 224,840 | 307 |
| | Tons | 44 | Tons | 26 |
| | EFLH | 753 | EFLH | 733 |

| Library - Loads Revised 2016-02-01 | | | | |
|---|---|---|---|---|
| | Geo Cooling | | Geo Heating | |
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 2944 | 76 | 92228 | 498 |
| Feb | 6618 | 121 | 74103 | 442 |
| Mar | 9465 | 208 | 55901 | 428 |
| Apr | 19538 | 315 | 16613 | 364 |
| May | 31168 | 392 | 7856 | 356 |
| Jun | 56369 | 544 | 825 | 205 |
| Jul | 90300 | 600 | 14 | 5 |
| Aug | 93134 | 592 | 73 | 42 |
| Sep | 45318 | 560 | 3579 | 286 |
| Oct | 12517 | 333 | 28559 | 412 |
| Nov | 8985 | 128 | 45079 | 445 |
| Dec | 4250 | 87 | 74467 | 473 |
| | 380,606 | 600 | 399,297 | 498 |
| | Tons | 50 | Tons | 41 |
| | EFLH | 634 | EFLH | 802 |

# Initial & updated energy load profile

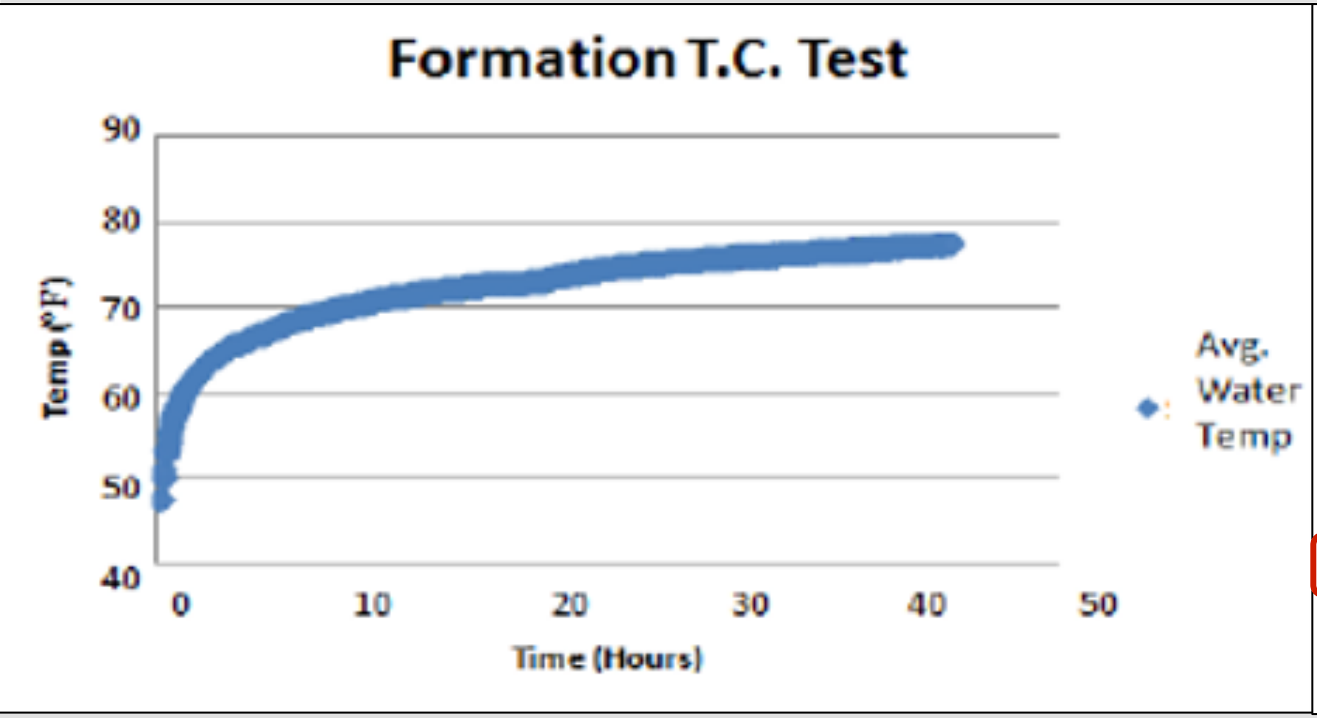
Graphic representation of building energy load profile. Cooling loads show a small increase, but heating loads have increased significantly. The loads are more balanced than initially estimated.



# Soil properties tested – thermal conductivity

A thermal conductivity test was completed in September, 2015. Calculated thermal conductivity is 0.971 Btu/hr * ft * °F. The conductivity seems reasonable based on the drilling log.




| | |
|---|---|
| Circulating Fluid | Water |
| Starting Borehole Temp. | 48.7° F |
| Avg. Volts | 239.3 |
| Avg. Amps | 11.26 |
| Avg. Power (Watts) | 2695.53 |
| Avg. Heat Injected (BTU/hour) | 9197.53 |
| Test Duration (Hours) | 48 |
| Test Period Analyzed | 1.00-48.00 |
| Slope | 2.513 |
| Calculated Thermal Conductivity | 0.971 Btu/hr-ft-°F |
| Estimated Thermal Diffusivity | 1.17 ft^2/day |

# Soil properties tested – thermal diffusivity

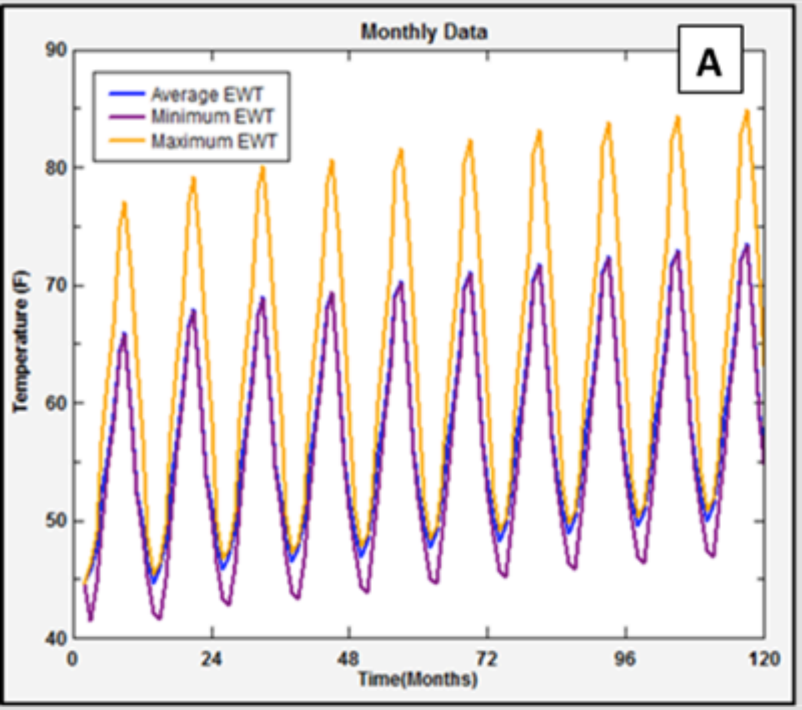
Thermal diffusivity is estimated based on the layers of clay, silt, sands and gravel found in the formation. Reviewing thermal diffusivity charts and calculating a weighted average shows a lower result: 0.74 $ft^2$ / day (used to calculate updated GHX field)

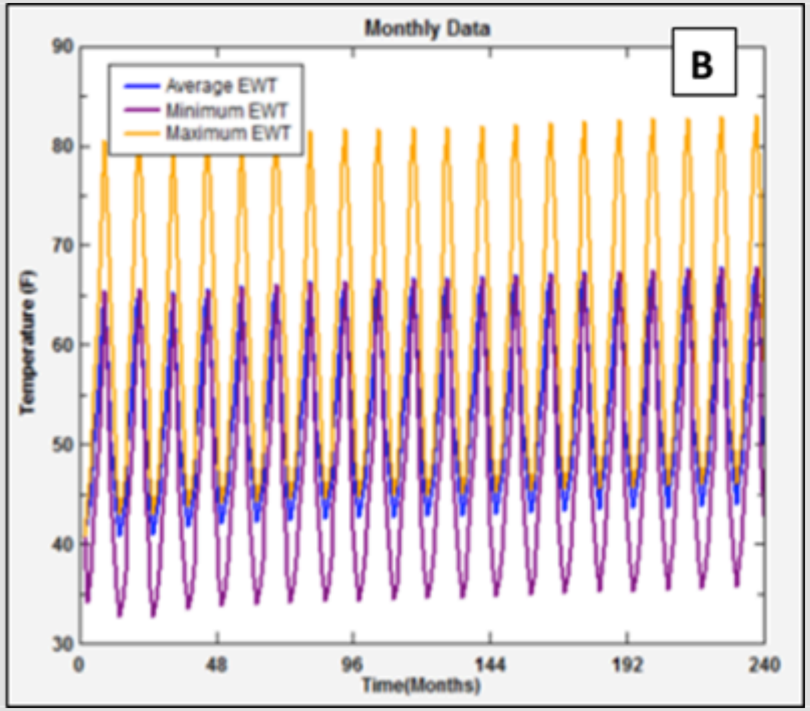
| Footage | | Net | Est'd Diff | Weighted | Lithology Descriptio |
|---|---|---|---|---|---|
| Start | End | | ft²/day | Average | |
| 0.0 | 8.0 | 8.0 | 0.70 | 0.0187 | Fill |
| 8.0 | 15.0 | 7.0 | 0.60 | 0.0140 | Brown Clay |
| 15.0 | 40.0 | 25.0 | 0.60 | 0.0500 | Gray Clay |
| 40.0 | 50.0 | 10.0 | 0.90 | 0.0300 | Sand |
| 50.0 | 75.0 | 25.0 | 1.00 | 0.0833 | Gravel |
| 75.0 | 95.0 | 20.0 | 0.80 | 0.0533 | Till with Gravel |
| 95.0 | 148.0 | 53.0 | 0.70 | 0.1237 | Till |
| 148.0 | 156.0 | 8.0 | 0.90 | 0.0240 | Sand |
| 156.0 | 220.0 | 64.0 | 0.70 | 0.1493 | Till |
| 220.0 | 226.0 | 6.0 | 0.90 | 0.0180 | Sand |
| 226.0 | 300.0 | 74.0 | 0.70 | 0.1727 | Till |
| | | | | 300.0 | Max depth drilled in feet |
| | | | | 0 | U-bend depth installed below grade |
| | | | | 0.74 | Total length weighted average, ft²/d |

| | |
|---|---|
| Circulating Fluid | Water |
| Starting Borehole Temp. | 48.7° F |
| Avg. Volts | 239.3 |
| Avg. Amps | 11.26 |
| Avg. Power (Watts) | 2695.53 |
| Avg. Heat Injected (BTU/hour) | 9197.53 |
| Test Duration (Hours) | 48 |
| Test Period Analyzed | 1.00-48.00 |
| Slope | 2.513 |
| Calculated Thermal Conductivity | 0.971 Btu/hr-ft-°F |
| Estimated Thermal Diffusivity | 1.17 ft^2/day |

# Long term performance of GHX

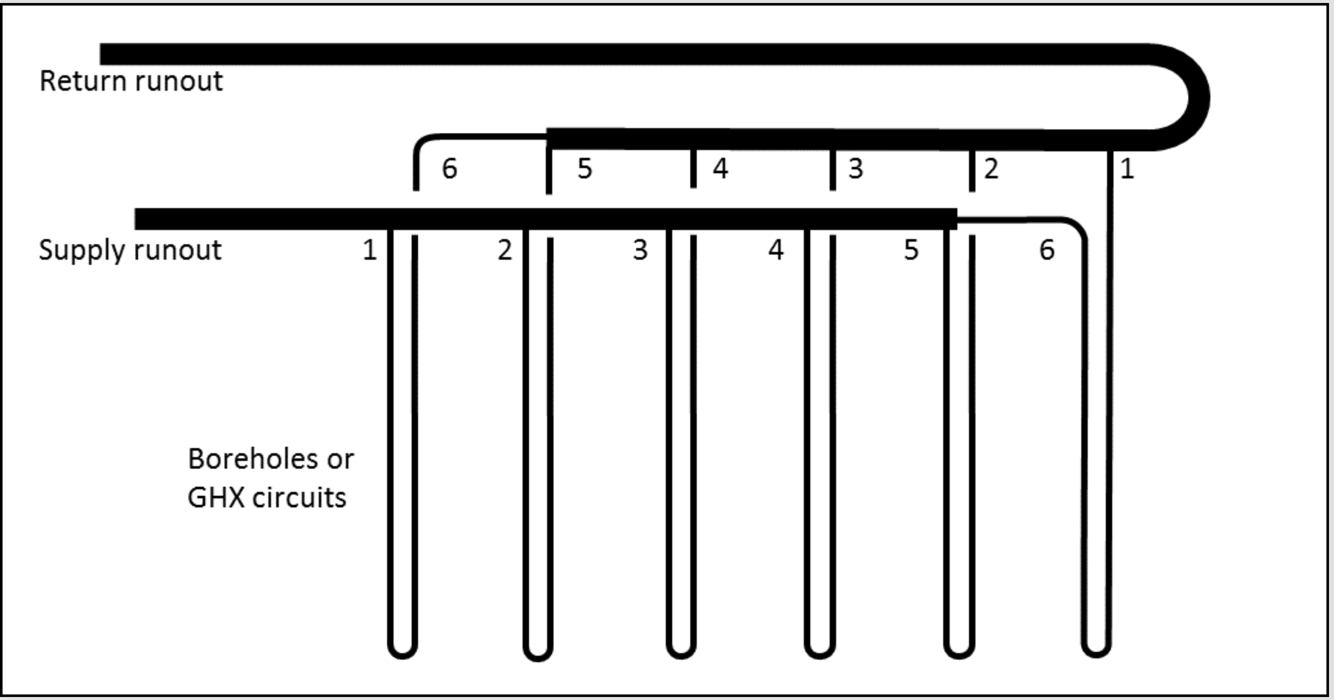
GHX modeling software can calculate the long term impact of unbalanced energy loads to and from the ground. Graph A is based on the energy model used in the feasibility assessment…it shows approximately an 8°F temperature increase over 10 years. Graph B shows calculations based on the updated energy model…approximately a 3°F rise over 10 years…because the loads are more balanced.



# GHX configuration

To ensure maximum performance from a GHX, flow rates in each of the boreholes should be approximately equal and high enough to ensure the flow is not laminar in some of the boreholes. The simplest method of ensuring equal flow is a reverse / return piping configuration.



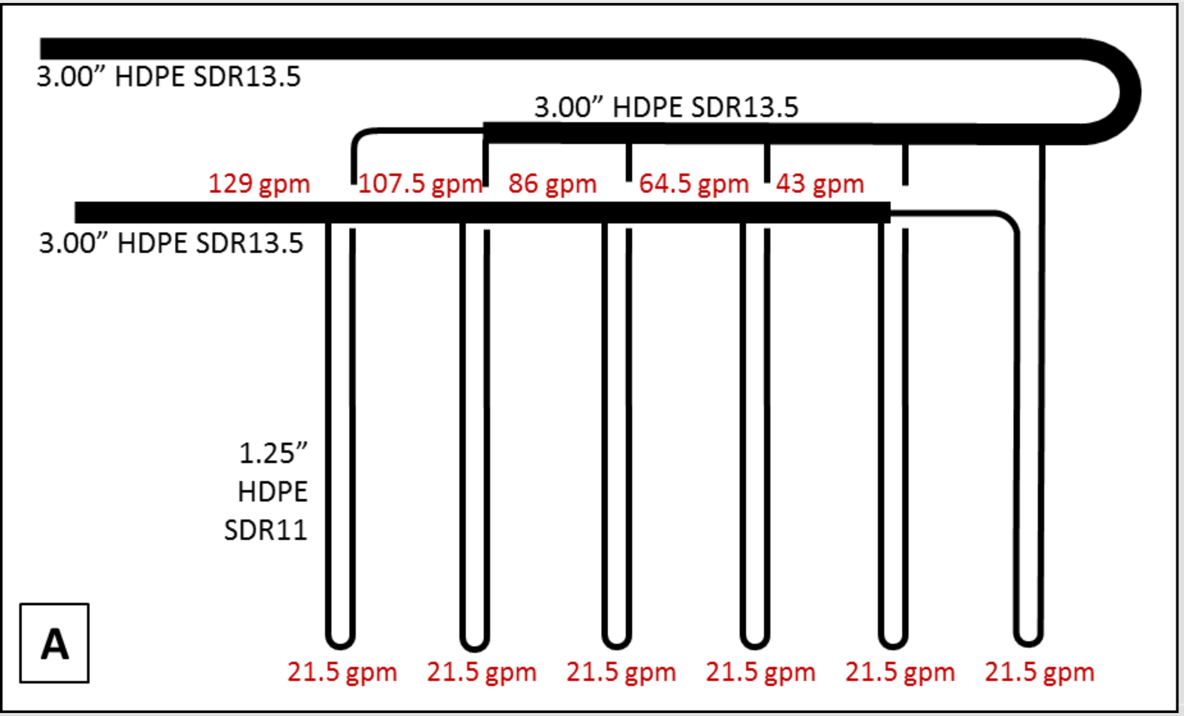
# Designing the GHX to facilitate air removal

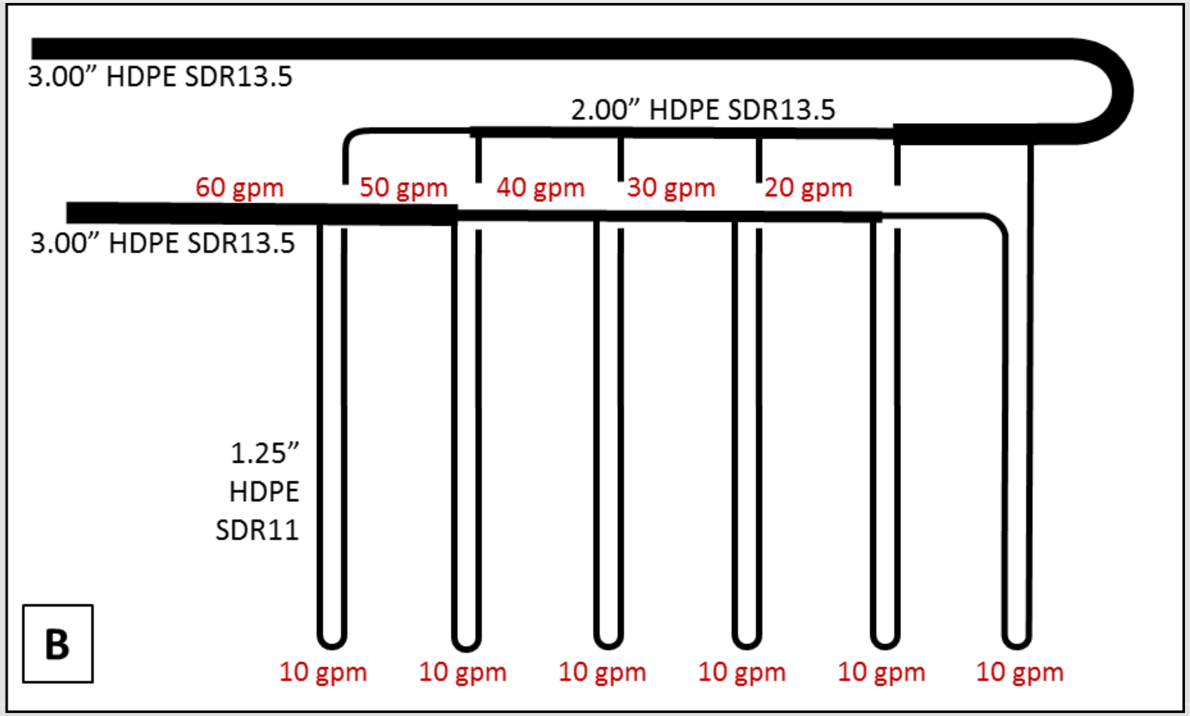
Air trapped in GHX piping can block flow through some boreholes. A flow velocity of 2 feet per second is needed through each section of the GHX piping to remove air. The chart shows the required flow rate needed to remove air from various pipe sizes used in the GHX design.

| | Flow rate (gpm) required to achieve velocity of 2 feet per second | | |
|---|---|---|---|
| **Pipe Diameter** | **SDR11** | **SDR13.5** | **SDR15.5** |
| **0.75”** | 3.55 | n/a | n/a |
| **1.00”** | **5.56** | n/a | n/a |
| **1.25”** | **8.87** | 9.65 | n/a |
| **2.00”** | 18.16 | **19.76** | 20.70 |
| **3.00”** | 39.44 | **42.93** | 44.96 |

# Reducing header

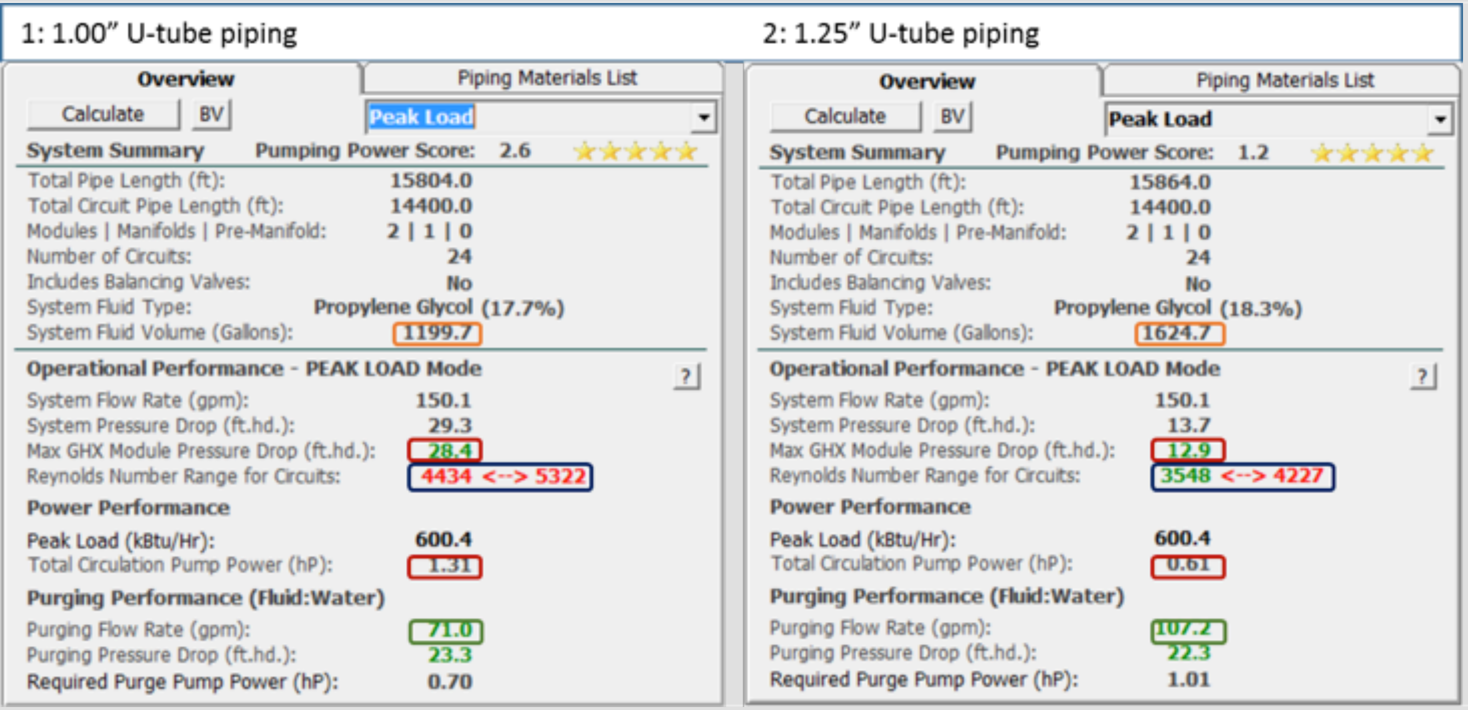
In most projects U-tubes in the boreholes are connected to a header. It is impractical to install valves to facilitate the removal of air. Reducing headers are used to ensure the flow rate in each section of the header is adequate to remove the air from the system.



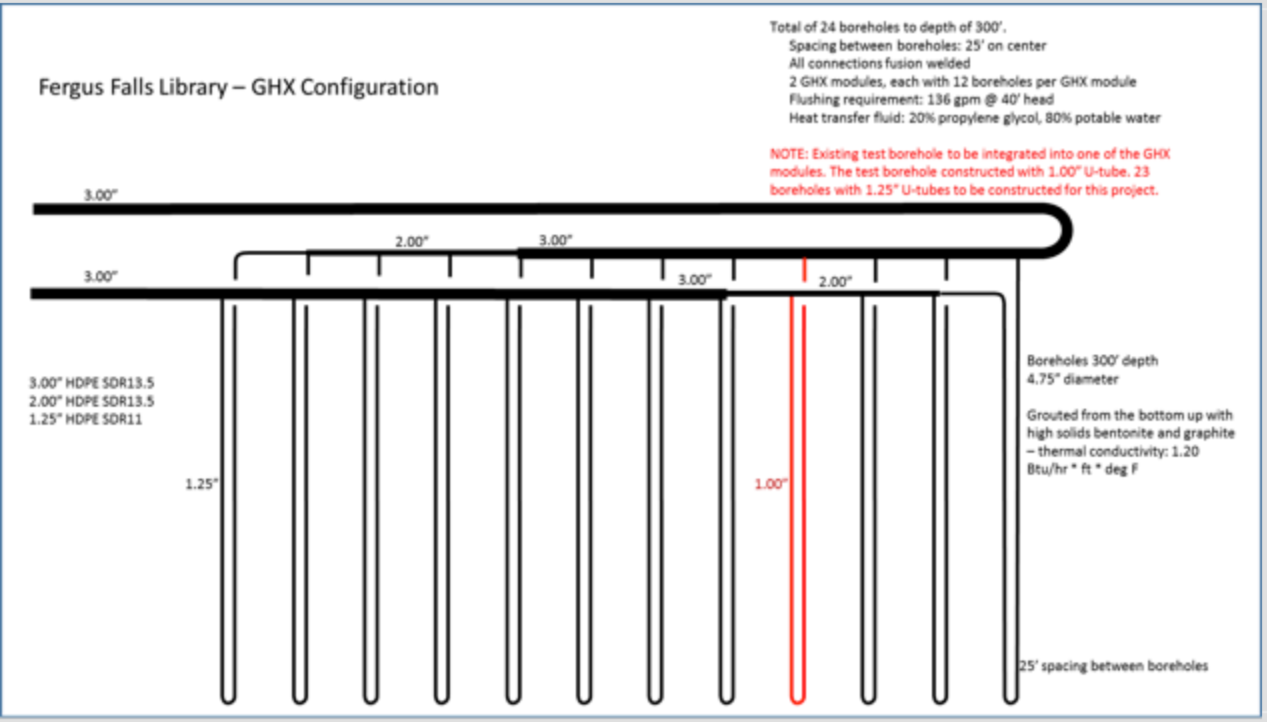
# U-tube pipe size in the borehole

Equipment specified for the Library requires flow rate of 150 gpm. Total borehole depth determined by test borehole depth…that in turn determines number of boreholes. Calculations run with 1.00” pipe (as per test borehole) and with 1.25” pipe. Pressure drop much lower with 1.25” and Reynolds number still high enough.



# Integrating the test borehole

Test borehole drilled in September, 2015. 1.00” U-tube was installed in the borehole… but pressure drop is much lower using 1.25” pipe. Calculations done to determine if Reynolds number still adequate if integrated with borehole field using 1.25” pipe.



# Check Reynolds numbers

During peak heat extraction heat transfer fluid becomes denser and more viscous… potentially going to laminar flow. In laminar flow (Reynolds number < 2,300) heat transfer is diminished. Calculations show that the Reynolds numbers are adequate with the 1.00” borehole connected to nearest GHX module.

1: 1.25” U-tube piping in all boreholes

| Module | Name | Pipe 1 Size | Pipe 2 Size | Pipe 1 Reyn... | Pipe 2 Reyn... |
|---|---|---|---|---|---|
| GHX 1 | Circuit #01 | 1 1/4" | 1 1/4" | 4096 | 4096 |
| GHX 1 | Circuit #02 | 1 1/4" | 1 1/4" | 4065 | 4065 |
| GHX 1 | Circuit #03 | 1 1/4" | 1 1/4" | 4006 | 4006 |
| GHX 1 | Circuit #04 | 1 1/4" | 1 1/4" | 4023 | 4023 |
| GHX 1 | Circuit #05 | 1 1/4" | 1 1/4" | 4130 | 4130 |
| GHX 1 | Circuit #06 | 1 1/4" | 1 1/4" | 4102 | 4102 |
| GHX 1 | Circuit #07 | 1 1/4" | 1 1/4" | 4102 | 4102 |
| GHX 1 | Circuit #08 | 1 1/4" | 1 1/4" | 4130 | 4130 |
| GHX 1 | Circuit #09 | 1 1/4" | 1 1/4" | 4023 | 4023 |
| GHX 1 | Circuit #10 | 1 1/4" | 1 1/4" | 4006 | 4006 |
| GHX 1 | Circuit #11 | 1 1/4" | 1 1/4" | 4065 | 4065 |
| GHX 1 | Circuit #12 | 1 1/4" | 1 1/4" | 4096 | 4096 |
| GHX 2 | Circuit #01 | 1 1/4" | 1 1/4" | 3724 | 3724 |
| GHX 2 | Circuit #02 | 1 1/4" | 1 1/4" | 3697 | 3697 |
| GHX 2 | Circuit #03 | 1 1/4" | 1 1/4" | 3643 | 3643 |
| GHX 2 | Circuit #04 | 1 1/4" | 1 1/4" | 3659 | 3659 |
| GHX 2 | Circuit #05 | 1 1/4" | 1 1/4" | 3756 | 3756 |
| GHX 2 | Circuit #06 | 1 1/4" | 1 1/4" | 3731 | 3731 |
| GHX 2 | Circuit #07 | 1 1/4" | 1 1/4" | 3731 | 3731 |
| GHX 2 | Circuit #08 | 1 1/4" | 1 1/4" | 3756 | 3756 |
| GHX 2 | Circuit #09 | 1 1/4" | 1 1/4" | 3659 | 3659 |
| GHX 2 | Circuit #10 | 1 1/4" | 1 1/4" | 3643 | 3643 |
| GHX 2 | Circuit #11 | 1 1/4" | 1 1/4" | 3697 | 3697 |
| GHX 2 | Circuit #12 | 1 1/4" | 1 1/4" | 3724 | 3724 |

2: 1.00” Test borehole integrated with nearest GHX module 1

| Module | Name | Pipe 1 Size | Pipe 2 Size | Pipe 1 Reyn... | Pipe 2 Reyn... |
|---|---|---|---|---|---|
| GHX 1 | Circuit #01 | 1 1/4" | 1 1/4" | 4277 | 4277 |
| GHX 1 | Circuit #02 | 1 1/4" | 1 1/4" | 4258 | 4258 |
| GHX 1 | Circuit #03 | 1" | 1" | 2605 | 2605 |
| GHX 1 | Circuit #04 | 1 1/4" | 1 1/4" | 4198 | 4198 |
| GHX 1 | Circuit #05 | 1 1/4" | 1 1/4" | 4273 | 4273 |
| GHX 1 | Circuit #06 | 1 1/4" | 1 1/4" | 4239 | 4239 |
| GHX 1 | Circuit #07 | 1 1/4" | 1 1/4" | 4234 | 4234 |
| GHX 1 | Circuit #08 | 1 1/4" | 1 1/4" | 4256 | 4256 |
| GHX 1 | Circuit #09 | 1 1/4" | 1 1/4" | 4140 | 4140 |
| GHX 1 | Circuit #10 | 1 1/4" | 1 1/4" | 4115 | 4115 |
| GHX 1 | Circuit #11 | 1 1/4" | 1 1/4" | 4169 | 4169 |
| GHX 1 | Circuit #12 | 1 1/4" | 1 1/4" | 4193 | 4193 |
| GHX 2 | Circuit #01 | 1 1/4" | 1 1/4" | 3760 | 3760 |
| GHX 2 | Circuit #02 | 1 1/4" | 1 1/4" | 3732 | 3732 |
| GHX 2 | Circuit #03 | 1 1/4" | 1 1/4" | 3678 | 3678 |
| GHX 2 | Circuit #04 | 1 1/4" | 1 1/4" | 3694 | 3694 |
| GHX 2 | Circuit #05 | 1 1/4" | 1 1/4" | 3792 | 3792 |
| GHX 2 | Circuit #06 | 1 1/4" | 1 1/4" | 3766 | 3766 |
| GHX 2 | Circuit #07 | 1 1/4" | 1 1/4" | 3766 | 3766 |
| GHX 2 | Circuit #08 | 1 1/4" | 1 1/4" | 3792 | 3792 |
| GHX 2 | Circuit #09 | 1 1/4" | 1 1/4" | 3694 | 3694 |
| GHX 2 | Circuit #10 | 1 1/4" | 1 1/4" | 3678 | 3678 |
| GHX 2 | Circuit #11 | 1 1/4" | 1 1/4" | 3732 | 3732 |
| GHX 2 | Circuit #12 | 1 1/4" | 1 1/4" | 3760 | 3760 |

# Location of 1.00” U-tube impacts flow rates

Supply & return runouts are longer to GHX module…reducing flow rates in U-tubes, and reducing Reynolds numbers. Reynolds number in 1.00” U-tube are close to laminar flow.

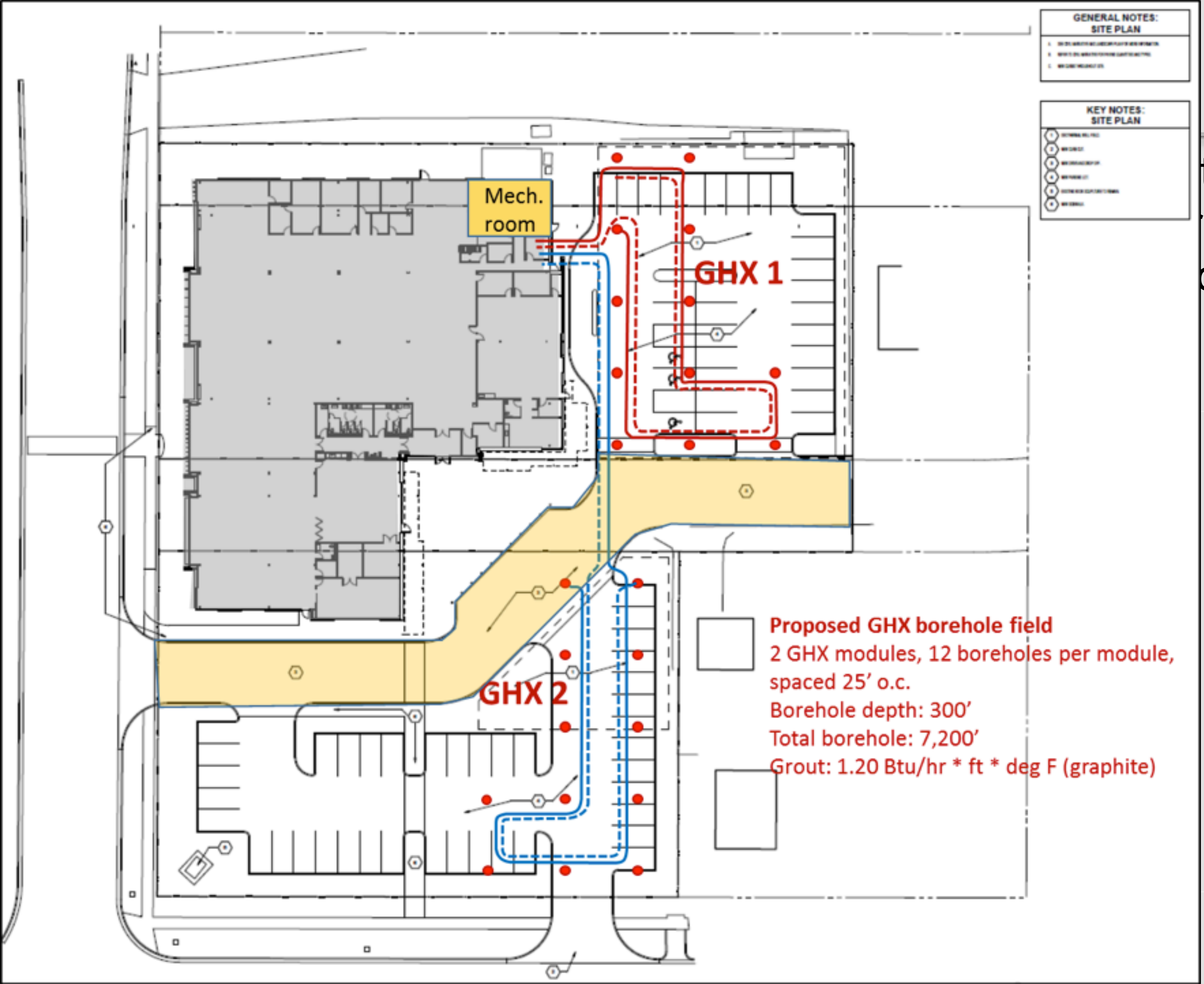
To increase flow rate to GHX module 2, balancing valves added at the manifold.

1.00” Test borehole integrated with GHX 2 – no balancing valve

| Name | Pipe 1 Size | Pipe 2 Size | Pipe 1 Reyn... | Pipe 2 Reyn... | GHX |
|---|---|---|---|---|---|
| Circuit #01 | 1 1/4" | 1 1/4" | 4128 | 4128 | GHX 1 |
| Circuit #02 | 1 1/4" | 1 1/4" | 4097 | 4097 | GHX 1 |
| Circuit #03 | 1 1/4" | 1 1/4" | 4037 | 4037 | GHX 1 |
| Circuit #04 | 1 1/4" | 1 1/4" | 4054 | 4054 | GHX 1 |
| Circuit #05 | 1 1/4" | 1 1/4" | 4162 | 4162 | GHX 1 |
| Circuit #06 | 1 1/4" | 1 1/4" | 4134 | 4134 | GHX 1 |
| Circuit #07 | 1 1/4" | 1 1/4" | 4134 | 4134 | GHX 1 |
| Circuit #08 | 1 1/4" | 1 1/4" | 4162 | 4162 | GHX 1 |
| Circuit #09 | 1 1/4" | 1 1/4" | 4054 | 4054 | GHX 1 |
| Circuit #10 | 1 1/4" | 1 1/4" | 4037 | 4037 | GHX 1 |
| Circuit #11 | 1 1/4" | 1 1/4" | 4097 | 4097 | GHX 1 |
| Circuit #12 | 1 1/4" | 1 1/4" | 4128 | 4128 | GHX 1 |
| Circuit #01 | 1 1/4" | 1 1/4" | 3890 | 3890 | GHX 2 |
| Circuit #02 | 1 1/4" | 1 1/4" | 3873 | 3873 | GHX 2 |
| Circuit #03 | 1" | 1" | 2366 | 2366 | GHX 2 |
| Circuit #04 | 1 1/4" | 1 1/4" | 3819 | 3819 | GHX 2 |
| Circuit #05 | 1 1/4" | 1 1/4" | 3887 | 3887 | GHX 2 |
| Circuit #06 | 1 1/4" | 1 1/4" | 3857 | 3857 | GHX 2 |
| Circuit #07 | 1 1/4" | 1 1/4" | 3851 | 3851 | GHX 2 |
| Circuit #08 | 1 1/4" | 1 1/4" | 3872 | 3872 | GHX 2 |
| Circuit #09 | 1 1/4" | 1 1/4" | 3766 | 3766 | GHX 2 |
| Circuit #10 | 1 1/4" | 1 1/4" | 3744 | 3744 | GHX 2 |
| Circuit #11 | 1 1/4" | 1 1/4" | 3792 | 3792 | GHX 2 |
| Circuit #12 | 1 1/4" | 1 1/4" | 3813 | 3813 | GHX 2 |

1.00” Test borehole in GHX 2 Balancing valves added

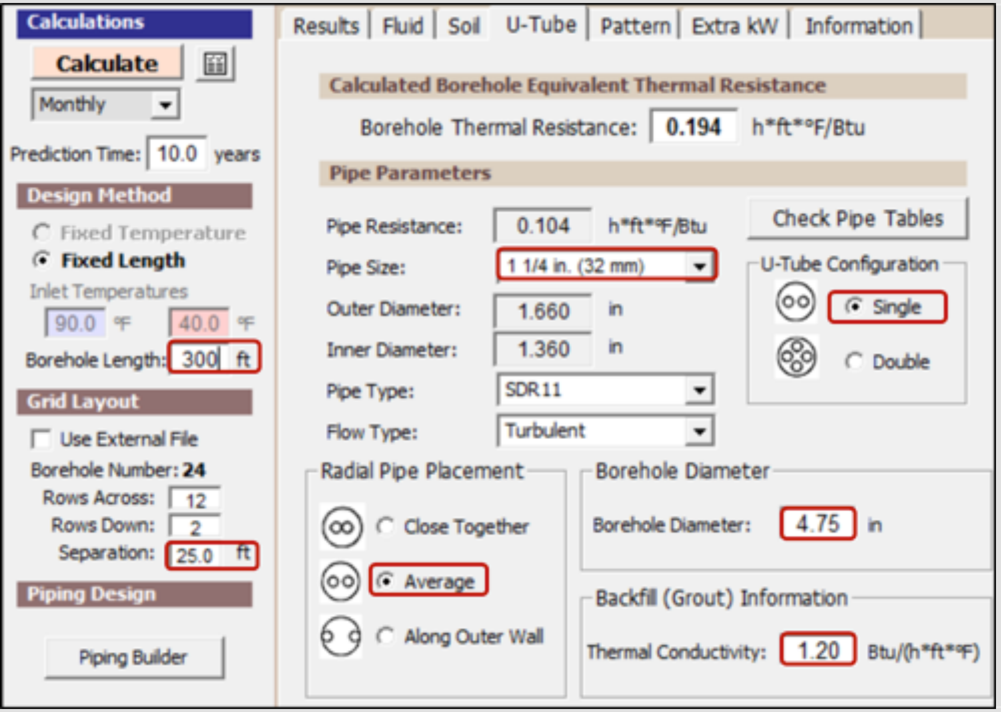
| Name | Pipe 1 Size | Pipe 2 Size | Pipe 1 Reyn... | Pipe 2 Reyn... | GHX |
|---|---|---|---|---|---|
| Circuit #01 | 1 1/4" | 1 1/4" | 3934 | 3934 | GHX 1 |
| Circuit #02 | 1 1/4" | 1 1/4" | 3904 | 3904 | GHX 1 |
| Circuit #03 | 1 1/4" | 1 1/4" | 3847 | 3847 | GHX 1 |
| Circuit #04 | 1 1/4" | 1 1/4" | 3863 | 3863 | GHX 1 |
| Circuit #05 | 1 1/4" | 1 1/4" | 3966 | 3966 | GHX 1 |
| Circuit #06 | 1 1/4" | 1 1/4" | 3939 | 3939 | GHX 1 |
| Circuit #07 | 1 1/4" | 1 1/4" | 3939 | 3939 | GHX 1 |
| Circuit #08 | 1 1/4" | 1 1/4" | 3966 | 3966 | GHX 1 |
| Circuit #09 | 1 1/4" | 1 1/4" | 3863 | 3863 | GHX 1 |
| Circuit #10 | 1 1/4" | 1 1/4" | 3847 | 3847 | GHX 1 |
| Circuit #11 | 1 1/4" | 1 1/4" | 3904 | 3904 | GHX 1 |
| Circuit #12 | 1 1/4" | 1 1/4" | 3934 | 3934 | GHX 1 |
| Circuit #01 | 1 1/4" | 1 1/4" | 4095 | 4095 | GHX 2 |
| Circuit #02 | 1 1/4" | 1 1/4" | 4077 | 4077 | GHX 2 |
| Circuit #03 | 1" | 1" | 2491 | 2491 | GHX 2 |
| Circuit #04 | 1 1/4" | 1 1/4" | 4020 | 4020 | GHX 2 |
| Circuit #05 | 1 1/4" | 1 1/4" | 4092 | 4092 | GHX 2 |
| Circuit #06 | 1 1/4" | 1 1/4" | 4060 | 4060 | GHX 2 |
| Circuit #07 | 1 1/4" | 1 1/4" | 4054 | 4054 | GHX 2 |
| Circuit #08 | 1 1/4" | 1 1/4" | 4076 | 4076 | GHX 2 |
| Circuit #09 | 1 1/4" | 1 1/4" | 3965 | 3965 | GHX 2 |
| Circuit #10 | 1 1/4" | 1 1/4" | 3941 | 3941 | GHX 2 |
| Circuit #11 | 1 1/4" | 1 1/4" | 3991 | 3991 | GHX 2 |
| Circuit #12 | 1 1/4" | 1 1/4" | 4014 | 4014 | GHX 2 |




tem. Runout pipe size,
fluid specifications, flow
ove air from the system and

# Borehole design details

Borehole design details and QA/QC program is critical to the performance of the GHX. Because the boreholes and connecting piping are buried under a parking lot it will be expensive and/or difficult to change anything after it is built.



# Grout specifications and quality control

The performance of a borehole is contingent is based on the design. If it's not built as designed it will not perform as expected. Borehole diameter, depth, pipe specifications, pipe placement, grout specifications…are all critical to performance of the system.

| TG Lite / PowerTECx Mix Table | | | | | | | | RECOMMENDED BATCH QUANTITIES | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Target TC (Btu / hr ft °F) | TG Lite (lb) | PowerTECx (lb) | Mix Water (gal) | Yield (gal) | Density (lb/gal) | % Total Solids (by weight) | % Active Solids (by weight) | TG Lite (bags) | PowerTECx (bags) | Water (gals) |
| **0.79** | 50 | 5.0 | 15.5 | 18.1 | 10.2 | 29.8 | 27.9 | 3 | 1 | 46.5 |
| **0.88** | 50 | 7.5 | 16.5 | 19.2 | 10.2 | 29.5 | 26.7 | 2 | 1 | 33.0 |
| **1.00** | 50 | 7.5 | 16.0 | 18.7 | 10.2 | 30.1 | 27.3 | 2 | 1 | 32.0 |
| **1.07** | 50 | 10.0 | 18.0 | 20.8 | 10.1 | 28.6 | 25.0 | 3 | 2 | 54.0 |
| **1.14** | 50 | 10.0 | 17.5 | 20.3 | 10.1 | 29.1 | 25.5 | 3 | 2 | 52.5 |
| **1.20** | 50 | 10.0 | 16.5 | 19.3 | 10.2 | 30.4 | 26.7 | 3 | 2 | 49.5 |

| Library GHX Details | Pipe 1 Size | Pipe 2 Size | Pipe 1 Flow Rate | Pipe 2 Flow Rate | Pipe 1 Reynold's Number | Pipe 2 Reynold's Number | Pipe 1 Pressure Drop | Pipe 2 Pressure Drop |
|---|---|---|---|---|---|---|---|---|
| Manifold #01 - Supply-Return Runout - Manifold 1 | 4" | 4" | 150.10 gpm | 150.10 gpm | 33042 | 33042 | 0.4 ft. hd | 0.4 ft. hd |
| Manifold #01 - Pipe Section #01 - Manifold 1 | 4" | 4" | 150.10 gpm | 150.10 gpm | 33042 | 33042 | 0.0 ft. hd | 0.0 ft. hd |
| GHX Module #01 - Supply-Return Runout - Module 1 | 3" | 3" | 75.82 gpm | 75.82 gpm | 21462 | 21462 | 0.6 ft. hd | 5.5 ft. hd |
| Circuit #01 | 1 1/4" | 1 1/4" | 6.57 gpm | 6.57 gpm | 4079 | 4079 | 3.7 ft. hd | 3.7 ft. hd |
| GHX Module #01 - Pipe Section #01 | 3" | 1 1/4" | 69.26 gpm | 6.57 gpm | 19603 | 4079 | 0.4 ft. hd | 0.3 ft. hd |
| Circuit #02 | 1 1/4" | 1 1/4" | 6.53 gpm | 6.53 gpm | 4056 | 4056 | 3.6 ft. hd | 3.6 ft. hd |
| GHX Module #01 - Pipe Section #02 | 3" | 2" | 62.73 gpm | 13.09 gpm | 17756 | 5686 | 0.4 ft. hd | 0.2 ft. hd |
| Circuit #03 | 1 1/4" | 1 1/4" | 6.45 gpm | 6.45 gpm | 4005 | 4005 | 3.5 ft. hd | 3.5 ft. hd |
| GHX Module #01 - Pipe Section #03 | 3" | 2" | 56.29 gpm | 19.54 gpm | 15931 | 8485 | 0.3 ft. hd | 0.4 ft. hd |
| Circuit #04 | 1 1/4" | 1 1/4" | 6.48 gpm | 6.48 gpm | 4029 | 4029 | 3.5 ft. hd | 3.5 ft. hd |
| GHX Module #01 - Pipe Section #04 | 3" | 2" | 49.80 gpm | 26.02 gpm | 14096 | 11301 | 0.2 ft. hd | 0.6 ft. hd |
| Circuit #05 | 1 1/4" | 1 1/4" | 6.67 gpm | 6.67 gpm | 4142 | 4142 | 3.7 ft. hd | 3.7 ft. hd |
| GHX Module #01 - Pipe Section #05 | 3" | 3" | 43.13 gpm | 32.69 gpm | 12209 | 9253 | 0.2 ft. hd | 0.1 ft. hd |
| Circuit #06 | 1 1/4" | 1 1/4" | 6.63 gpm | 6.63 gpm | 4120 | 4120 | 3.6 ft. hd | 3.6 ft. hd |
| GHX Module #01 - Pipe Section #06 | 3" | 3" | 36.50 gpm | 39.32 gpm | 10332 | 11129 | 0.1 ft. hd | 0.2 ft. hd |
| Circuit #07 | 1 1/4" | 1 1/4" | 6.64 gpm | 6.64 gpm | 4126 | 4126 | 3.7 ft. hd | 3.7 ft. hd |
| GHX Module #01 - Pipe Section #07 | 3" | 3" | 29.86 gpm | 45.96 gpm | 8453 | 13009 | 0.1 ft. hd | 0.2 ft. hd |
| Circuit #08 | 1 1/4" | 1 1/4" | 6.69 gpm | 6.69 gpm | 4159 | 4159 | 3.7 ft. hd | 3.7 ft. hd |
| GHX Module #01 - Pipe Section #08 | 2" | 3" | 23.17 gpm | 52.65 gpm | 10062 | 14903 | 0.5 ft. hd | 0.3 ft. hd |
| Circuit #09 | 1 1/4" | 1 1/4" | 6.57 gpm | 6.57 gpm | 4085 | 4085 | 3.6 ft. hd | 3.6 ft. hd |
| GHX Module #01 - Pipe Section #09 | 2" | 3" | 16.60 gpm | 59.23 gpm | 7207 | 16764 | 0.3 ft. hd | 0.3 ft. hd |
| Circuit #10 | 1" | 1" | 3.23 gpm | 3.23 gpm | 2533 | 2533 | 2.7 ft. hd | 2.7 ft. hd |
| GHX Module #01 - Pipe Section #10 | 2" | 3" | 13.37 gpm | 62.46 gpm | 5804 | 17678 | 0.2 ft. hd | 0.4 ft. hd |
| Circuit #11 | 1 1/4" | 1 1/4" | 6.67 gpm | 6.67 gpm | 4143 | 4143 | 3.7 ft. hd | 3.7 ft. hd |
| GHX Module #01 - Pipe Section #11 | 1 1/4" | 3" | 6.70 gpm | 69.13 gpm | 4162 | 19566 | 0.3 ft. hd | 0.4 ft. hd |
| Circuit #12 | 1 1/4" | 1 1/4" | 6.70 gpm | 6.70 gpm | 4162 | 4162 | 3.8 ft. hd | 3.8 ft. hd |
| Manifold #01 - Pipe Section #02 - Manifold 1 | 4" | 4" | 74.28 gpm | 74.28 gpm | 16351 | 16351 | 0.0 ft. hd | 0.0 ft. hd |
| GHX Module #02 - Supply-Return Runout - Module 2 | 3" | 3" | 74.28 gpm | 74.28 gpm | 21024 | 21024 | 1.1 ft. hd | 5.7 ft. hd |
| Circuit #01 | 1 1/4" | 1 1/4" | 6.23 gpm | 6.23 gpm | 3869 | 3869 | 3.4 ft. hd | 3.4 ft. hd |
| GHX Module #02 - Pipe Section #01 | 3" | 1 1/4" | 68.05 gpm | 6.23 gpm | 19261 | 3869 | 0.4 ft. hd | 0.3 ft. hd |
| Circuit #02 | 1 1/4" | 1 1/4" | 6.18 gpm | 6.18 gpm | 3841 | 3841 | 3.3 ft. hd | 3.3 ft. hd |
| GHX Module #02 - Pipe Section #02 | 3" | 2" | 61.87 gpm | 12.41 gpm | 17511 | 5389 | 0.3 ft. hd | 0.2 ft. hd |
| Circuit #03 | 1 1/4" | 1 1/4" | 6.09 gpm | 6.09 gpm | 3785 | 3785 | 3.2 ft. hd | 3.2 ft. hd |
| GHX Module #02 - Pipe Section #03 | 3" | 2" | 55.78 gpm | 18.50 gpm | 15787 | 8034 | 0.3 ft. hd | 0.3 ft. hd |
| Circuit #04 | 1 1/4" | 1 1/4" | 6.12 gpm | 6.12 gpm | 3801 | 3801 | 3.2 ft. hd | 3.2 ft. hd |
| GHX Module #02 - Pipe Section #04 | 3" | 2" | 49.66 gpm | 24.62 gpm | 14055 | 10691 | 0.2 ft. hd | 0.5 ft. hd |
| Circuit #05 | 1 1/4" | 1 1/4" | 6.28 gpm | 6.28 gpm | 3902 | 3902 | 3.3 ft. hd | 3.3 ft. hd |
| GHX Module #02 - Pipe Section #05 | 3" | 3" | 43.38 gpm | 30.90 gpm | 12278 | 8746 | 0.2 ft. hd | 0.1 ft. hd |
| Circuit #06 | 1 1/4" | 1 1/4" | 6.24 gpm | 6.24 gpm | 3876 | 3876 | 3.3 ft. hd | 3.3 ft. hd |
| GHX Module #02 - Pipe Section #06 | 3" | 3" | 37.14 gpm | 37.14 gpm | 10512 | 10512 | 0.1 ft. hd | 0.1 ft. hd |
| Circuit #07 | 1 1/4" | 1 1/4" | 6.24 gpm | 6.24 gpm | 3876 | 3876 | 3.3 ft. hd | 3.3 ft. hd |
| GHX Module #02 - Pipe Section #07 | 3" | 3" | 30.90 gpm | 43.38 gpm | 8746 | 12277 | 0.1 ft. hd | 0.2 ft. hd |
| Circuit #08 | 1 1/4" | 1 1/4" | 6.28 gpm | 6.28 gpm | 3902 | 3902 | 3.3 ft. hd | 3.3 ft. hd |
| GHX Module #02 - Pipe Section #08 | 2" | 3" | 24.62 gpm | 49.66 gpm | 10691 | 14055 | 0.5 ft. hd | 0.2 ft. hd |
| Circuit #09 | 1 1/4" | 1 1/4" | 6.12 gpm | 6.12 gpm | 3801 | 3801 | 3.2 ft. hd | 3.2 ft. hd |
| GHX Module #02 - Pipe Section #09 | 2" | 3" | 18.50 gpm | 55.77 gpm | 8034 | 15787 | 0.3 ft. hd | 0.3 ft. hd |
| Circuit #10 | 1 1/4" | 1 1/4" | 6.09 gpm | 6.09 gpm | 3785 | 3785 | 3.2 ft. hd | 3.2 ft. hd |
| GHX Module #02 - Pipe Section #10 | 2" | 3" | 12.41 gpm | 61.87 gpm | 5389 | 17511 | 0.2 ft. hd | 0.3 ft. hd |
| Circuit #11 | 1 1/4" | 1 1/4" | 6.18 gpm | 6.18 gpm | 3841 | 3841 | 3.3 ft. hd | 3.3 ft. hd |
| GHX Module #02 - Pipe Section #11 | 1 1/4" | 3" | 6.23 gpm | 68.05 gpm | 3869 | 19261 | 0.3 ft. hd | 0.4 ft. hd |
| Circuit #12 | 1 1/4" | 1 1/4" | 6.23 gpm | 6.23 gpm | 3869 | 3869 | 3.4 ft. hd | 3.4 ft. hd |

aders is important for pressure
n. Because it will be buried, it’s
used to ensure accuracy and

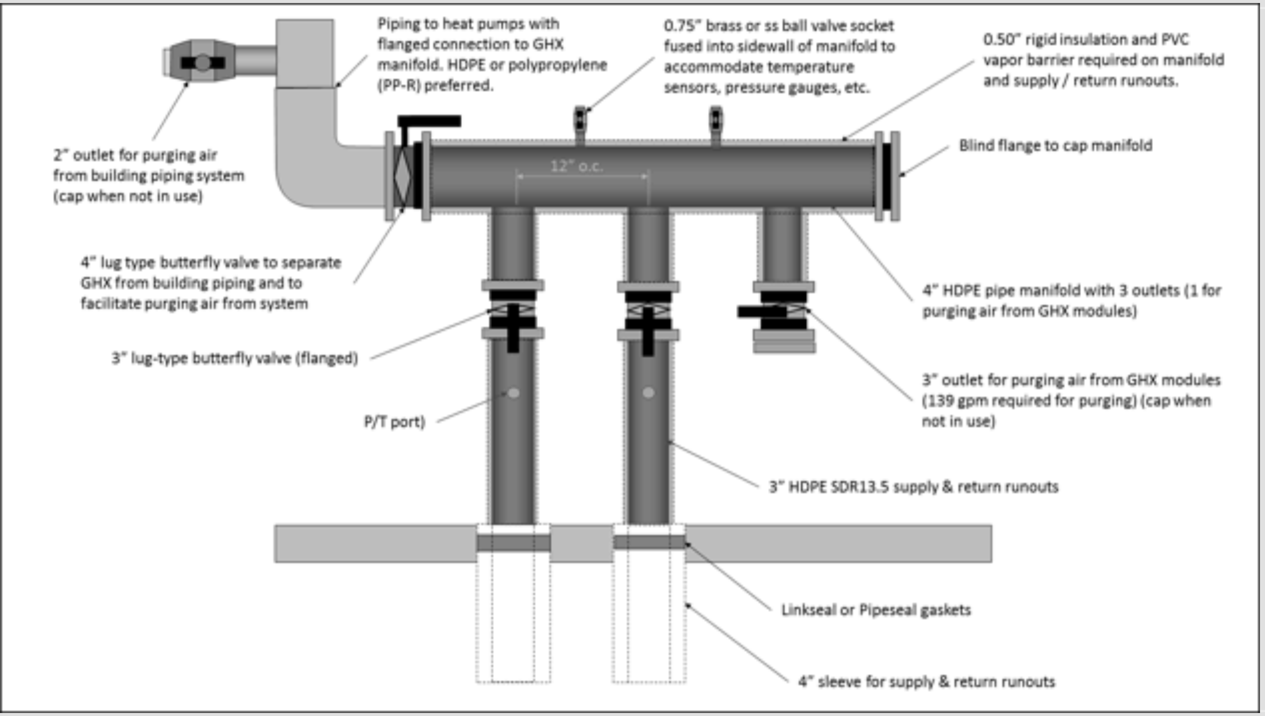
from system

should facilitate air

| Library - purging flow rate | Pipe 1 Size | Pipe 2 Size | Pipe 1 Flow Rate | Pipe 2 Flow Rate | Pipe 1 Velocity | Pipe 2 Velocity | Pipe 1 Reynold's Number | Pipe 2 Reynold's Number | Pipe 1 Pressure Drop | Pipe 2 Pressure Drop |
|---|---|---|---|---|---|---|---|---|---|---|
| Manifold #01 - Supply-Return Runout - Manifold 1 | 4" | 4" | 276.09 gpm | 276.09 gpm | 7.68 ft/s | 7.68 ft/s | 127247 | 127247 | 1.0 ft. hd | 1.0 ft. hd |
| Manifold #01 - Pipe Section #01 - Manifold 1 | 4" | 4" | 276.09 gpm | 276.09 gpm | 7.68 ft/s | 7.68 ft/s | 127247 | 127247 | 0.0 ft. hd | 0.0 ft. hd |
| GHX Module #01 - Supply-Return Runout - Module 1 | 3" | 3" | 139.32 gpm | 139.32 gpm | 6.40 ft/s | 6.40 ft/s | 82561 | 82561 | 1.5 ft. hd | 13.5 ft. hd |
| Circuit #01 | 1 1/4" | 1 1/4" | 12.07 gpm | 12.07 gpm | 2.67 ft/s | 2.67 ft/s | 15697 | 15697 | 8.4 ft. hd | 8.4 ft. hd |
| GHX Module #01 - Pipe Section #01 | 3" | 1 1/4" | 127.25 gpm | 12.07 gpm | 5.85 ft/s | 2.67 ft/s | 75410 | 15697 | 1.0 ft. hd | 0.7 ft. hd |
| Circuit #02 | 1 1/4" | 1 1/4" | 11.99 gpm | 11.99 gpm | 2.66 ft/s | 2.66 ft/s | 15603 | 15603 | 8.2 ft. hd | 8.2 ft. hd |
| GHX Module #01 - Pipe Section #02 | 3" | 2" | 115.26 gpm | 24.06 gpm | 5.30 ft/s | 2.60 ft/s | 68302 | 21876 | 0.9 ft. hd | 0.4 ft. hd |
| Circuit #03 | 1 1/4" | 1 1/4" | 11.84 gpm | 11.84 gpm | 2.62 ft/s | 2.62 ft/s | 15401 | 15401 | 8.0 ft. hd | 8.0 ft. hd |
| GHX Module #01 - Pipe Section #03 | 3" | 2" | 103.42 gpm | 35.90 gpm | 4.75 ft/s | 3.88 ft/s | 61286 | 32640 | 0.7 ft. hd | 0.9 ft. hd |
| Circuit #04 | 1 1/4" | 1 1/4" | 11.91 gpm | 11.91 gpm | 2.64 ft/s | 2.64 ft/s | 15492 | 15492 | 8.1 ft. hd | 8.1 ft. hd |
| GHX Module #01 - Pipe Section #04 | 3" | 2" | 91.51 gpm | 47.81 gpm | 4.21 ft/s | 5.17 ft/s | 54228 | 43468 | 0.6 ft. hd | 1.4 ft. hd |
| Circuit #05 | 1 1/4" | 1 1/4" | 12.25 gpm | 12.25 gpm | 2.71 ft/s | 2.71 ft/s | 15929 | 15929 | 8.5 ft. hd | 8.5 ft. hd |
| GHX Module #01 - Pipe Section #05 | 3" | 3" | 79.26 gpm | 60.05 gpm | 3.64 ft/s | 2.76 ft/s | 46972 | 35589 | 0.5 ft. hd | 0.3 ft. hd |
| Circuit #06 | 1 1/4" | 1 1/4" | 12.18 gpm | 12.18 gpm | 2.70 ft/s | 2.70 ft/s | 15844 | 15844 | 8.4 ft. hd | 8.4 ft. hd |
| GHX Module #01 - Pipe Section #06 | 3" | 3" | 67.08 gpm | 72.23 gpm | 3.08 ft/s | 3.32 ft/s | 39754 | 42807 | 0.3 ft. hd | 0.4 ft. hd |
| Circuit #07 | 1 1/4" | 1 1/4" | 12.20 gpm | 12.20 gpm | 2.70 ft/s | 2.70 ft/s | 15865 | 15865 | 8.4 ft. hd | 8.4 ft. hd |
| GHX Module #01 - Pipe Section #07 | 3" | 3" | 54.89 gpm | 84.43 gpm | 2.52 ft/s | 3.88 ft/s | 32527 | 50034 | 0.2 ft. hd | 0.5 ft. hd |
| Circuit #08 | 1 1/4" | 1 1/4" | 12.29 gpm | 12.29 gpm | 2.72 ft/s | 2.72 ft/s | 15993 | 15993 | 8.6 ft. hd | 8.6 ft. hd |
| GHX Module #01 - Pipe Section #08 | 2" | 3" | 42.59 gpm | 96.72 gpm | 4.61 ft/s | 4.45 ft/s | 38725 | 57320 | 1.2 ft. hd | 0.6 ft. hd |
| Circuit #09 | 1 1/4" | 1 1/4" | 12.08 gpm | 12.08 gpm | 2.68 ft/s | 2.68 ft/s | 15710 | 15710 | 8.3 ft. hd | 8.3 ft. hd |
| GHX Module #01 - Pipe Section #09 | 2" | 3" | 30.52 gpm | 108.80 gpm | 3.30 ft/s | 5.00 ft/s | 27745 | 64477 | 0.7 ft. hd | 0.8 ft. hd |
| Circuit #10 | 1" | 1" | 5.95 gpm | 5.95 gpm | 2.10 ft/s | 2.10 ft/s | 9771 | 9771 | 8.4 ft. hd | 8.4 ft. hd |
| GHX Module #01 - Pipe Section #10 | 2" | 3" | 24.56 gpm | 114.75 gpm | 2.66 ft/s | 5.28 ft/s | 22334 | 68004 | 0.4 ft. hd | 0.9 ft. hd |
| Circuit #11 | 1 1/4" | 1 1/4" | 12.25 gpm | 12.25 gpm | 2.71 ft/s | 2.71 ft/s | 15940 | 15940 | 8.6 ft. hd | 8.6 ft. hd |
| GHX Module #01 - Pipe Section #11 | 1 1/4" | 3" | 12.31 gpm | 127.01 gpm | 2.73 ft/s | 5.84 ft/s | 16015 | 75265 | 0.7 ft. hd | 1.0 ft. hd |
| Circuit #12 | 1 1/4" | 1 1/4" | 12.31 gpm | 12.31 gpm | 2.73 ft/s | 2.73 ft/s | 16015 | 16015 | 8.7 ft. hd | 8.7 ft. hd |
| Manifold #01 - Pipe Section #02 - Manifold 1 | 4" | 4" | 136.78 gpm | 136.78 gpm | 3.80 ft/s | 3.80 ft/s | 63038 | 63038 | 0.0 ft. hd | 0.0 ft. hd |
| GHX Module #02 - Supply-Return Runout - Module 2 | 3" | 3" | 136.78 gpm | 136.78 gpm | 6.29 ft/s | 6.29 ft/s | 81055 | 81055 | 2.6 ft. hd | 14.2 ft. hd |
| Circuit #01 | 1 1/4" | 1 1/4" | 11.47 gpm | 11.47 gpm | 2.54 ft/s | 2.54 ft/s | 14926 | 14926 | 7.7 ft. hd | 7.7 ft. hd |
| GHX Module #02 - Pipe Section #01 | 3" | 1 1/4" | 125.30 gpm | 11.47 gpm | 5.76 ft/s | 2.54 ft/s | 74256 | 14926 | 1.0 ft. hd | 0.6 ft. hd |
| Circuit #02 | 1 1/4" | 1 1/4" | 11.38 gpm | 11.38 gpm | 2.52 ft/s | 2.52 ft/s | 14810 | 14810 | 7.6 ft. hd | 7.6 ft. hd |
| GHX Module #02 - Pipe Section #02 | 3" | 2" | 113.92 gpm | 22.86 gpm | 5.24 ft/s | 2.47 ft/s | 67509 | 20783 | 0.9 ft. hd | 0.4 ft. hd |
| Circuit #03 | 1 1/4" | 1 1/4" | 11.22 gpm | 11.22 gpm | 2.48 ft/s | 2.48 ft/s | 14592 | 14592 | 7.3 ft. hd | 7.3 ft. hd |
| GHX Module #02 - Pipe Section #03 | 3" | 2" | 102.70 gpm | 34.08 gpm | 4.72 ft/s | 3.69 ft/s | 60861 | 30982 | 0.7 ft. hd | 0.8 ft. hd |
| Circuit #04 | 1 1/4" | 1 1/4" | 11.26 gpm | 11.26 gpm | 2.50 ft/s | 2.50 ft/s | 14653 | 14653 | 7.4 ft. hd | 7.4 ft. hd |
| GHX Module #02 - Pipe Section #04 | 3" | 2" | 91.44 gpm | 45.34 gpm | 4.20 ft/s | 4.91 ft/s | 54186 | 41222 | 0.6 ft. hd | 1.3 ft. hd |
| Circuit #05 | 1 1/4" | 1 1/4" | 11.56 gpm | 11.56 gpm | 2.56 ft/s | 2.56 ft/s | 15043 | 15043 | 7.7 ft. hd | 7.7 ft. hd |
| GHX Module #02 - Pipe Section #05 | 3" | 3" | 79.87 gpm | 56.90 gpm | 3.67 ft/s | 2.62 ft/s | 47333 | 33722 | 0.5 ft. hd | 0.3 ft. hd |
| Circuit #06 | 1 1/4" | 1 1/4" | 11.48 gpm | 11.48 gpm | 2.54 ft/s | 2.54 ft/s | 14940 | 14940 | 7.6 ft. hd | 7.6 ft. hd |
| GHX Module #02 - Pipe Section #06 | 3" | 3" | 68.39 gpm | 68.39 gpm | 3.14 ft/s | 3.14 ft/s | 40527 | 40527 | 0.3 ft. hd | 0.3 ft. hd |
| Circuit #07 | 1 1/4" | 1 1/4" | 11.48 gpm | 11.48 gpm | 2.54 ft/s | 2.54 ft/s | 14940 | 14940 | 7.6 ft. hd | 7.6 ft. hd |
| GHX Module #02 - Pipe Section #07 | 3" | 3" | 56.90 gpm | 79.87 gpm | 2.62 ft/s | 3.67 ft/s | 33722 | 47333 | 0.3 ft. hd | 0.5 ft. hd |
| Circuit #08 | 1 1/4" | 1 1/4" | 11.56 gpm | 11.56 gpm | 2.56 ft/s | 2.56 ft/s | 15043 | 15043 | 7.7 ft. hd | 7.7 ft. hd |
| GHX Module #02 - Pipe Section #08 | 2" | 3" | 45.34 gpm | 91.44 gpm | 4.91 ft/s | 4.20 ft/s | 41222 | 54186 | 1.3 ft. hd | 0.6 ft. hd |
| Circuit #09 | 1 1/4" | 1 1/4" | 11.26 gpm | 11.26 gpm | 2.50 ft/s | 2.50 ft/s | 14653 | 14653 | 7.4 ft. hd | 7.4 ft. hd |
| GHX Module #02 - Pipe Section #09 | 2" | 3" | 34.08 gpm | 102.70 gpm | 3.69 ft/s | 4.72 ft/s | 30982 | 60861 | 0.8 ft. hd | 0.7 ft. hd |
| Circuit #10 | 1 1/4" | 1 1/4" | 11.22 gpm | 11.22 gpm | 2.48 ft/s | 2.48 ft/s | 14592 | 14592 | 7.3 ft. hd | 7.3 ft. hd |
| GHX Module #02 - Pipe Section #10 | 2" | 3" | 22.86 gpm | 113.92 gpm | 2.47 ft/s | 5.24 ft/s | 20783 | 67509 | 0.4 ft. hd | 0.9 ft. hd |
| Circuit #11 | 1 1/4" | 1 1/4" | 11.38 gpm | 11.38 gpm | 2.52 ft/s | 2.52 ft/s | 14810 | 14810 | 7.6 ft. hd | 7.6 ft. hd |
| GHX Module #02 - Pipe Section #11 | 1 1/4" | 3" | 11.47 gpm | 125.30 gpm | 2.54 ft/s | 5.76 ft/s | 14926 | 74256 | 0.6 ft. hd | 1.0 ft. hd |
| Circuit #12 | 1 1/4" | 1 1/4" | 11.47 gpm | 11.47 gpm | 2.54 ft/s | 2.54 ft/s | 14926 | 14926 | 7.7 ft. hd | 7.7 ft. hd |

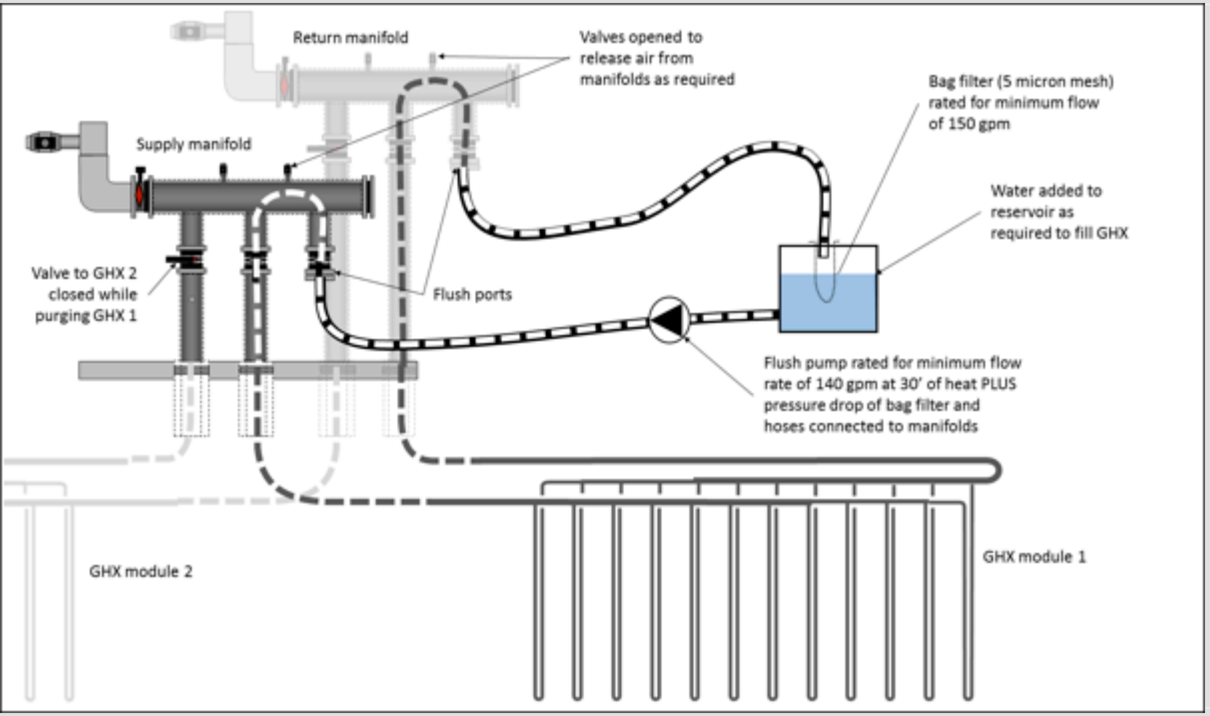
# Detailed manifold design

Specifications for the manifold and transitions from HDPE supply / return runouts to manifold and building piping system should be clear. Building penetrations should be appropriate for soil conditions.



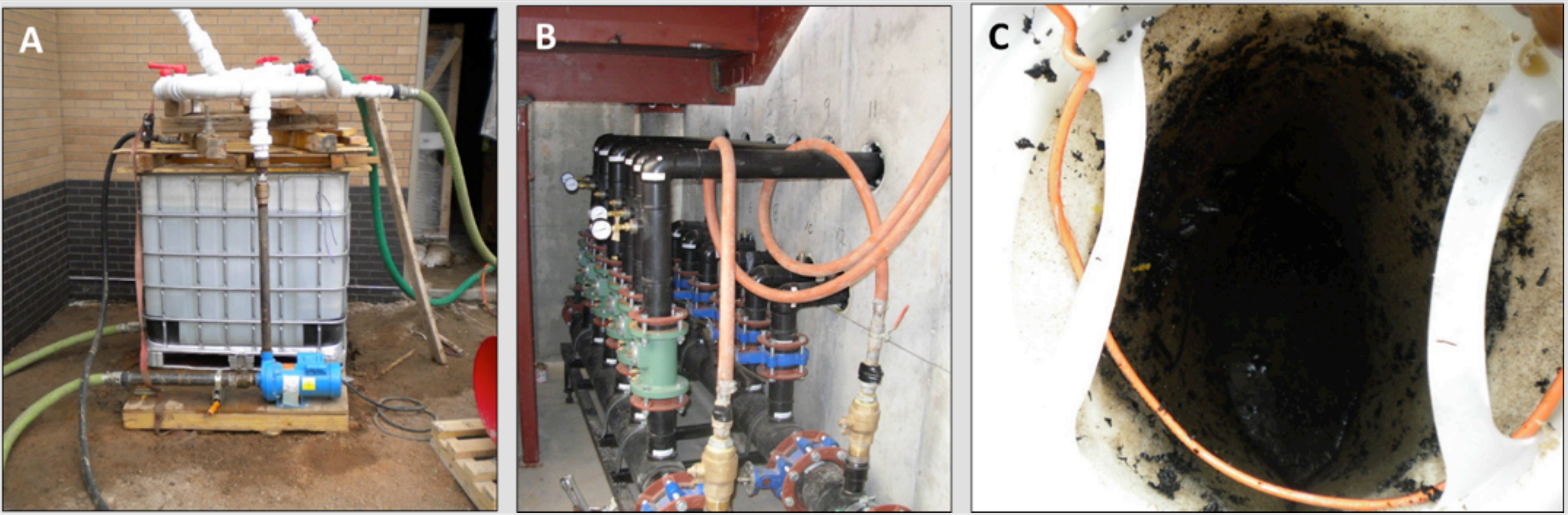
# Flushing procedures

Design should facilitate the contractor's ability to fill, flush and purge the system as easily as possible. Flush ports and valves should be designed for flow rates required.



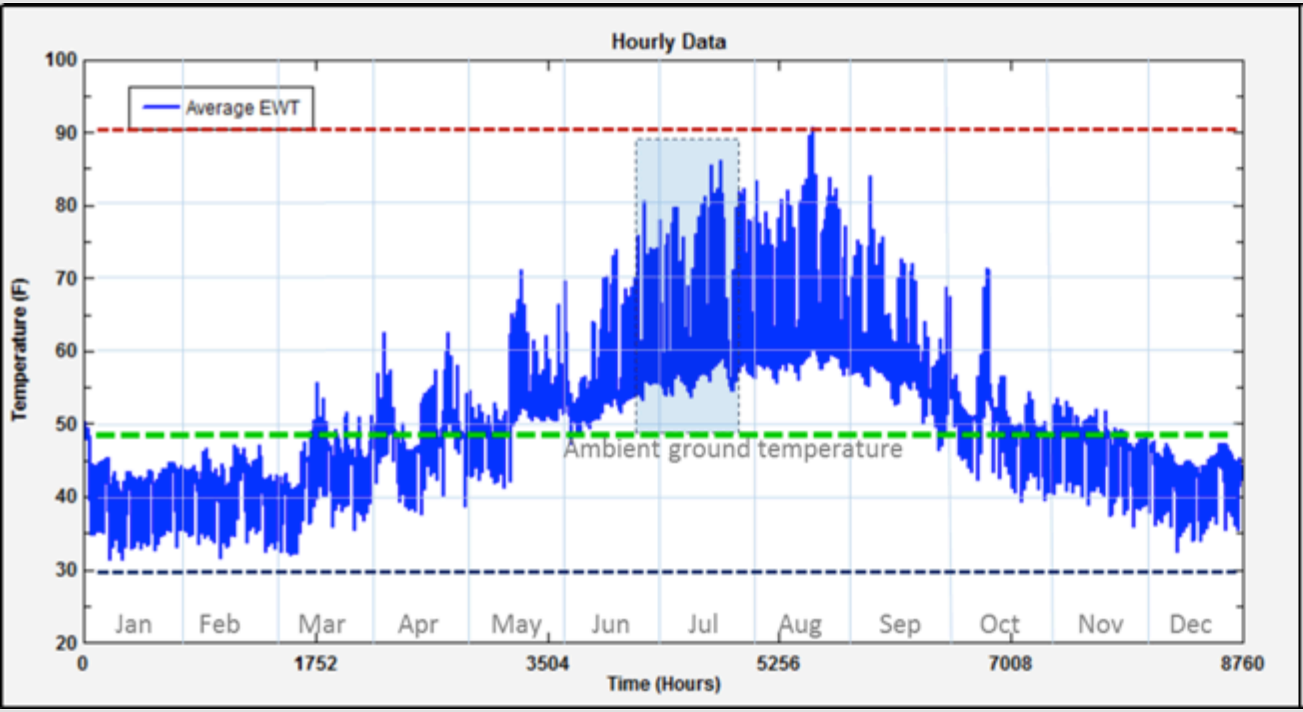
# Design specifications for contractor should be very clear

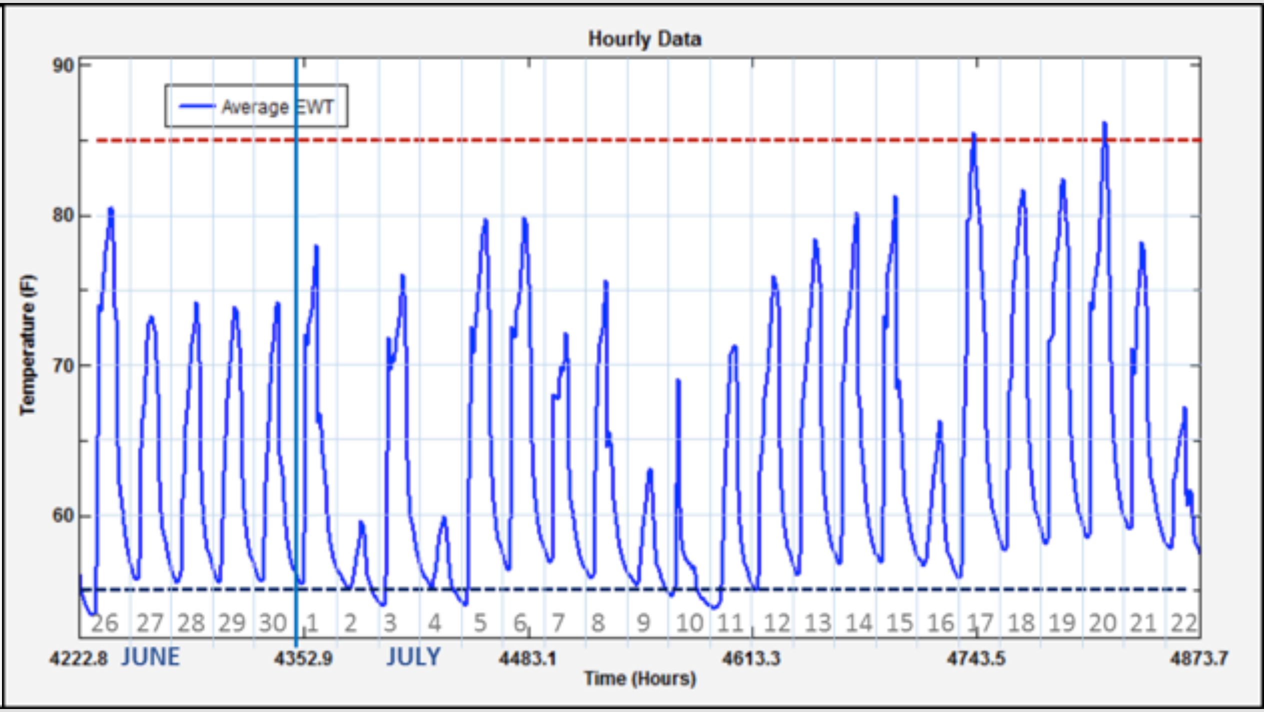
Specifications for contractor should be as clear as possible. Should indicate the minimum flow rates required to flush air, dirt and debris from the system…to prevent poor operation after turnover.



# Annual GHX temperature profile for building owner / operator

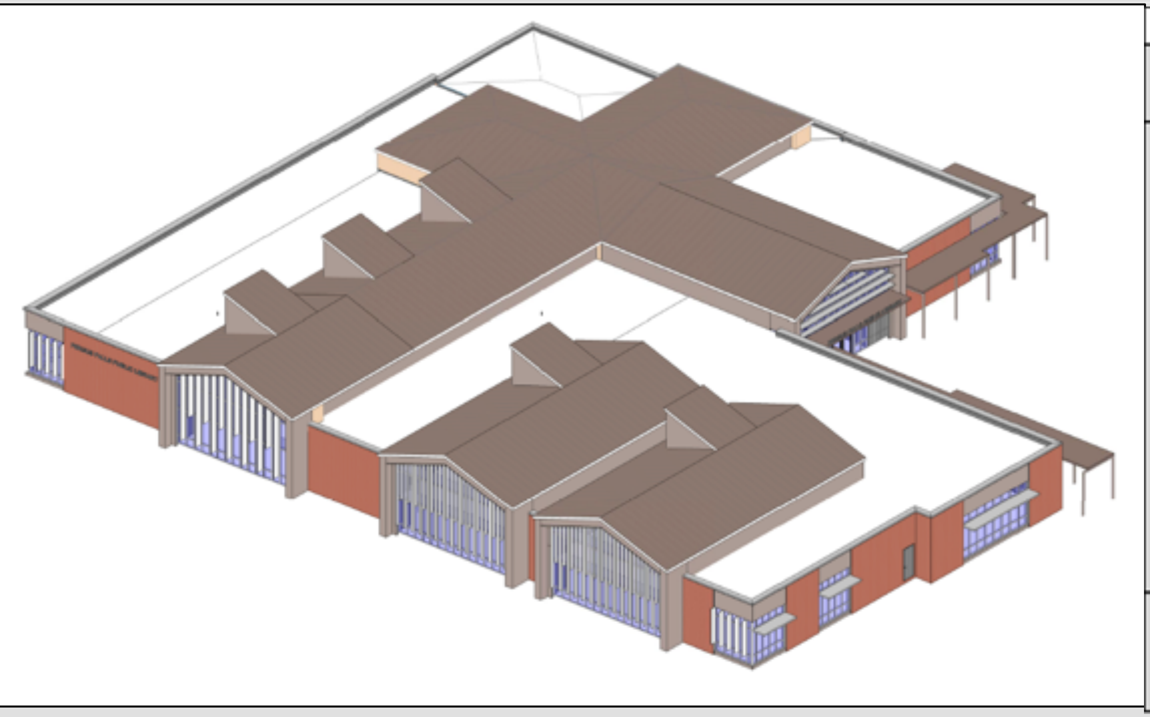
Building owner / operator should be provided with annual temperature profile the GHX is expected to operate at. If temperature deviates very much from expected profile, the cause should be determined. Operator should also be aware of the daily temperature range that can be expected.



# Daily GHX temperature profile

- Energy model indicates cooling load of 50 tons, heating load 408 kBtu/hr
- GHX design based on actual TC test and energy model: 7,200' of borehole
- 7,200' X $16 = $115,000
- Geothermal vault - not required
- **Total extra cost of GSHP system = $115,000** (versus $256,000)



Fergus Falls Library - Loads Revised 2016-02-01

| | Geo Cooling | | Geo Heating | |
|---|---|---|---|---|
| | kBtu | kBtu/hr | kBtu | kBtu/hr |
| Jan | 2944 | 76 | 92228 | 498 |
| Feb | 6618 | 121 | 74103 | 442 |
| Mar | 9465 | 208 | 55901 | 428 |
| Apr | 19538 | 315 | 16613 | 364 |
| May | 31168 | 392 | 7856 | 356 |
| Jun | 56369 | 544 | 825 | 205 |
| Jul | 90300 | 600 | 14 | 5 |
| Aug | 93134 | 592 | 73 | 42 |
| Sep | 45318 | 560 | 3579 | 286 |
| Oct | 12517 | 333 | 28559 | 412 |
| Nov | 8985 | 128 | 45079 | 445 |
| Dec | 4250 | 87 | 74467 | 473 |
| | 380,606 | 600 | 399,297 | 498 |
| | Tons | 50 | Tons | 41 |
| | EFLH | 634 | EFLH | 802 |

# Keeping Ground Source Heat Pump Projects on the Table

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ENERGY DESIGN
conference & expo

**Duluth, MN**

February 20-22, 2017

GEOptimize.ca