Using GLHEPRO for Ground Heat Exchanger Design

Part 1

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Goals

- The main goal of this lecture are to introduce the use of GLHEPRO for designing a ground heat exchanger used with a traditional GSHP system.
- Some things not covered because they are covered in other lectures:
  - Overview of GLHEPRO
  - Treating loads in GLHEPRO
  - Modeling heat pumps in GLHEPRO
  - Design and modeling of the borehole in GLHEPRO

Goals

- Some things not covered here may be covered in the future:
    - Hybrid ground source heat pump systems.
    - Horizontal and Slinky ground heat exchangers
    - Free Placement Finite Line Source (FPFLS) GHE model
    - Standing Column Wells
    - Hourly simulation

Outline

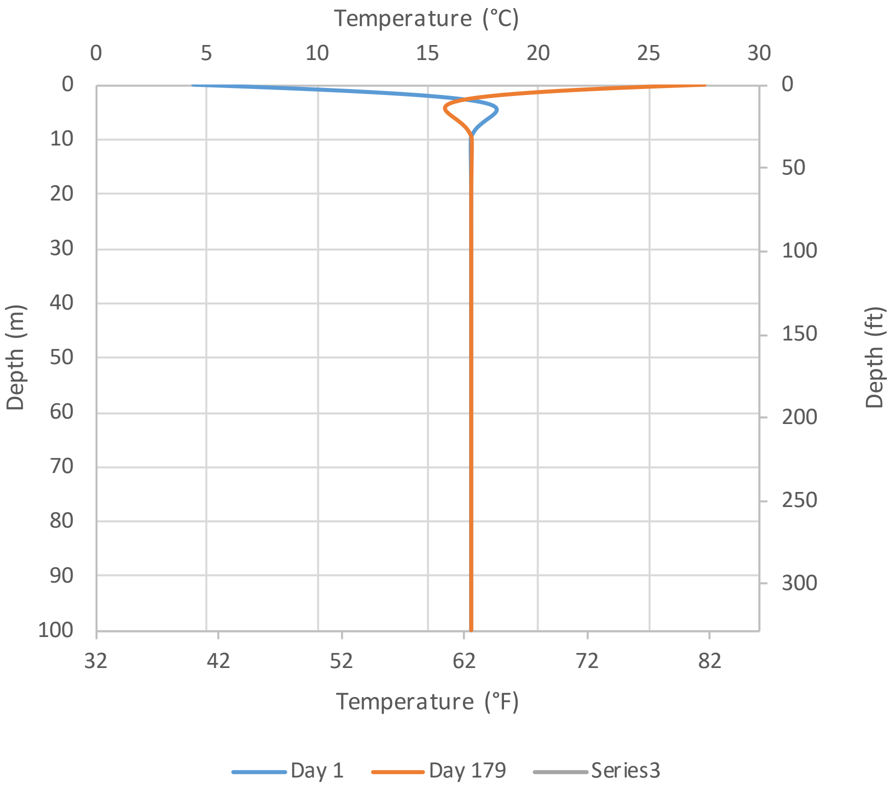
- Introduction to a few topics not yet covered
  - Undisturbed ground temperatures.
  - Fluid types and flow rates.
  - Temperature limits for sizing.
  - Design work flow.
- Demonstration

Undisturbed ground temperatures (UGT)

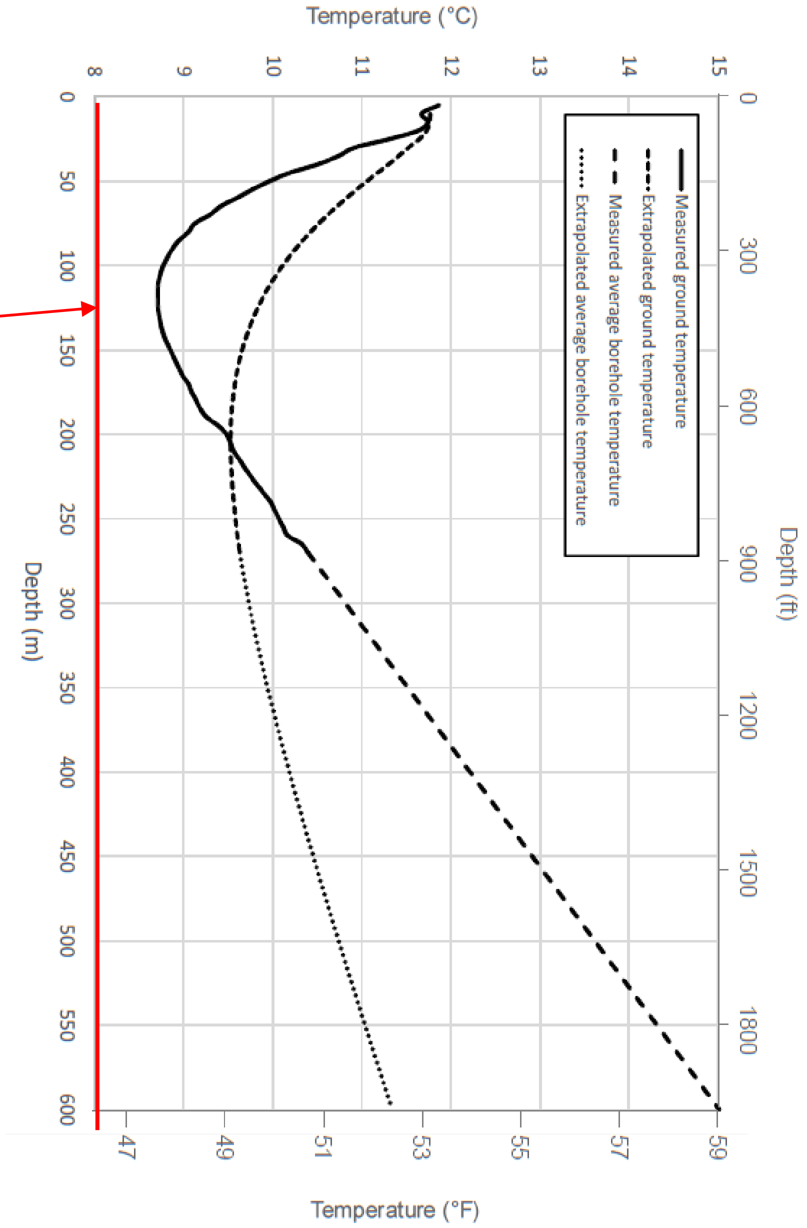
- For vertical boreholes, a single mean value suffices.
  - Temperature variation over the year has minimal effect on the mean ground temperature for a borehole of, say, 75 m or deeper.
  - Best determined with a downhole measurement, or estimated with data collected before the heat pulse starts in a thermal response test.
  - GLHEPRO has a method for estimating this for undisturbed conditions. (I.e. not affected by buildings or pavement)
- For shallow horizontal ground heat exchangers, GLHEPRO has a model that predicts T=f(depth, date)

GLHEPRO model

- Based on Xing and Spitler (2017a,b) and Xing, et al. (2017)
- 4112 sites worldwide
- Parameters estimated from typical weather data and detailed simulation.
- Does not include:
    - Geothermal gradient
    - Urban effects.
- User can change parameters to account for these effects.



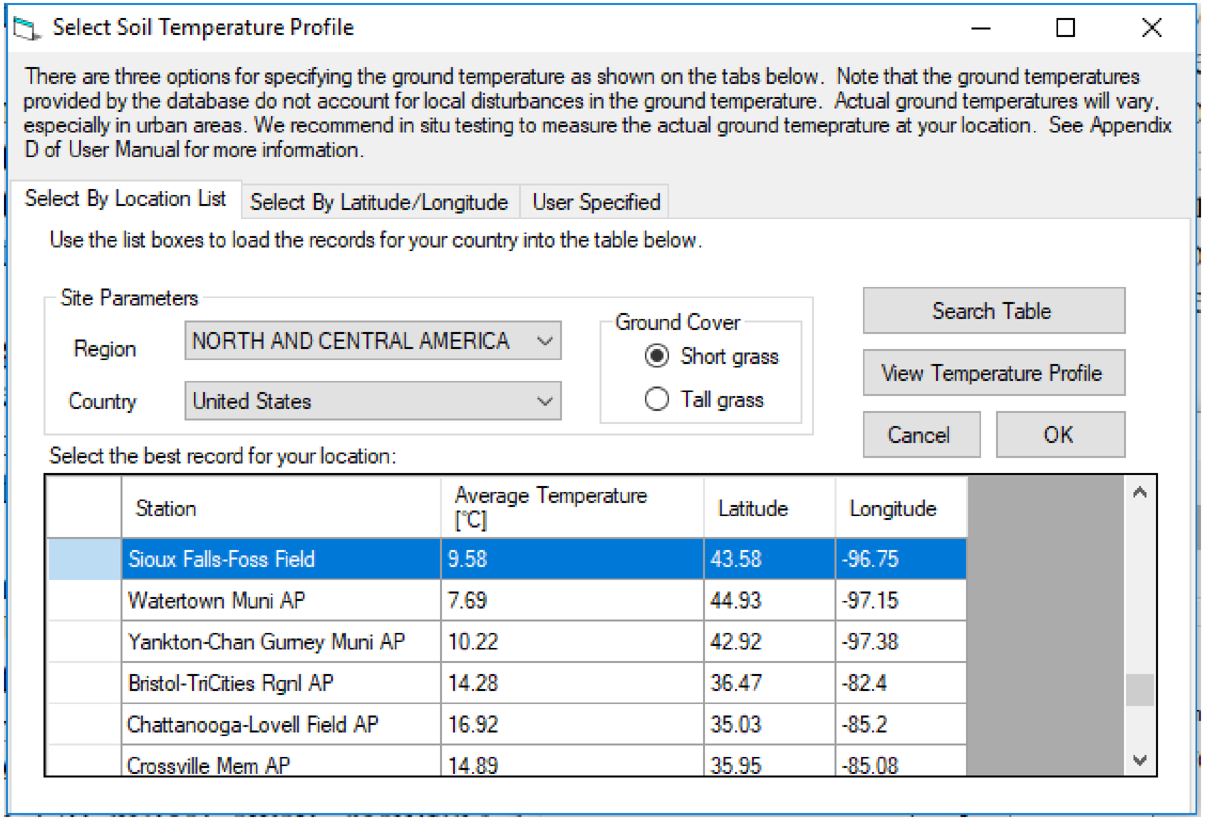
Stockholm example



Expected Stockholm UGT

Source: Gehlin, et al. 2016

UGT Interface



There are three options for specifying the ground temperature as shown on the tabs below. Note that the ground temperatures provided by the database do not account for local disturbances in the ground temperature. Actual ground temperatures will vary, especially in urban areas. We recommend in situ testing to measure the actual ground temeprature at your location. See Appendix D of User Manual for more information.

Use the list boxes to load the records for your country into the table below.

Site Parameters

Region: NORTH AND CENTRAL AMERICA

Country: United States

Ground Cover

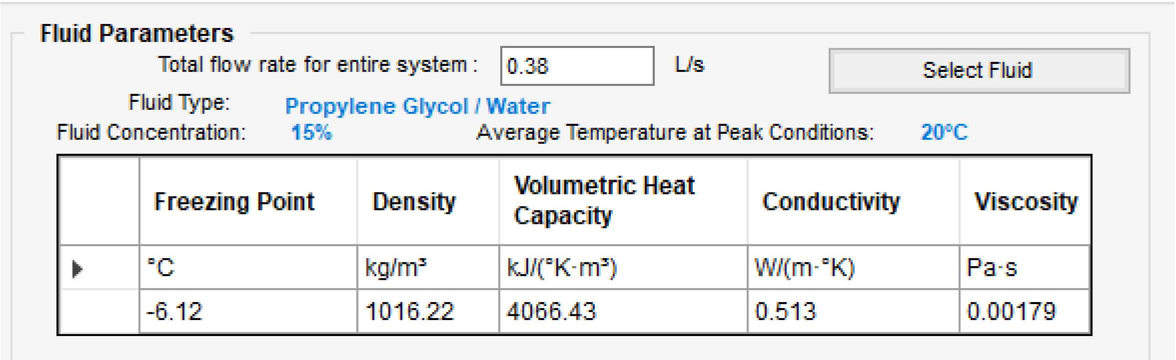
● Short grass

○ Tall grass

Select the best record for your location:

Station	Average Temperature [°C]	Latitude	Longitude
Sioux Falls-Foss Field	9.58	43.58	-96.75
Watertown Muni AP	7.69	44.93	-97.15
Yankton-Chan Gurney Muni AP	10.22	42.92	-97.38
Bristol-TriCities Rgnl AP	14.28	36.47	-82.4
Chattanooga-Lovell Field AP	16.92	35.03	-85.2
Crossville Mem AP	14.89	35.95	-85.08

Fluid types and flow rates



Fluid Parameters

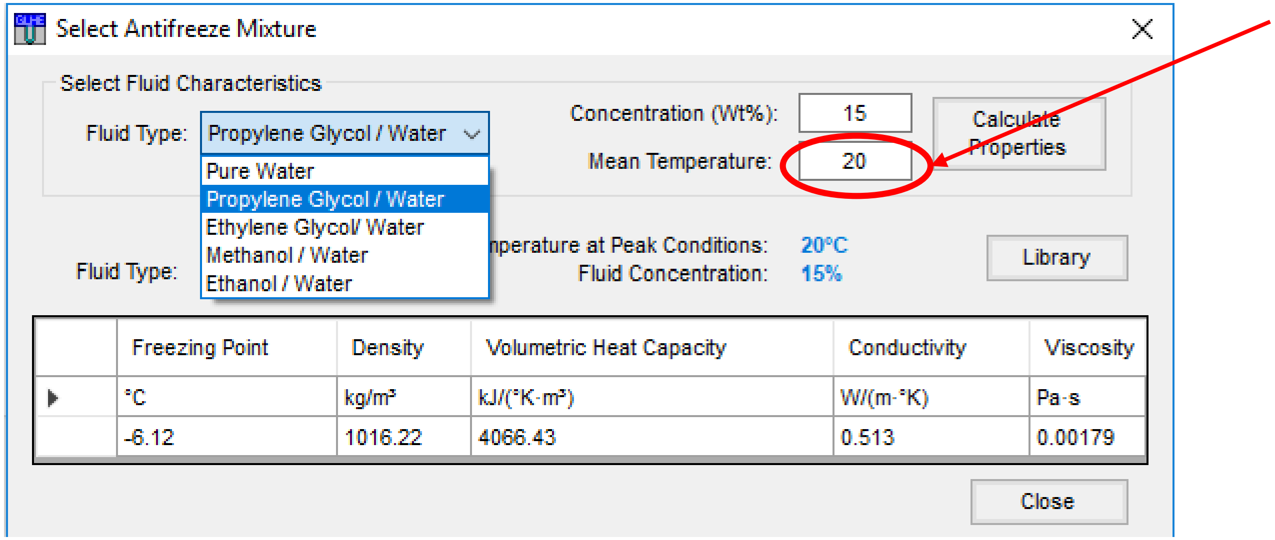
Total flow rate for entire system : 0.38 L/s

Fluid Type: Propylene Glycol / Water

Fluid Concentration: 15%

Average Temperature at Peak Conditions: 20°C

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▶	°C	kg/m³	kJ/(°K·m³)	W/(m·°K)	Pa·s
	-6.12	1016.22	4066.43	0.513	0.00179



Select Antifreeze Mixture

Select Fluid Characteristics

Fluid Type: Propylene Glycol / Water

Concentration (Wt%): 15

Mean Temperature: 20

nperature at Peak Conditions: 20°C

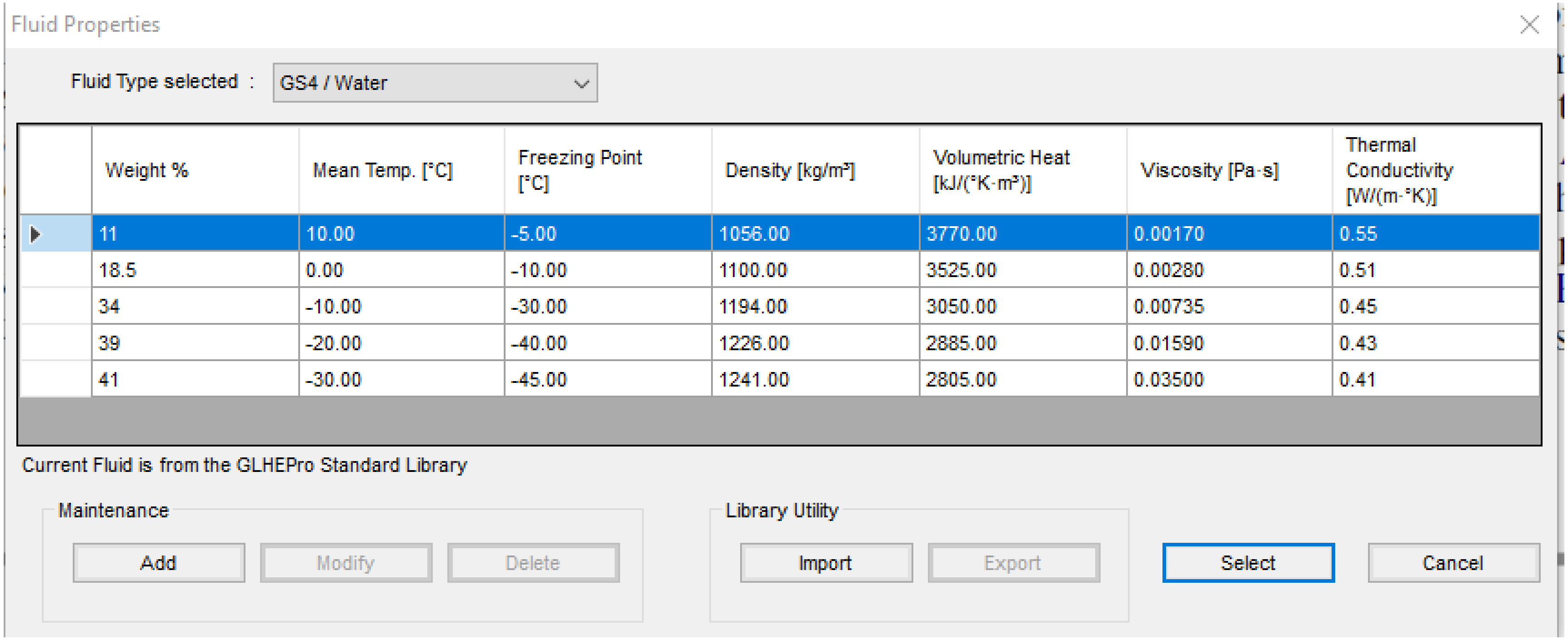
Fluid Type:

Fluid Concentration: 15%

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▶	°C	kg/m³	kJ/(°K·m³)	W/(m·°K)	Pa·s
	-6.12	1016.22	4066.43	0.513	0.00179

Set temperature near design constraint (Max EFT or Min EFT)

Fluid types and flow rates



Fluid Type selected : GS4 / Water

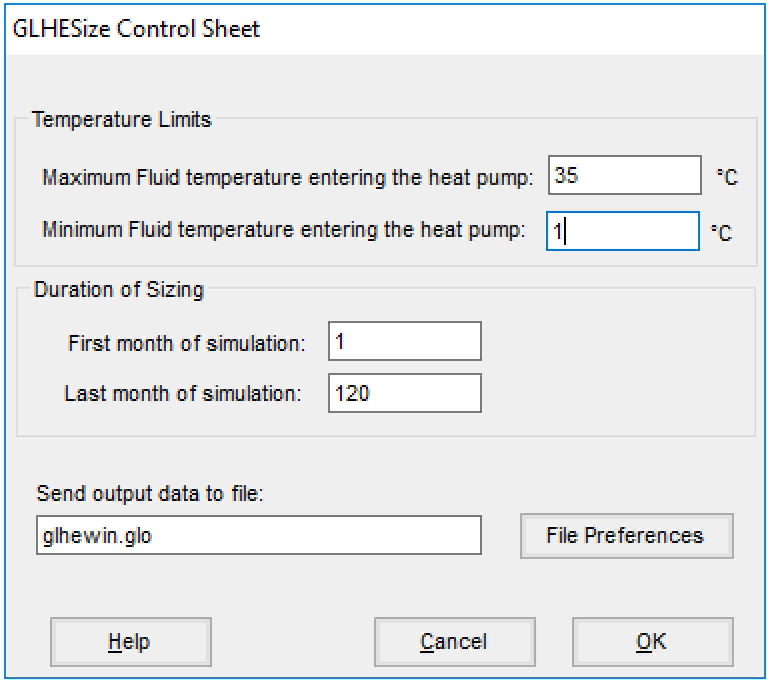
	Weight %	Mean Temp. [°C]	Freezing Point [°C]	Density [kg/m³]	Volumetric Heat [kJ/(°K·m³)]	Viscosity [Pa·s]	Thermal Conductivity [W/(m·°K)]
▶	11	10.00	-5.00	1056.00	3770.00	0.00170	0.55
	18.5	0.00	-10.00	1100.00	3525.00	0.00280	0.51
	34	-10.00	-30.00	1194.00	3050.00	0.00735	0.45
	39	-20.00	-40.00	1226.00	2885.00	0.01590	0.43
	41	-30.00	-45.00	1241.00	2805.00	0.03500	0.41

Current Fluid is from the GLHEPro Standard Library

Temperature limits

- Set by user when sizing.
- Temperatures should be consistent with heat pump unit selection.
- For commercial buildings, recommended range:
    - Max EFT: 20-30°F above GT (11-17°C above GT)
    - Min EFT: 10-16°F below GT (6-9°C below GT)

(Meline and Kavanaugh 2019)



GLHESize Control Sheet

Temperature Limits

Maximum Fluid temperature entering the heat pump: 35 °C

Minimum Fluid temperature entering the heat pump: 1 °C

Duration of Sizing

First month of simulation: 1

Last month of simulation: 120

Send output data to file: glhewin.glo

Work flow

- Determine hourly heating and cooling loads on heat pumps for typical year.
- Use a thermal response test to determine ground thermal properties, drilling conditions, GT.
- Select minimum and maximum heat pump EFT
- Interior design: select heat pumps to meet internal loads. Apply corrections for actual conditions.
- Size field, adjusting borehole spacing, borehole design, and other factors to minimize required drilling and overall costs.

Work flow

- Other steps to be covered in Part 2 (not recorded yet):
    - Checking hydraulic efficiency.
    - Checking system efficiency.
- Meline and Kavanaugh (2013) make suggestions. I plan to add some more.

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Part 2 – Not available yet

(Checking hydraulic and system efficiency)

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Part 3 – Example

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Example

- 3-story office building.
- Based on the medium office building reference model from Deru, et al. (2011)
- An ASHRAE 90.1 baseline reference case.
- Uses VAV systems with electric reheat and packaged air conditioning units.
- Reference building in Denver; moved to Stillwater.

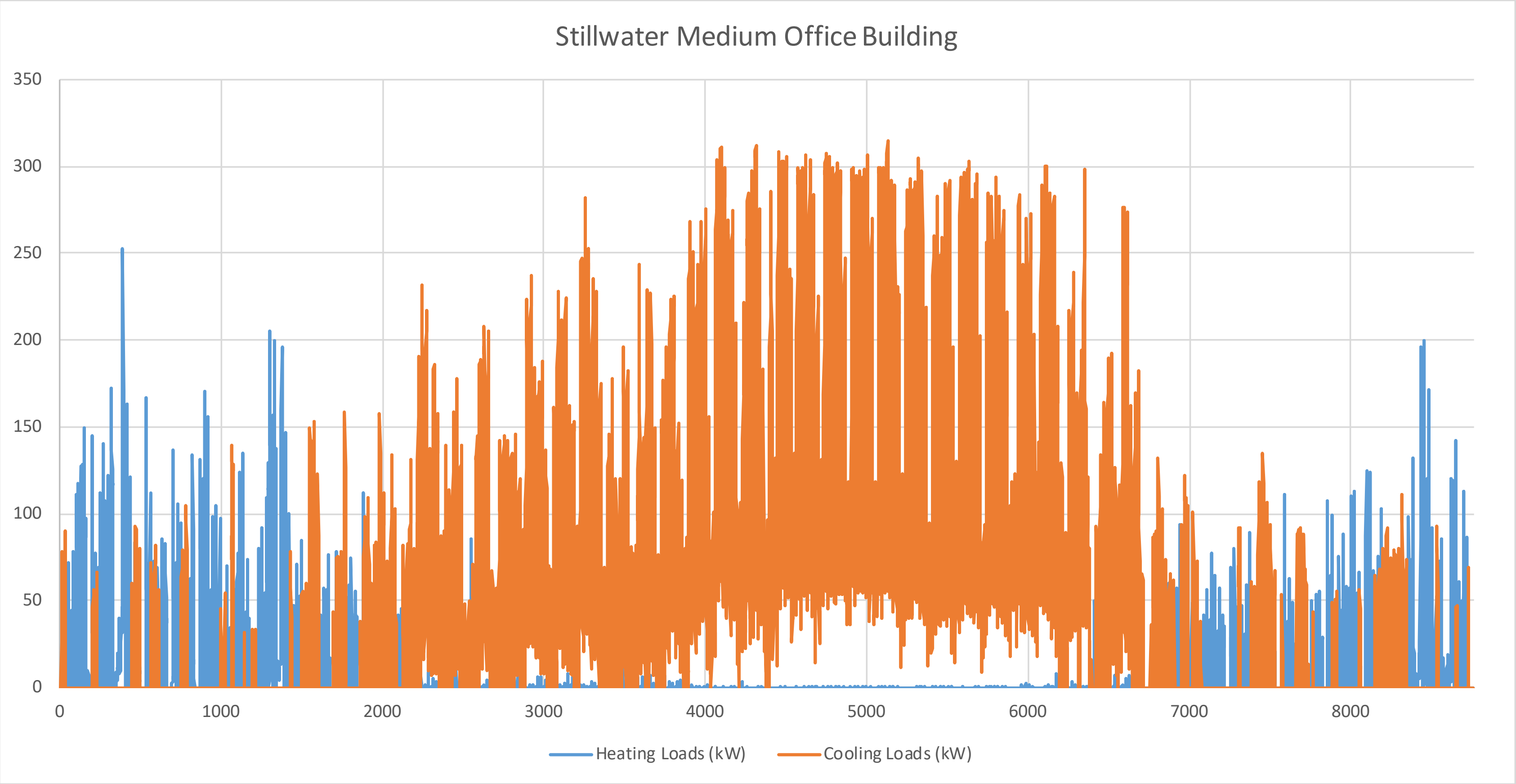
Example – EnergyPlus (9.2)

- I output the hourly heating and cooling coil loads for three packaged AC units + reheat coils in the zones.
- Obtained block loads by summing:
  - All hourly heating loads
  - All hourly cooling loads
- This is NOT an EnergyPlus training lecture, but the relevant lines in the IDF are:

```
Output:Variable,*,Heating Coil Heating Rate,hourly;
Output:Variable,*,Cooling Coil Total Cooling Rate,hourly;
```

Hourly Loads

Annual cooling is 7.4x annual heating



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Ground thermal properties and borehole thermal resistance

	SI Units	IP Units
Thermal conductivity	$2.8\,\frac{\mathrm{W}}{\mathrm{m\cdot K}}$	$1.62\,\frac{\mathrm{Btu}}{\mathrm{h\cdot ft\cdot{}^{\circ}F}}$
Volumetric specific heat ($\rho\cdot c_p$)	$2500\frac{\mathrm{kJ}}{\mathrm{m^{3}K}}$	$37.28\,\frac{\mathrm{Btu}}{\mathrm{ft^{3}{}^{\circ}F}}$
Borehole thermal resistance	$0.118\frac{\mathrm{K}}{\left(\mathrm{W}/\mathrm{m}\right)}$	$0.2048\frac{{}^{\circ}\mathrm{F}}{\left(\mathrm{Btu}/\mathrm{h{\cdot}ft}\right)}$
Ground temperature	17.53°C	63.55°F

Example

- Analyze hourly loads in peak load analysis tool.
- Utilize ground properties determined (approximately) using a thermal response test.
- Start with conventional borehole design.
- Utilize heat pump that we've analyzed earlier.
- Iteratively revise design.

Example

- Check sensitivity to corrections in heat pump model.
- Check sensitivity to UGT
- Check sensitivity to design temperatures.

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Part 4 – Live demo

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Live demo here

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Part 5 – Live demo, continued

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Part 6 – Example, continued

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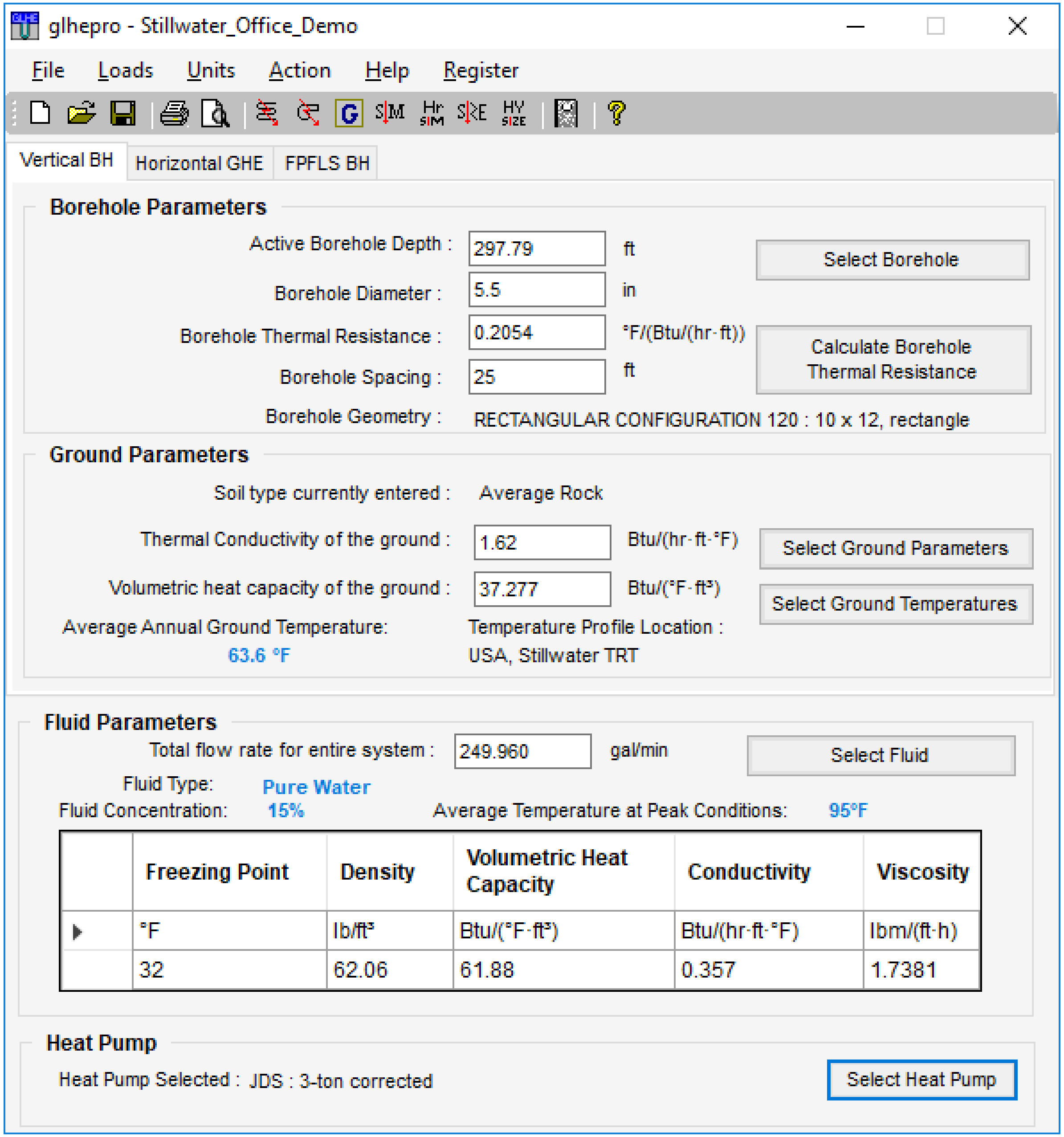
Live demo here

Base case

Max EFT= 92.5°F

Depth = 303.5 ft



Borehole Parameters

Active Borehole Depth : 297.79 ft

Borehole Diameter : 5.5 in

Borehole Thermal Resistance : 0.2054 °F/(Btu/(hr·ft))

Borehole Spacing : 25 ft

Borehole Geometry : RECTANGULAR CONFIGURATION 120 : 10 x 12, rectangle

Ground Parameters

Soil type currently entered : Average Rock

Thermal Conductivity of the ground : 1.62 Btu/(hr·ft·°F)

Volumetric heat capacity of the ground : 37.277 Btu/(°F·ft³)

Average Annual Ground Temperature: 63.6 °F

Temperature Profile Location : USA, Stillwater TRT

Fluid Parameters

Total flow rate for entire system : 249.960 gal/min

Fluid Type: Pure Water

Fluid Concentration: 15%

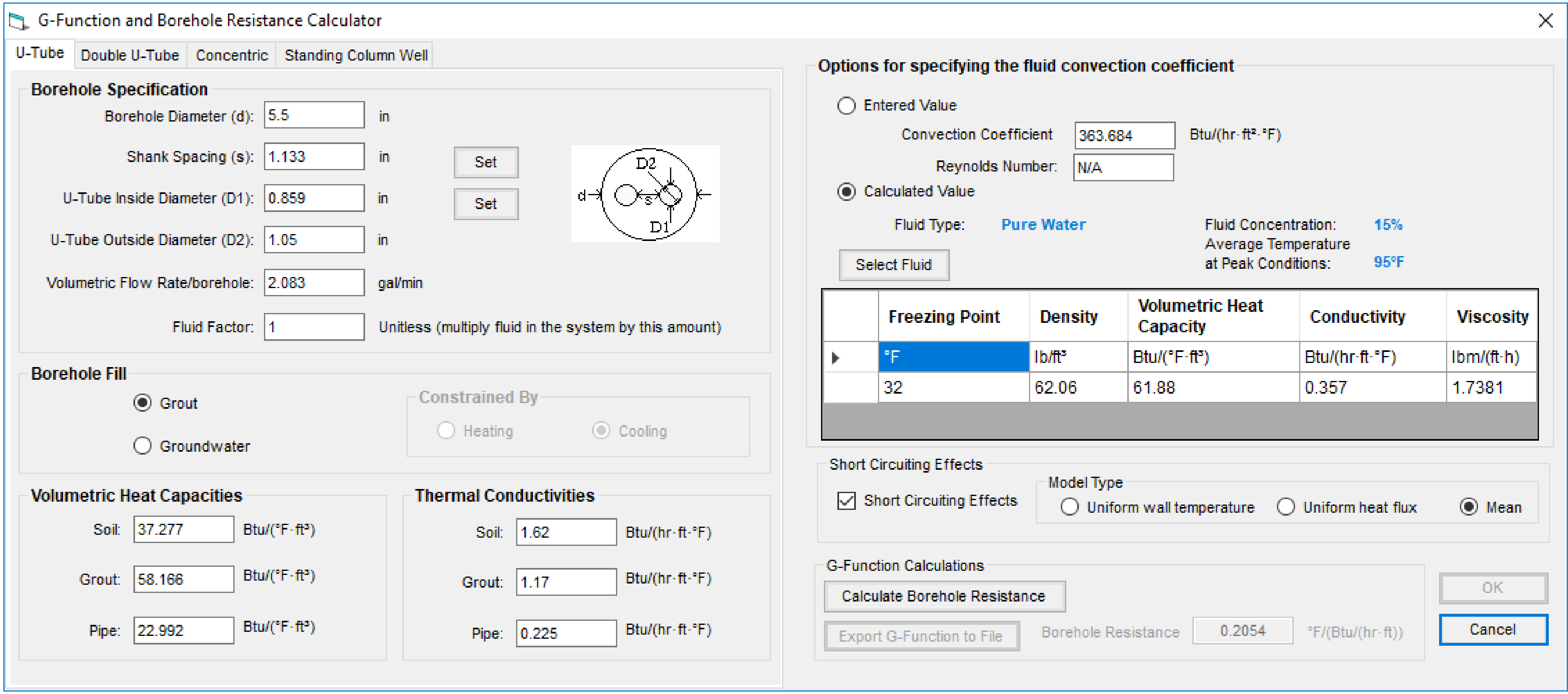
Average Temperature at Peak Conditions: 95°F

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▶	°F	lb/ft³	Btu/(°F·ft³)	Btu/(hr·ft·°F)	lbm/(ft·h)
	32	62.06	61.88	0.357	1.7381

Heat Pump

Heat Pump Selected : JDS : 3-ton corrected

Base case



Borehole Specification

Borehole Diameter (d): 5.5 in

Shank Spacing (s): 1.133 in

U-Tube Inside Diameter (D1): 0.859 in

U-Tube Outside Diameter (D2): 1.05 in

Volumetric Flow Rate/borehole: 2.083 gal/min

Fluid Factor: 1 Unitless (multiply fluid in the system by this amount)

Borehole Fill

● Grout

○ Groundwater

Constrained By: ○ Heating ● Cooling

Volumetric Heat Capacities

Soil: 37.277 Btu/(°F·ft³)

Grout: 58.166 Btu/(°F·ft³)

Pipe: 22.992 Btu/(°F·ft³)

Thermal Conductivities

Soil: 1.62 Btu/(hr·ft·°F)

Grout: 1.17 Btu/(hr·ft·°F)

Pipe: 0.225 Btu/(hr·ft·°F)

Options for specifying the fluid convection coefficient

○ Entered Value

Convection Coefficient 363.684 Btu/(hr·ft²·°F)

Reynolds Number: N/A

● Calculated Value

Fluid Type: Pure Water

Fluid Concentration: 15%

Average Temperature at Peak Conditions: 95°F

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▸	°F	lb/ft³	Btu/(°F·ft³)	Btu/(hr·ft·°F)	lbm/(ft·h)
	32	62.06	61.88	0.357	1.7381

Short Circuiting Effects

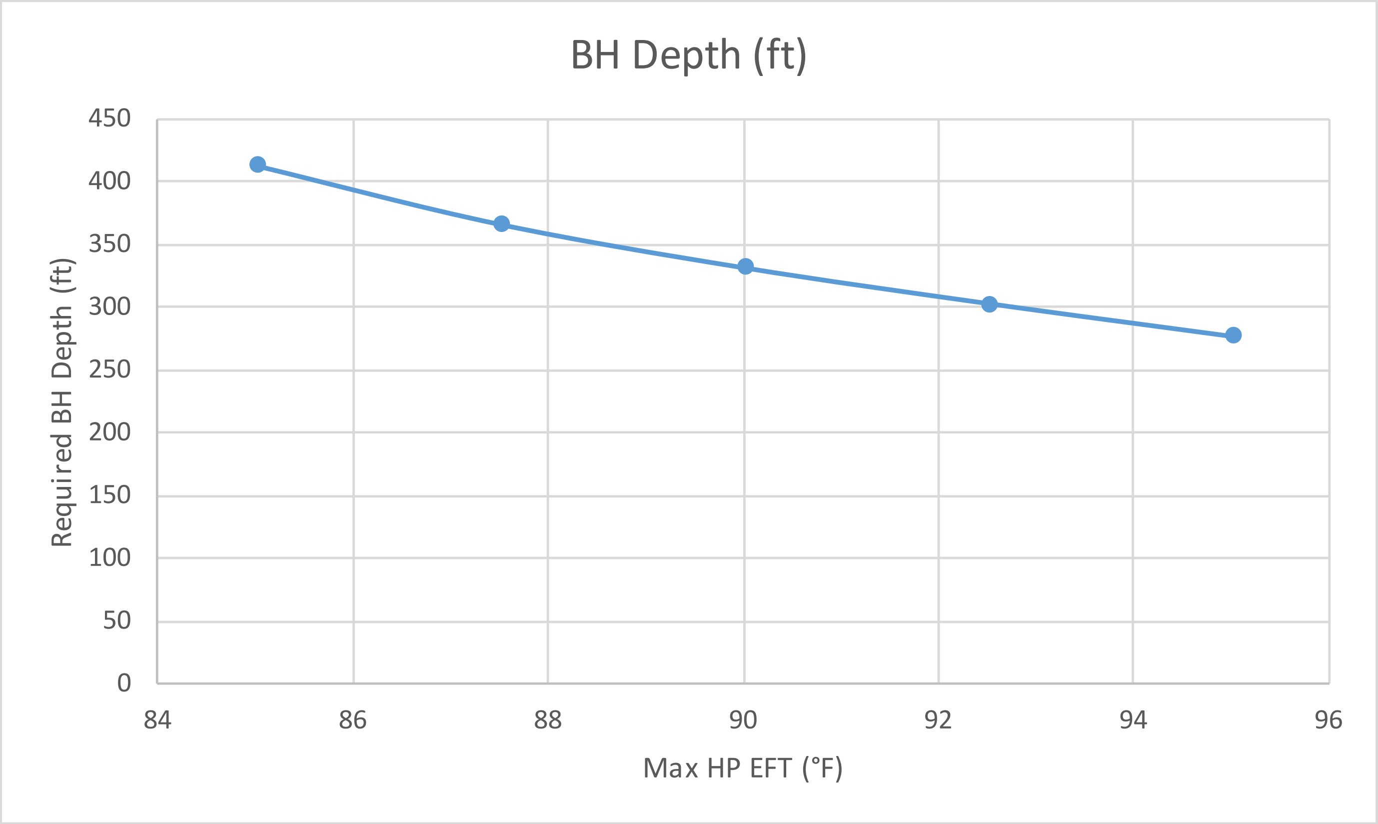
☑ Short Circuiting Effects

Model Type: ○ Uniform wall temperature ○ Uniform heat flux ● Mean

G-Function Calculations

Borehole Resistance 0.2054 °F/(Btu/(hr·ft))

Sensitivity to max HP EFT



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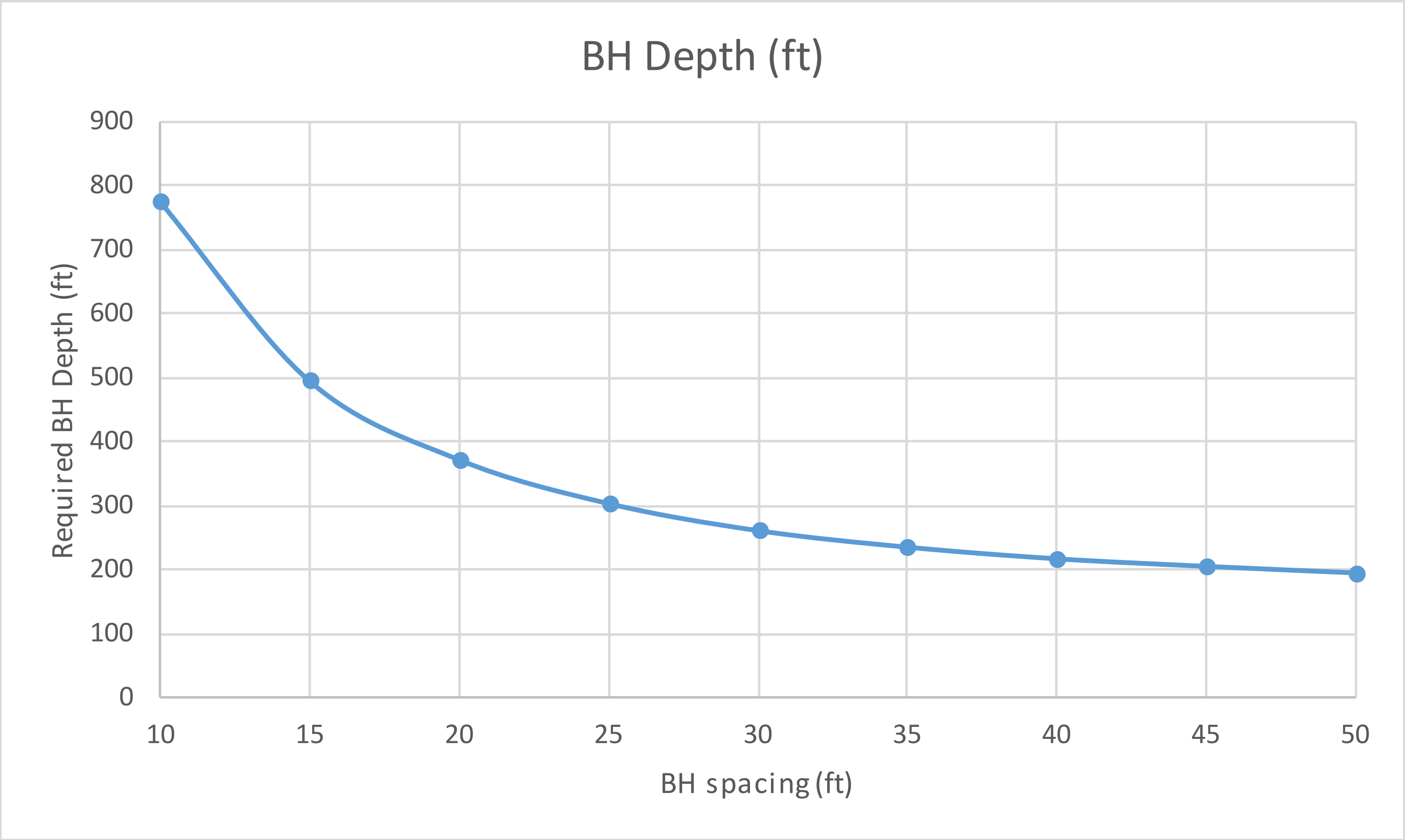
Sensitivity

- Base case: 303.5’
- Use uncorrected heat pump: 297.8’ (2%)
- Use spacers to get C spacing: 279.5’ (8%)
- Use 62.5°F as UGT (instead of 63.55°F): 292.8’ (4%)

Sensitivity to spacing



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Suggests general strategy

- Maximize spacing.
- With fixed surface (land) area:
  - Decrease number of boreholes
  - Increase spacing
- Our 12x10 base case uses a rectangle: 275’ x 225’
  - 36,420’ total drilling
- Try: 10x8, 30.6’ spacing: 406.3’ depth
  - 32,504’ total drilling (11% reduction)

Other strategies

- Use hybrid GSHP system.
- Or make use of excess heating:
  - Hot water for dishwashing
  - Parking lot de-icing
- Adjust building envelope design, e.g. change the windows. See Javed, et al. (2019).

References

- Software
  - GLHEPRO: https://hvac.okstate.edu/glhepro/overview
- References
  - GLHEPRO Manual*

* available at https://hvac.okstate.edu

References

Deru, M., K. Field, D. Studer, K. Benne, B. Griffith, P. A. Torcellini, B. Liu, M. Halverson, D. Winiarski, M. Rosenberg, M. Yazdanian, J. Huang and D. Crawley 2011. U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. NREL, NREL/TP-5500-46861. **

Gehlin, S. E. A., J. D. Spitler and G. Hellström 2016. Deep Boreholes for Ground Source Heat Pump Systems – Scandinavian Experience and Future Prospect. ASHRAE Winter Conference. Orlando, ASHRAE.*

Javed, S., I. R. Ornes, M. Myrup and T. H. Dokka. 2019. *Design optimization of the borehole system for a plus-Energy kindergarten in Oslo, Norway*. Architectural Engineering and Design Management 15(3): 181-195.**

Meline, L. and S. Kavanaugh. 2019. *Geothermal Heat Pumps - Simply Efficient*. ASHRAE Transactions 125(2): 566-576.

.

* available at https://hvac.okstate.edu **open access

References

Xing, L. and J. D. Spitler. 2017a. *Prediction of undisturbed ground temperature using analytical and numerical modeling. Part I: Model development and experimental validation*. Science and Technology for the Built Environment 23(5): 787-808.

Xing, L. and J. D. Spitler. 2017b. *Prediction of undisturbed ground temperature using analytical and numerical modeling. Part II: Methodology for developing a world-wide dataset*. Science and Technology for the Built Environment 23(5): 809-825.

Xing, L., J. D. Spitler and A. Bandyopadhyay. 2017. *Prediction of undisturbed ground temperature using analytical and numerical modeling. Part III: Experimental validation of a world-wide dataset*. Science and Technology for the Built Environment 23(5): 826-842.

* available at https://hvac.okstate.edu