

# Ground Heat Exchangers Introduction to Design with GLHEPRO

## Part 1

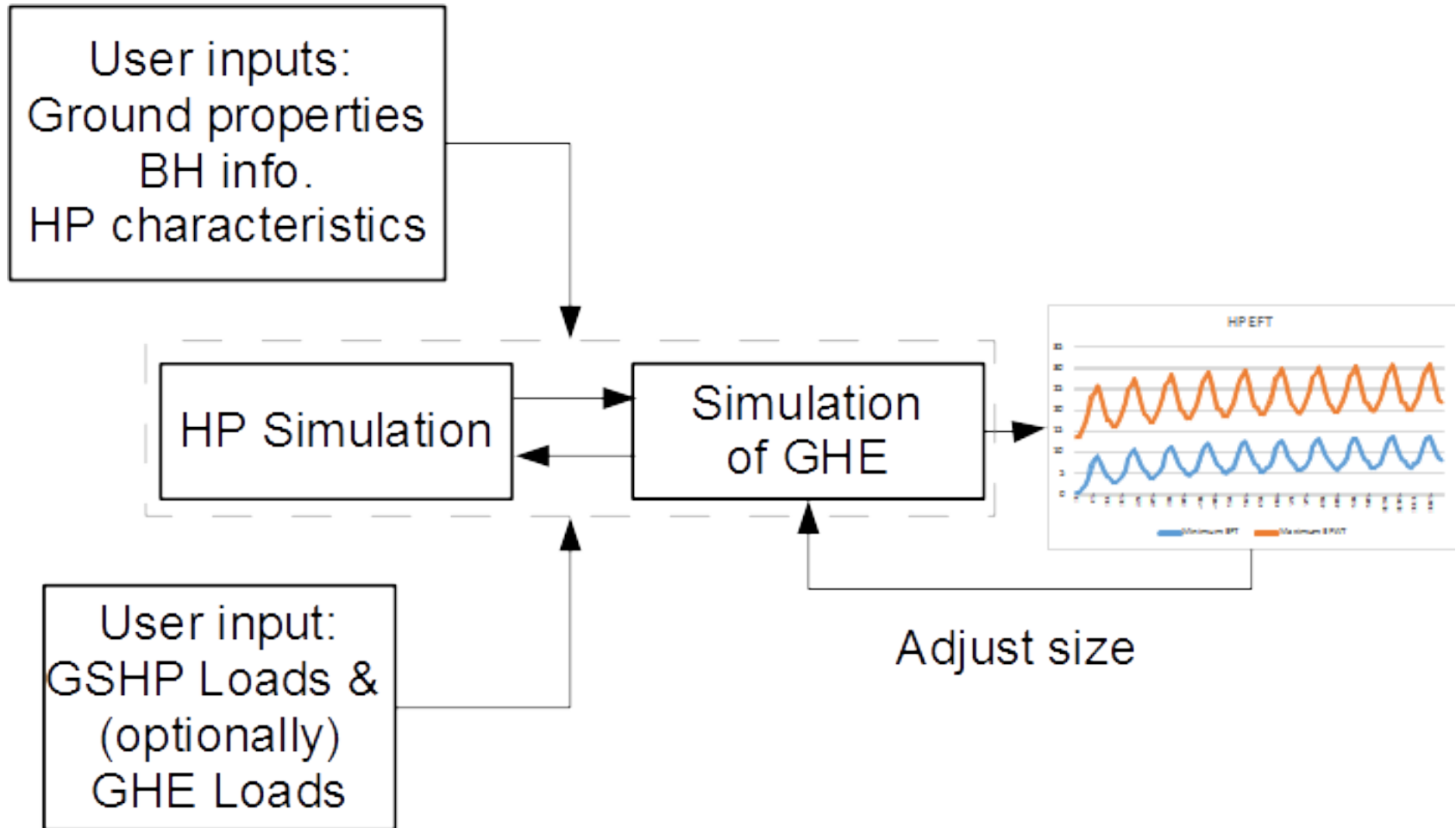
Jeffrey D. Spitler  
spitler@okstate.edu

<https://hvac.okstate.edu/>

*©2020, Jeffrey D. Spitler  
All rights reserved*

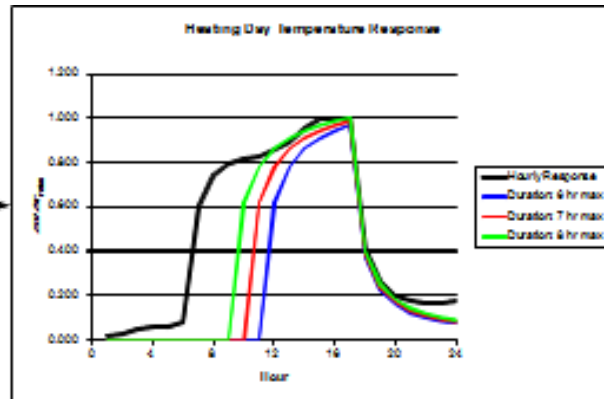


# GLHEPRO



# Peak Load Analysis Tool

Hourly Htg.  
& Clg. Loads

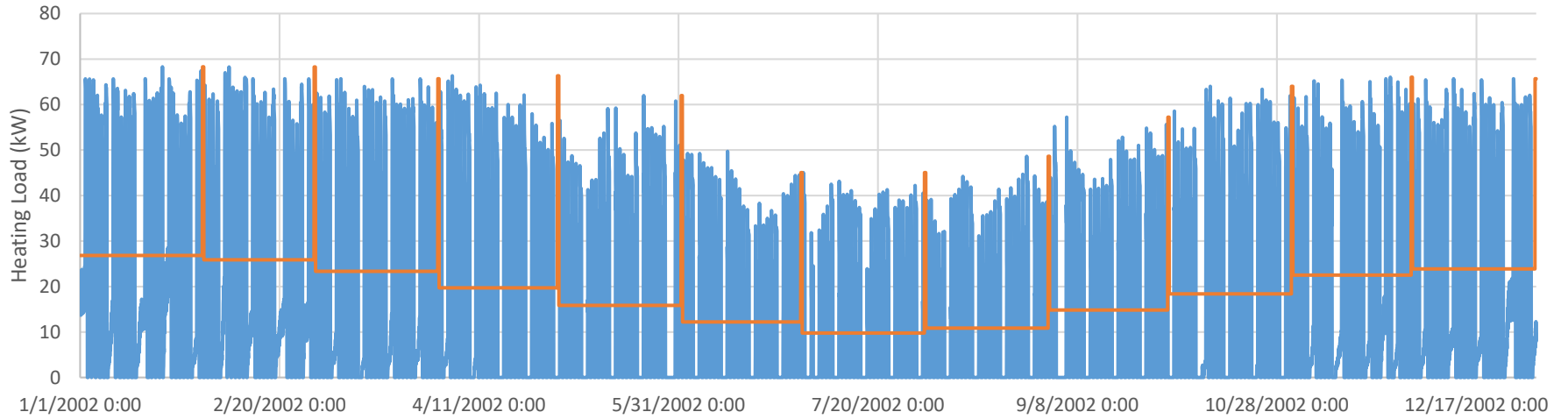


*Peak load analysis tool*

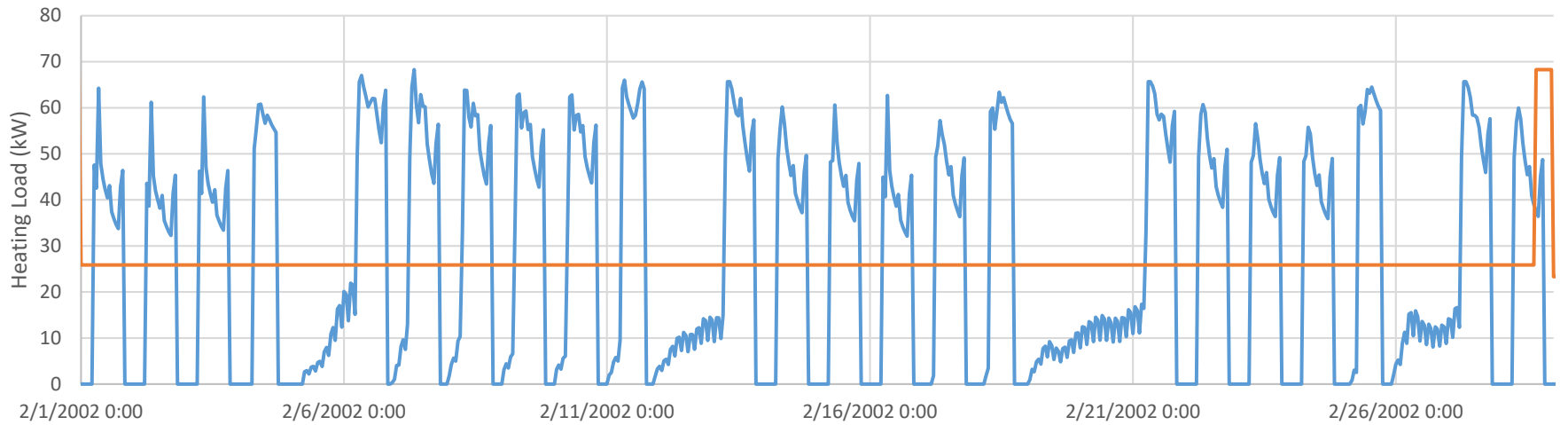
User input:  
GSHP Loads &  
(optionally)  
GHE Loads

*Monthly & monthly  
peak loads*

### Heating Load Representations



### Heating Load Representations



# Step 1

- Calculate hourly heating and cooling loads on heat pumps for typical year.
- Use building simulation tool:
  - EnergyPlus
  - eQuest
  - Others

Step 2: Paste in 8760 hourly loads

Step 3: Compute peak days

The spreadsheet displays a table with the following columns: Date/Time, Heating delivered kW, Cooling delivered kW, Location, and Unit System. The data covers the period from 1/1/2002 1:00 to 1/2/2002 7:00.

Date/Time	Heating delivered kW	Cooling delivered kW	Location	Unit System
1/1/2002 1:00	21.76246	-7.47316	Stockholm	Metric (SI)
1/1/2002 2:00	19.86573	-7.77564		English (IP)
1/1/2002 3:00	13.68528	-5.15616		
1/1/2002 4:00	20.9252	-7.67328		
1/1/2002 5:00	20.12411	-7.88536		
1/1/2002 6:00	13.88888	-5.18508		
1/1/2002 7:00	21.37021	-7.67378		
1/1/2002 8:00	20.76862	-7.86494		
1/1/2002 9:00	14.83803	-5.13558		
1/1/2002 10:00	23.74778	-7.52333		
1/1/2002 11:00	22.63524	-7.65501		
1/1/2002 12:00	15.09649	-5.00214		
1/1/2002 13:00	22.54924	-7.40703		
1/1/2002 14:00	20.78142	-7.62792		
1/1/2002 15:00	14.0822	-5.02342		
1/1/2002 16:00	21.31755	-7.4507		
1/1/2002 17:00	20.26418	-7.67678		
1/1/2002 18:00	14.19022	-5.05019		
1/1/2002 19:00	21.87893	-7.46427		
1/1/2002 20:00	20.74487	-7.66754		
1/1/2002 21:00	14.34266	-5.04792		
1/1/2002 22:00	22.2464	-7.48822		
1/1/2002 23:00	21.51573	-7.70806		
1/2/2002 1:00	14.98396	-5.0546		
1/2/2002 2:00	22.94623	-7.43603		
1/2/2002 3:00	21.94159	-7.61132		
1/2/2002 4:00	15.41203	-4.98546		
1/2/2002 5:00	24.39639	-7.34024		
1/2/2002 6:00	23.47523	-7.5049		
1/2/2002 7:00	32.82498	-8.37573		

**Instructions:**

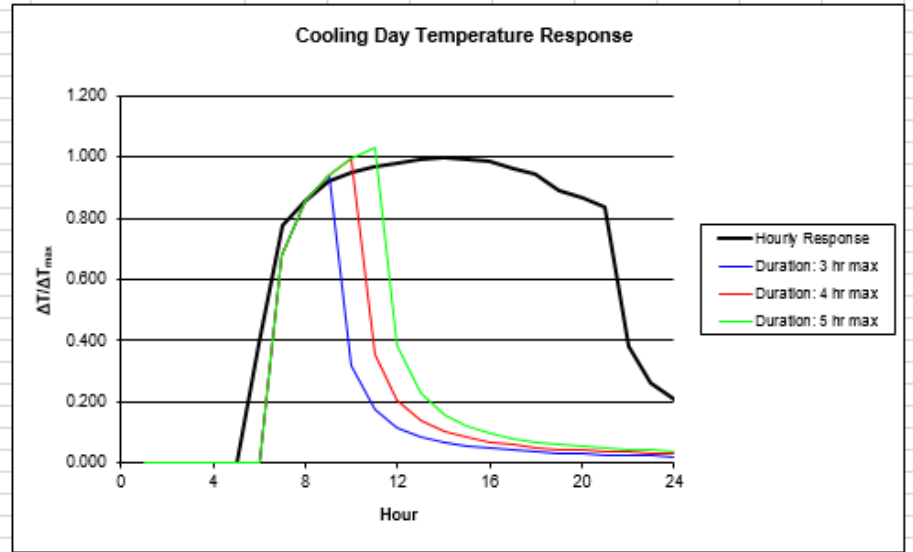
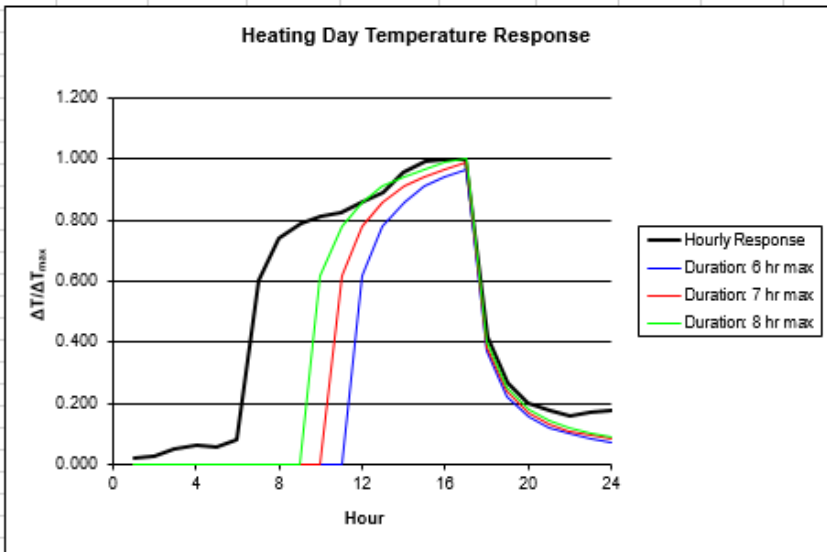
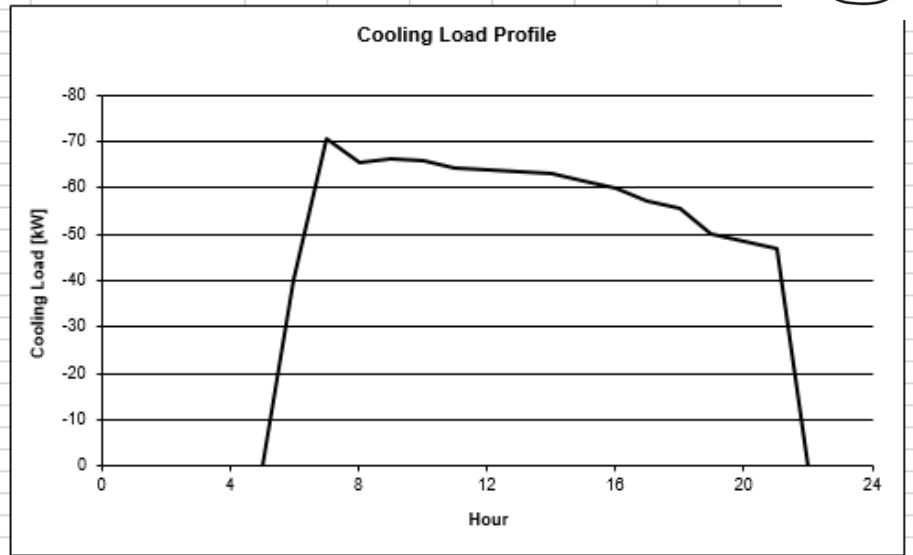
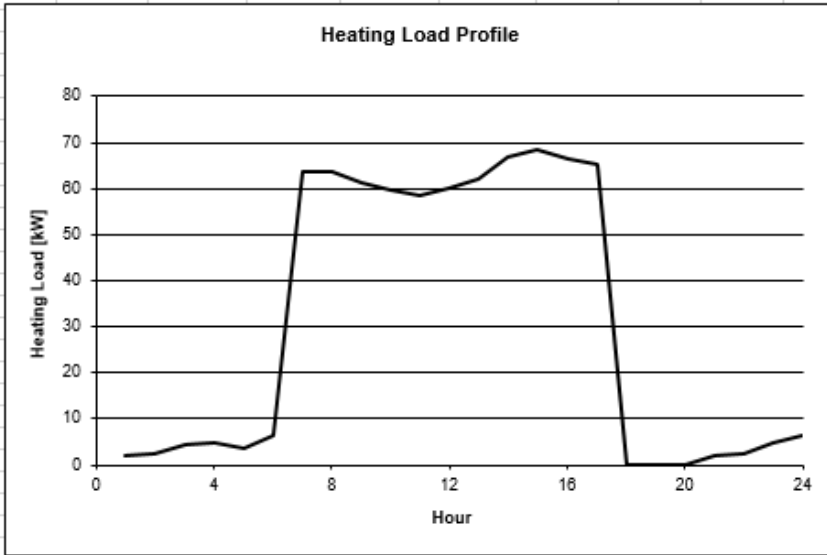
- Press the "Compute Peak Days" button to find days of maximum loads.
- Use the input form to select peak load durations and peak determination method
- \*Average over duration: Determines the highest average value for
- \*Maximum
- Review and revise section entirely new impact on the
- Press OK on the input
- for both the peak day and the three peak approximations.
- Visually decide which approximation is nearest the true response profile. This may require several runs of the program with different durations and/or peak methods.
- In the "Monthly Loads" form area below, enter the heating and cooling peak methods and durations, and click the button. This will generate both total and peak loads for each month, for use in GLHEPRO.
- See instructions next to the "Monthly Loads" form to use these loads in GLHEPRO.

**Note: Convention – cooling loads are specified as negative**

**Form below can also be used to get daily peak response profiles.**

Metric	Value
Heating Peak Duration #1	6
Heating Peak Duration #2	7
Heating Peak Duration #3	8
Cooling Peak Duration #1	3
Cooling Peak Duration #2	4
Cooling Peak Duration #3	5
Peak Determination Mode	Maximum
<input type="radio"/> Average over duration	
<input checked="" type="radio"/> Maximum during duration	

Buttons: Compute Peak Days, Launch Input Form, Calculate Peak Responses



Step 4: Choose durations and peak load method.

**Control Sheet - Primary Parameters**

**Input the primary system parameters on this sheet. To enter hourly loads, Cancel this form and paste loads into column B of the Main Sheet.**

Heating Peak Durations		Cooling Peak Durations	
#1:	6	#1:	3
#2:	7	#2:	4
#3:	8	#3:	5

Peak Load Method

Average over duration  
 Maximum during duration

Fluid Factor: 1

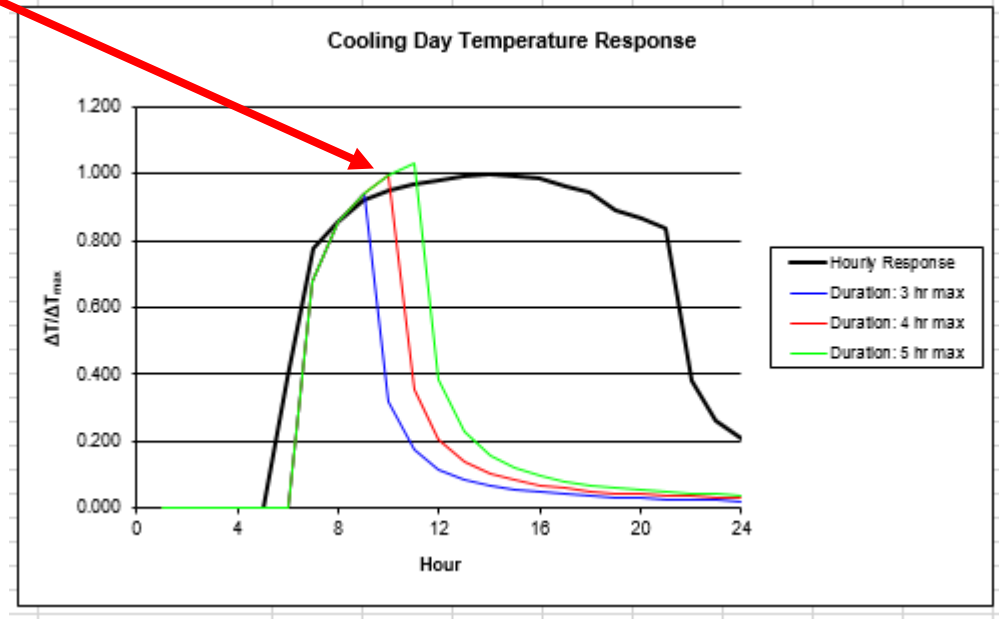
Edit Secondary Parameters

Cancel OK



Step 5: Adjust durations until good match is found

Here, a 4-hour duration of the maximum peak load gives a good match.



Step 6: Specify duration, method to create load profile.

Step 7: Copy loads and paste into GLHEPRO

<b>Monthly Loads</b>				
Heating		Cooling		
<input type="checkbox"/>	Average over duration	<input type="checkbox"/>	Average over duration	
<input checked="" type="checkbox"/>	Maximum during duration	<input checked="" type="checkbox"/>	Maximum during duration	
Duration:	7	Duration:	4	
Note that it is not necessarily the case that the best method for heating and cooling (average or maximum) will be the same.				
<div style="border: 1px solid black; padding: 5px; display: inline-block;">Get Summary Data</div>				
	Total Loads [kW-h]		Peak Loads [kW]	
	Heating	Cooling	Heating	Cooling
January	19969.1	11226.1	68.3	40.6
February	17388.3	10681.0	68.3	41.1
March	17368.8	14079.4	65.7	46.7
April	14192.0	14581.2	66.3	51.7
May	11806.5	17809.8	62.0	59.0
June	8805.4	20311.3	49.7	67.4
July	7272.0	21145.4	45.0	67.2
August	8088.5	23070.3	48.6	70.6
September	10676.7	18786.6	57.2	61.2
October	13669.7	15374.2	64.0	50.8
November	16221.4	12904.4	66.0	41.7
December	17762.4	12930.5	65.7	42.7

# Ground Heat Exchangers Introduction to Design with GLHEPRO

## Part 2

Jeffrey D. Spitler  
spitler@okstate.edu

<https://hvac.okstate.edu/>

©2020, Jeffrey D. Spitler  
All rights reserved



Specify loads on GHE, GSHP

Simulate, size GHE, or size GHE and hybrid source/sink

Set borehole dimensions

Set ground properties

Select number & arrangement of boreholes

Specify inside-the-borehole details

Choose antifreeze type, concentration; set total flow rate

Choose or specify heat pump

The screenshot shows the GLHEPro software interface with the following sections and parameters:

- Menu Bar:** File, Loads, Units, Action, Help, Register
- Toolbar:** Includes icons for simulation (SIM), hydraulic simulation (HY SIM), and sizing (SIZE).
- Borehole Parameters:**
  - Active Borehole Depth: 1130.23 m
  - Borehole Diameter: 110 mm
  - Borehole Thermal Resistance: 0.0703  $^{\circ}\text{K}/(\text{W}/\text{m})$
  - Borehole Spacing: 5 m
  - Borehole Geometry: RECTANGULAR CONFIGURATION 4 : 2 x 2, rectangle
- Ground Parameters:**
  - Soil type currently entered: Dense Rock
  - Thermal Conductivity of the ground: 3.5  $\text{W}/(\text{m}\cdot^{\circ}\text{K})$
  - Volumetric heat capacity of the ground: 2700.000  $\text{kJ}/(^{\circ}\text{K}\cdot\text{m}^3)$
  - Average Annual Ground Temperature: 8  $^{\circ}\text{C}$
  - Temperature Profile Location: Unspecified, Unspecified
- Fluid Parameters:**
  - Total flow rate for entire system: 3.340 L/s
  - Fluid type: Ethanol / Water
  - Fluid Concentration: 26%
  - Average Temperature at Peak Conditions: 2  $^{\circ}\text{C}$

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
	$^{\circ}\text{C}$	$\text{kg}/\text{m}^3$	$\text{kJ}/(^{\circ}\text{K}\cdot\text{m}^3)$	$\text{W}/(\text{m}\cdot^{\circ}\text{K})$	$\text{Pa}\cdot\text{s}$
	-16.31	967.56	4003.75	0.429	0.00562
- Heat Pump:**
  - Heat Pump Selected: ClimateMaster-custom : TMW340

GLHEPro - Test\_building

File Loads Units Action Help Register

Vertical BH Horizontal GHE FPFLS BH

### Borehole Parameters

Active Borehole Depth : 130.23 m Select Borehole

Borehole Diameter : 110 mm

Borehole Thermal Resistance : 0.0703 \*K/(W/m) Calculate Borehole Thermal Resistance

### Ground Parameters

Thermal Conductivity : Ground Parameters

Volumetric Heat Capacity : Ground Temperatures

Average Annual Ground Temperature : Ground Temperatures

### Fluid Parameters

Total fluid length : Select Fluid

Fluid Type : Select Fluid

Fluid Concentration : Concentration: 2°C

Freezing Point	Activity	Viscosity
°C	K)	Pa·s
-16.31		0.00562

Heat Pump Selected : Climate Select Heat Pump

#### Select Borehole Configuration

Select Configuration

RECTANGULAR CONFIGURATION

Select sub configuration

- 10 : 2 x 5, rectangle
- 10 : 2 x 5, rectangle**
- 12 : 2 x 6, rectangle
- 14 : 2 x 7, rectangle
- 16 : 2 x 8, rectangle
- 18 : 2 x 9, rectangle
- 20 : 2 x 10, rectangle
- 24 : 2 x 12, rectangle
- 28 : 2 x 14, rectangle
- 32 : 2 x 16, rectangle
- 36 : 2 x 18, rectangle
- 40 : 2 x 20, rectangle
- 50 : 2 x 25, rectangle
- 9 : 3 x 3, rectangle
- 12 : 3 x 4, rectangle
- 15 : 3 x 5, rectangle
- 18 : 3 x 6, rectangle
- 21 : 3 x 7, rectangle
- 24 : 3 x 8, rectangle
- 27 : 3 x 9, rectangle
- 30 : 3 x 10, rectangle
- 36 : 3 x 12, rectangle
- 42 : 3 x 14, rectangle
- 48 : 3 x 16, rectangle
- 54 : 3 x 18, rectangle
- 60 : 3 x 20, rectangle
- 75 : 3 x 25, rectangle
- 16 : 4 x 4, rectangle
- 20 : 4 x 5, rectangle
- 24 : 4 x 6, rectangle
- 28 : 4 x 7, rectangle

Reynolds number appears here after borehole resistance is calculated.

**G-Function and Borehole Resistance Calculator**

U-Tube: Double U-Tube | Concentric | Standing Column Well

**Borehole Specification**

Borehole Diameter (d): 110 mm

Shank Spacing (s): 15.33 mm

U-Tube Inside Diameter (D1): 28.2 mm

U-Tube Outside Diameter (D2): 32 mm

Volumetric Flow Rate/borehole: 0.334 L/s

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

**Borehole Fill**

Grout

Groundwater

Constrained By:  Heating  Cooling

**Volumetric Heat Capacities**

Soil: 2700.000 J/(°K·m³)

Grout: 3901.000 J/(°K·m³)

Pipe: 1542.000 J/(°K·m³)

**Thermal Conductivities**

Soil: 3.500 W/(m·°K)

Grout: 2.700 W/(m·°K)

Pipe: 0.389 W/(m·°K)

**Options for specifying the fluid convection coefficient**

Entered Value

Convection Coefficient: 55.218 W/(m²·°K)

Reynolds Number: 2596

Calculated Value

Fluid Type: Ethanol / Water

Fluid Concentration: 26%

Average Temperature at Peak Conditions: 2°C

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
	°C	kg/m³	kJ/(°K·m³)	W/(m·°K)	Pa·s
▶	-16.31	967.56	4003.75	0.429	0.00562

**Short Circuiting Effects**

Short Circuiting Effects

Model Type:  Uniform wall temperature  Uniform heat flux  Mean

**G-Function Calculations**

Borehole Resistance: 0.0772 °K/(W/m)

Choose borehole filling here.

Choose treatment of short circuiting here.

Used for simulation tools

Select Heat Pump
✕

Currently Selected Pump is loaded from an input file (.gli)

Brand Name :

Model :

**Cooling**

Heat of Rejection =  $QC[a + b(EFT) + c(EFT^2)]$  (kW)

Power =  $QC[d + e(EFT) + f(EFT^2)]$  (kW)

a <input type="text" value="0.118435"/>	d <input type="text" value="1.118435"/>
b <input type="text" value="0.000807"/>	e <input type="text" value="0.000807"/>
c <input type="text" value="0.000074"/>	f <input type="text" value="0.000074"/>

**Heating**

Heat of Absorption =  $QH[u + v(EFT) + w(EFT^2)]$  (kW)

Power =  $QH[x + y(EFT) + z(EFT^2)]$  (kW)

u <input type="text" value="0.260098"/>	x <input type="text" value="0.739941"/>
v <input type="text" value="-0.005339"/>	y <input type="text" value="0.005345"/>
w <input type="text" value="0.000091"/>	z <input type="text" value="-0.000092"/>

**Library Utility**

**Maintenance**

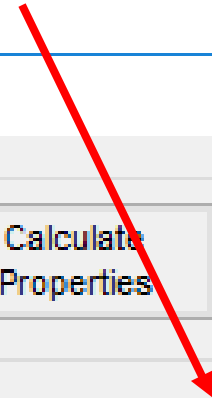
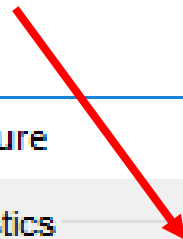
**View Data**

QC = Cooling load (kW)  
 QH = Heating load (kW)  
 EFT = Fluid temperature entering the Heat pump (°C)

Export data to HVACSIM+ Type 565 parameter file

Complete property formulations for ethanol, methanol, propylene glycol, ethylene glycol

Library for potassium acetate, salt and calcium chloride brines



**Select Antifreeze Mixture**

Select Fluid Characteristics

Fluid Type: **Ethanol / Water**

Concentration (Wt%): **26**

Mean Temperature: **2**

**Calculate Properties**

Fluid Type: **Ethanol / Water**

Average Temperature at Peak Conditions: **2°C**

Fluid Concentration: **26%**

**Library**

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▶	°C	kg/m <sup>3</sup>	kJ/(°K·m <sup>3</sup> )	W/(m·°K)	Pa·s
	-16.31	967.56	4003.75	0.429	0.00562

**Close**



### Edit Loads on Heat Pump

Heat Pump Loads

Month	Total Heating kWh	Total Cooling kWh	Peak Heating kW	Peak Cooling kW
January	<input type="text" value="19969.11"/>	<input type="text" value="11226.07"/>	<input type="text" value="68.3"/>	<input type="text" value="40.65"/>
February	<input type="text" value="17388.26"/>	<input type="text" value="10680.96"/>	<input type="text" value="68.27"/>	<input type="text" value="41.11"/>
March	<input type="text" value="17368.81"/>	<input type="text" value="14079.42"/>	<input type="text" value="65.67"/>	<input type="text" value="46.68"/>
April	<input type="text" value="14192.04"/>	<input type="text" value="14581.25"/>	<input type="text" value="66.31"/>	<input type="text" value="51.65"/>
May	<input type="text" value="11806.53"/>	<input type="text" value="17809.77"/>	<input type="text" value="61.98"/>	<input type="text" value="58.99"/>
June	<input type="text" value="8805.4"/>	<input type="text" value="20311.34"/>	<input type="text" value="49.7"/>	<input type="text" value="67.4"/>
July	<input type="text" value="7272"/>	<input type="text" value="21145.44"/>	<input type="text" value="45.04"/>	<input type="text" value="67.21"/>
August	<input type="text" value="8088.54"/>	<input type="text" value="23070.34"/>	<input type="text" value="48.64"/>	<input type="text" value="70.6"/>
September	<input type="text" value="10676.72"/>	<input type="text" value="18786.59"/>	<input type="text" value="57.21"/>	<input type="text" value="61.23"/>
October	<input type="text" value="13669.73"/>	<input type="text" value="15374.2"/>	<input type="text" value="64"/>	<input type="text" value="50.81"/>
November	<input type="text" value="16221.41"/>	<input type="text" value="12904.41"/>	<input type="text" value="66.01"/>	<input type="text" value="41.65"/>
December	<input type="text" value="17762.43"/>	<input type="text" value="12930.46"/>	<input type="text" value="65.68"/>	<input type="text" value="42.68"/>

Duration of Peak Loads

Number of Peak heating hours:       Number of Peak Cooling hours:

Loads are pasted in from peak load analysis tool.

Durations are manually entered.

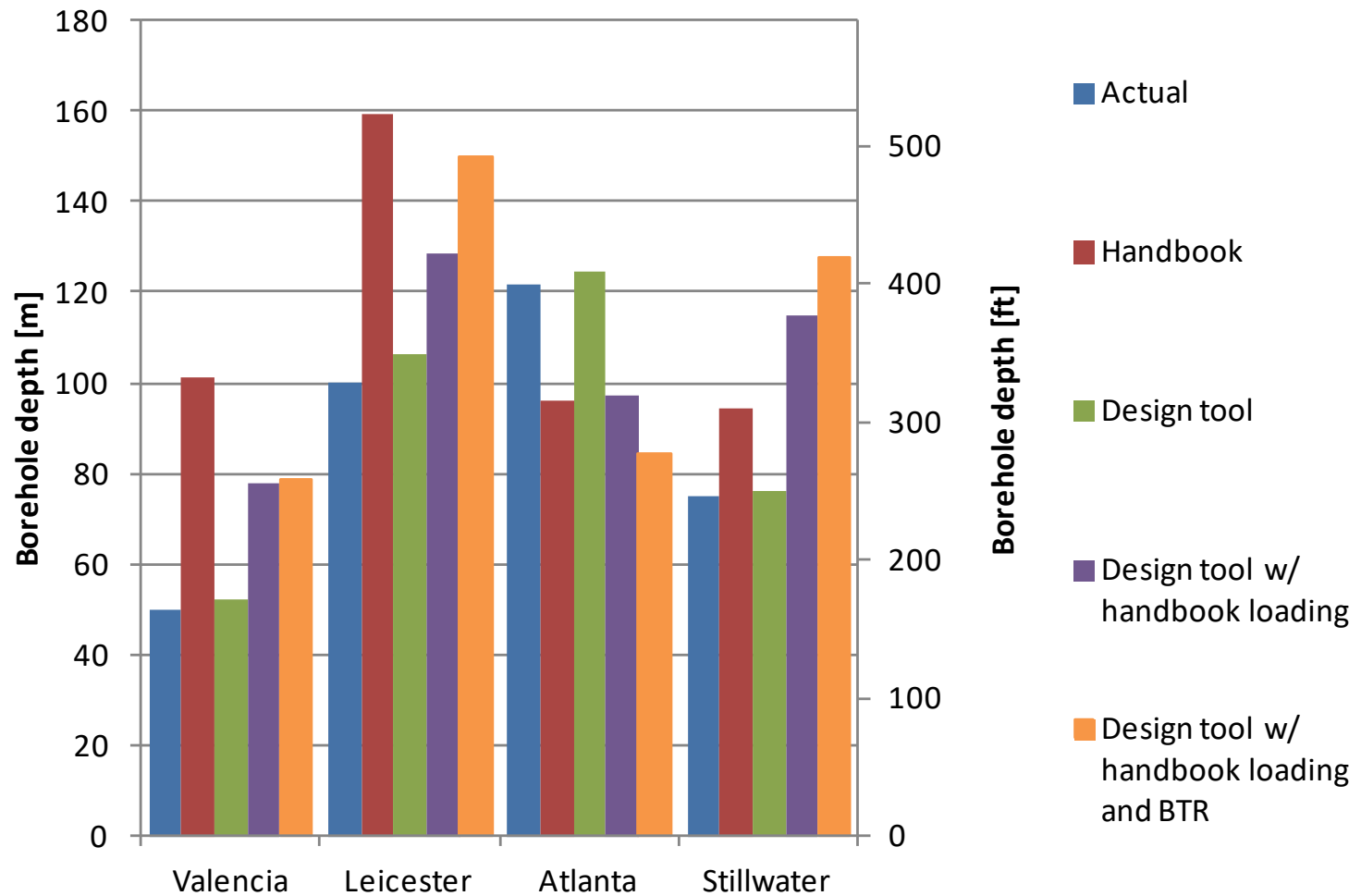
# Other features

- Hourly simulation support:
  - EnergyPlus
  - HVACSIM+
  - A standalone simulation (in GLHEPRO)
- Design of hybrid systems
- Ability to enter direct-to-the-heat-exchanger loads, e.g. free cooling with a fan coil
- Design of user-specified borehole configurations – vertical or inclined, up to 36 boreholes
- Horizontal ground heat exchangers – straight, Slinky

# Yes, but does it work?

- Four installed ground heat exchangers:
  - Stillwater, Oklahoma, 3 boreholes, 19 months
  - Atlanta, Georgia, 12 boreholes, 55 months
  - Valencia, Spain, 6 boreholes, 6 years
  - Leicester, England, 56 boreholes, 24 months
- Using actual peak temperatures reached:
  - Computed required size with GLHEPRO
  - Computed required size with ASHRAE Handbook method
  - Computed required size with GLHEPRO with simplifications (making it more like handbook method)

# Results



# Conclusions

- Three studies that give uncertainties in design, when loads are known:
  - Study just discussed:  $\pm 5\%$
  - Study looking at monthly/monthly peak loads:  $\pm 8\%$  (Cullin and Spitler 2011)
  - Study looking at uncertainty in TRT results:  $\pm 10\%$  (Javed, et al. 2011)
- Suggests a safety factor of 10% not unreasonable.
- Uncertainty in loads is harder to quantify!

# Resources

- GLHEPRO:  
<https://hvac.okstate.edu/glhepro/overview>
- Papers:
  - Javed, S. and J.D. Spitler. 2017. *Accuracy of Borehole Thermal Resistance Calculation Methods for Grouted Single U-tube Ground Heat Exchangers*. Applied Energy. 187:790-806.
  - Spitler, J.D., S. Javed and R. Kalskin Ramstad. 2016. *Natural convection in groundwater-filled boreholes used as ground heat exchangers*. Applied Energy. 164:352-365.
  - Cullin, J.R., J.D. Spitler, C. Montagud, F. Ruiz-Calvo, S.J. Rees, S.S. Naicker, P. Konečný, and L.E. Southard. 2015. *Validation of Vertical Ground Heat Exchanger Design Methodologies*. Science and Technology for the Built Environment. 21(2):137-149.
  - Xiong, Z., D.E. Fisher, J.D. Spitler. 2015. *Development and Validation of a Slinky™ Ground Heat Exchanger Model*. Applied Energy. 141:57-69.
  - Cullin, J.R., C. Montagud, F. Ruiz-Calvo, and J.D. Spitler. 2014. *Experimental Validation of Ground Heat Exchanger Design Methodologies Using Real, Monitored Data*. ASHRAE Transactions. 120 (2): 357-369.
  - Cullin, J.R. and J.D. Spitler. 2011. *A Computationally Efficient Hybrid Time Step Methodology for Simulation of Ground Heat Exchangers*. Geothermics. 40(2): 144-156.
  - Javed, S., J.D. Spitler and P. Fahlén. 2011. *An Experimental Investigation of the Accuracy of Thermal Response Tests Used to Measure Ground Thermal Properties*. ASHRAE Transactions. 117(1):13-21.
- Many theses and papers at [hvac.okstate.edu](http://hvac.okstate.edu)