Ground Heat Exchangers Introduction to Design with GLHEPRO

Part 1

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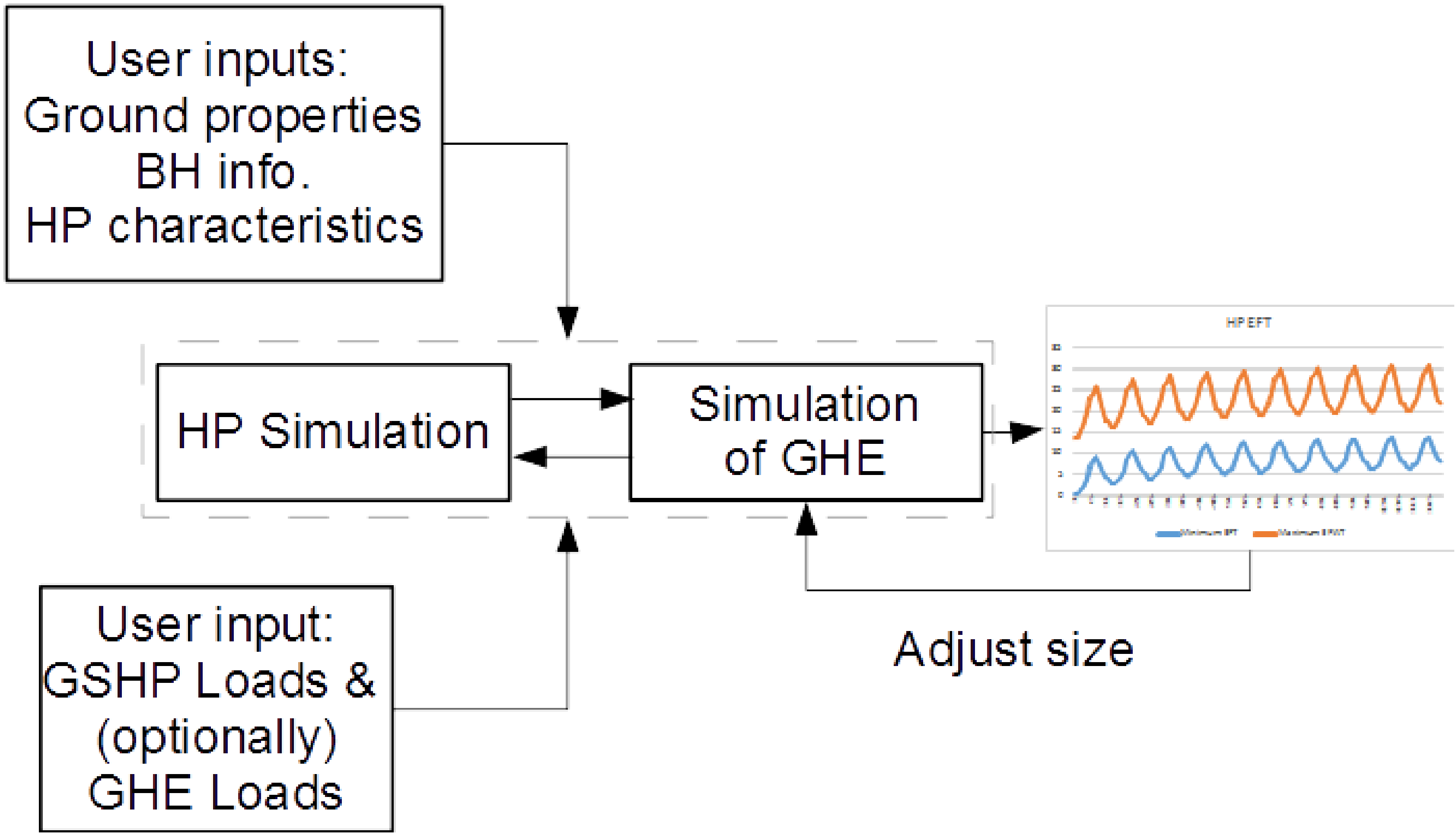
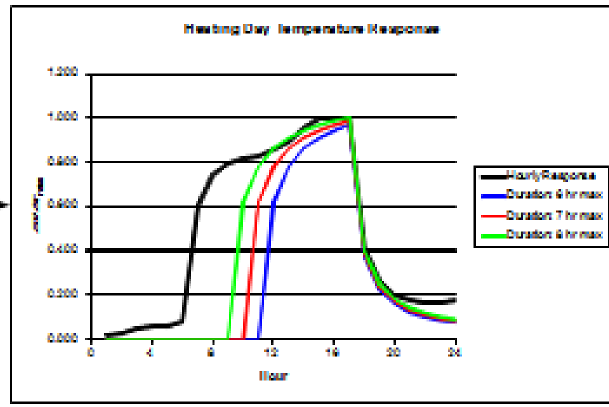
GSHP

GLHEPRO


User inputs:
Ground properties
BH info.
HP characteristics
HP Simulation
Simulation
of GHE
HP EFT
User input:
GSHP Loads &
(optionally)
GHE Loads
Adjust size

Peak Load Analysis Tool

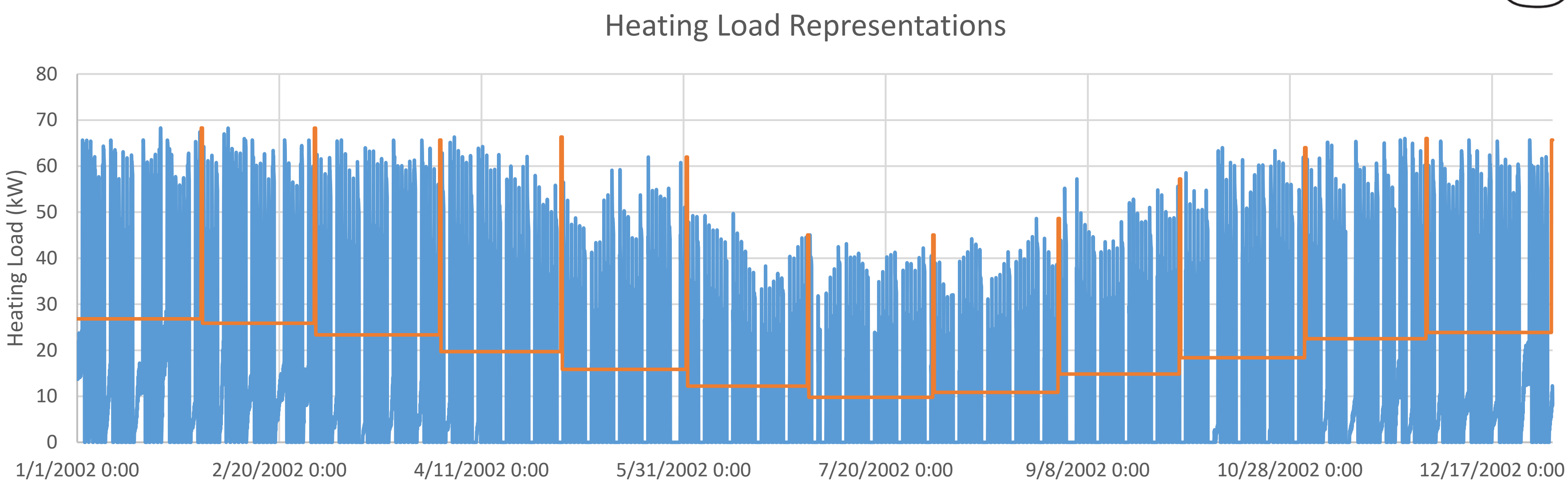
Hourly Htg. & Clg. Loads

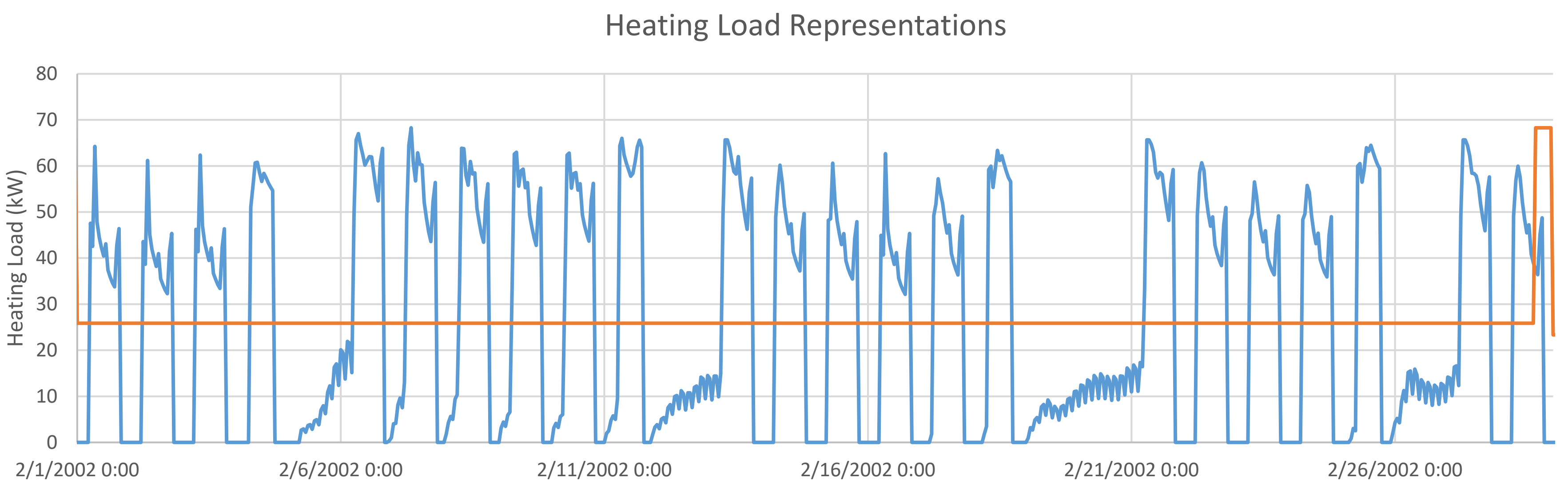


Peak load analysis tool

User input: GSHP Loads & (optionally) GHE Loads

Monthly & monthly peak loads


Heating Load Representations
Heating Load (kW)
0
10
20
30
40
50
60
70
80
1/1/2002 0:00
2/20/2002 0:00
4/11/2002 0:00
5/31/2002 0:00
7/20/2002 0:00
9/8/2002 0:00
10/28/2002 0:00
12/17/2002 0:00

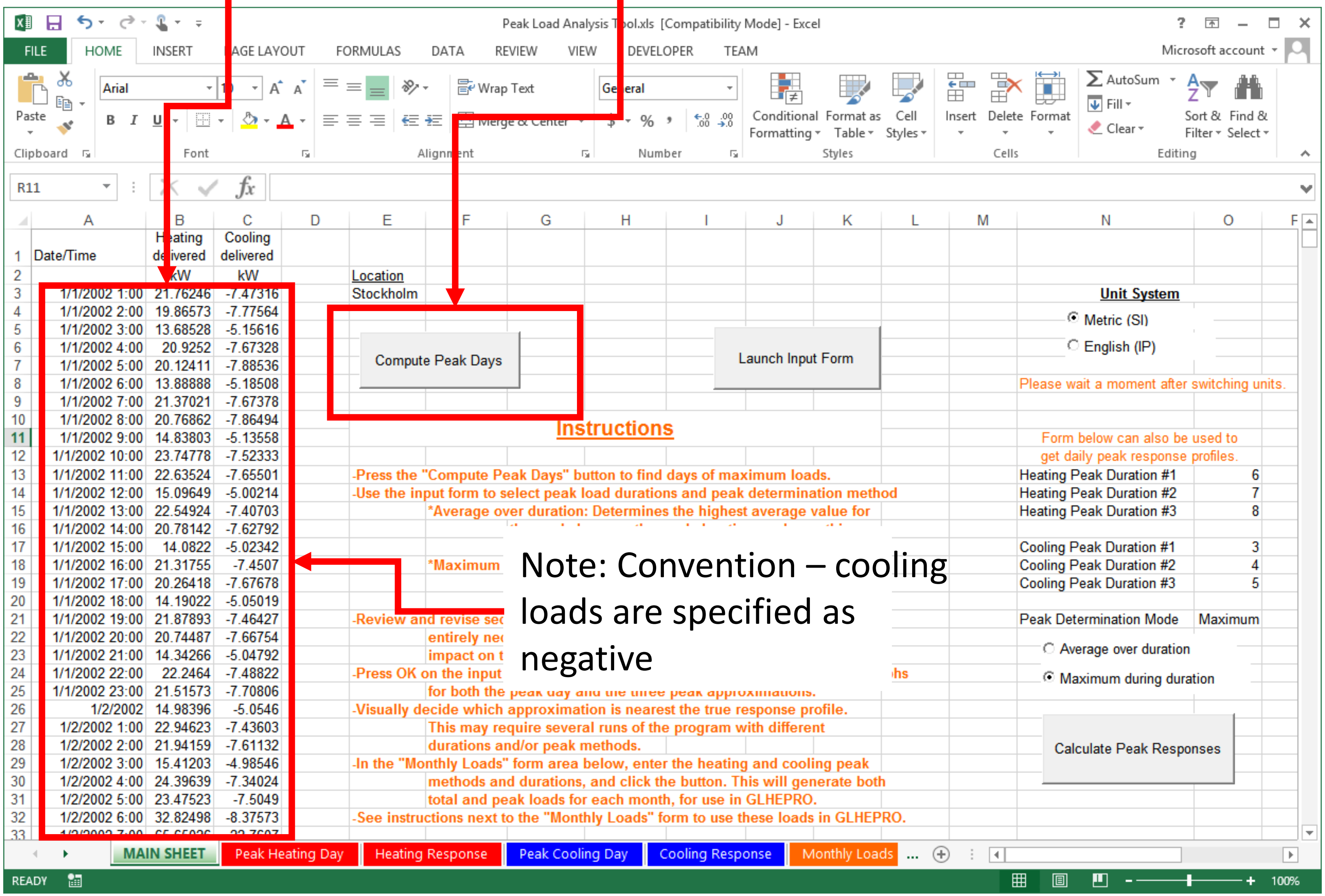

Heating Load Representations
Heating Load (kW)
0
10
20
30
40
50
60
70
80
2/1/2002 0:00
2/6/2002 0:00
2/11/2002 0:00
2/16/2002 0:00
2/21/2002 0:00
2/26/2002 0:00

Step 1

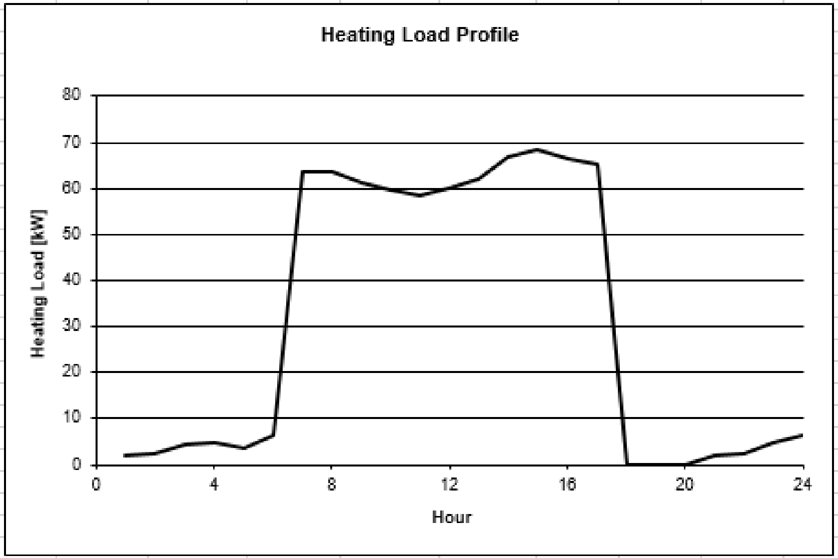
- Calculate hourly heating and cooling loads on heat pumps for typical year.
- Use building simulation tool:
  - EnergyPlus
  - eQuest
  - Others

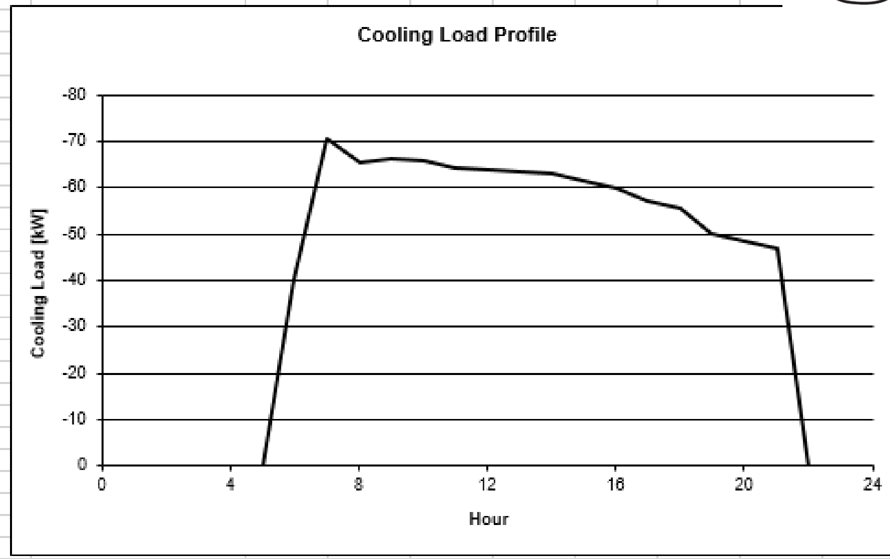
Step 2: Paste in 8760 hourly loads

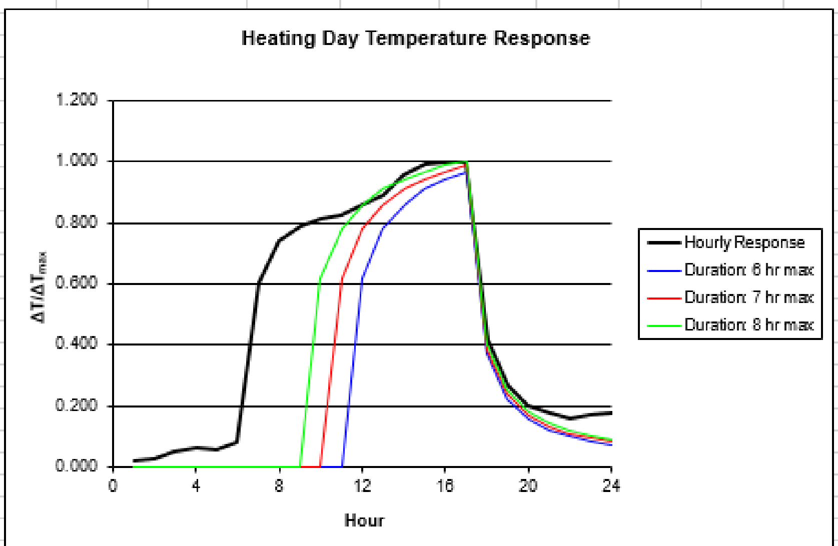
Step 3: Compute peak days

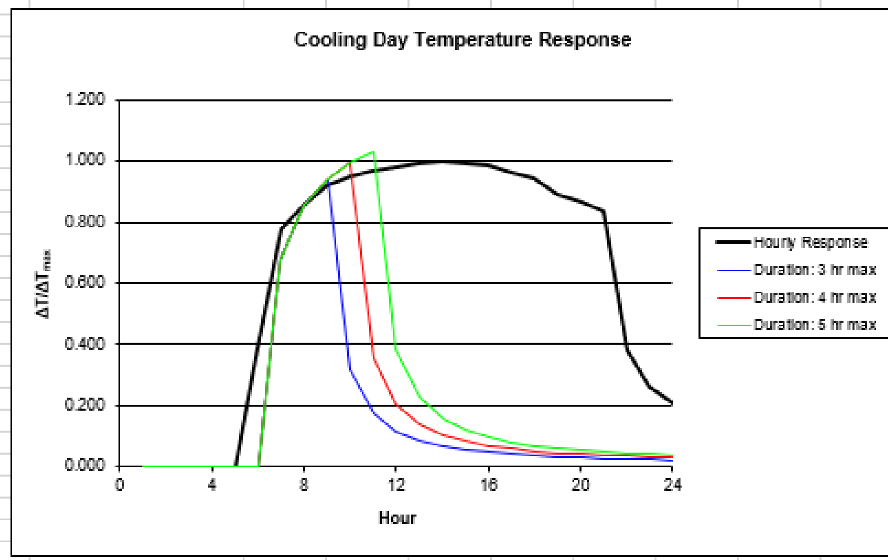


Note: Convention – cooling loads are specified as negative

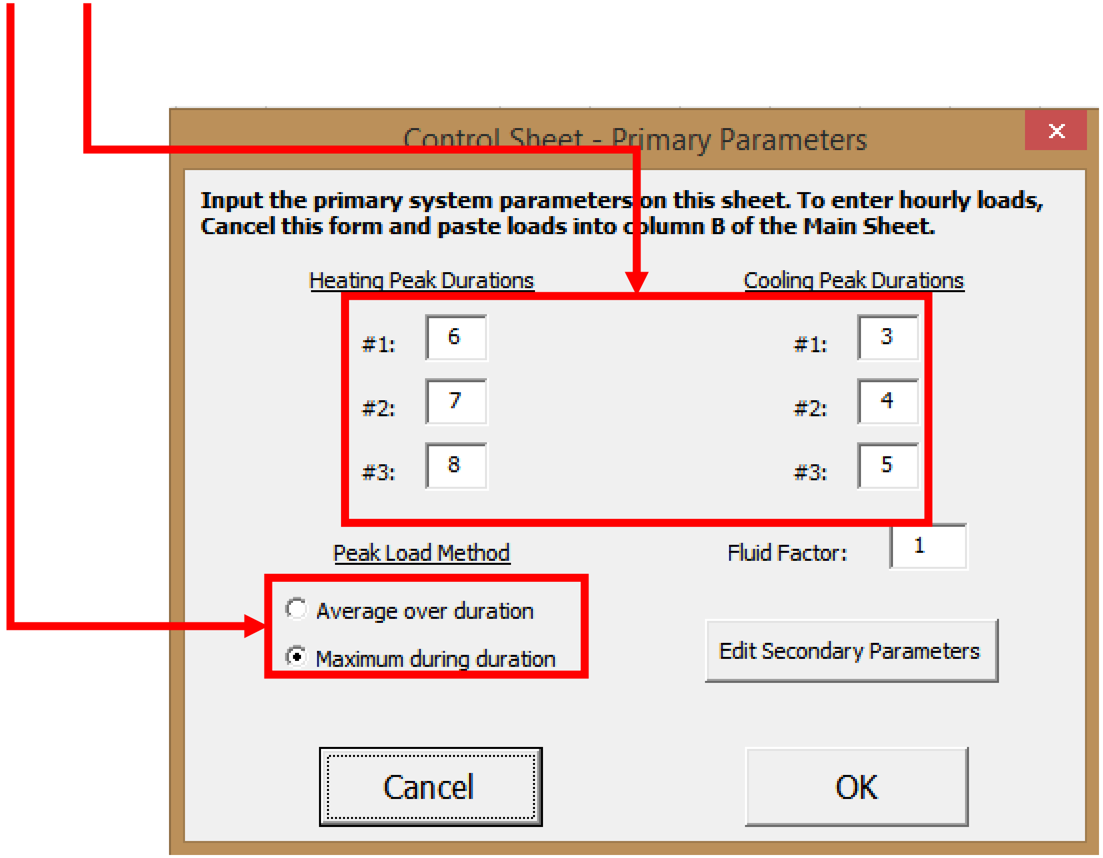

Heating Load Profile
Heating Load [kW]
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
Hour


Cooling Load Profile
Cooling Load [kW]
-80
-70
-60
-50
-40
-30
-20
-10
0
0
4
8
12
16
20
24
Hour


Heating Day Temperature Response
ΔT/ΔTmax
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
4
8
12
16
20
24
Hour
Hourly Response
Duration: 6 hr max
Duration: 7 hr max
Duration: 8 hr max

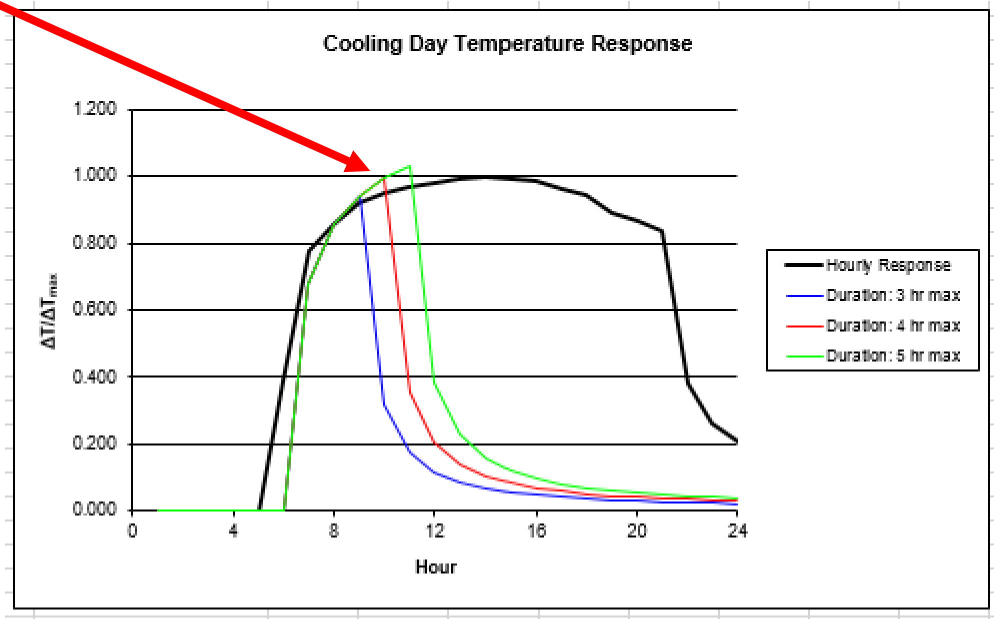

Cooling Day Temperature Response
ΔT/ΔTmax
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
4
8
12
16
20
24
Hour
Hourly Response
Duration: 3 hr max
Duration: 4 hr max
Duration: 5 hr max

Step 4: Choose durations and peak load method.



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

Monthly Loads

Heating		Cooling	
☐ Average over duration		☐ Average over duration	
☑ Maximum during duration		☑ 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.

Get Summary Data

	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

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Part 2

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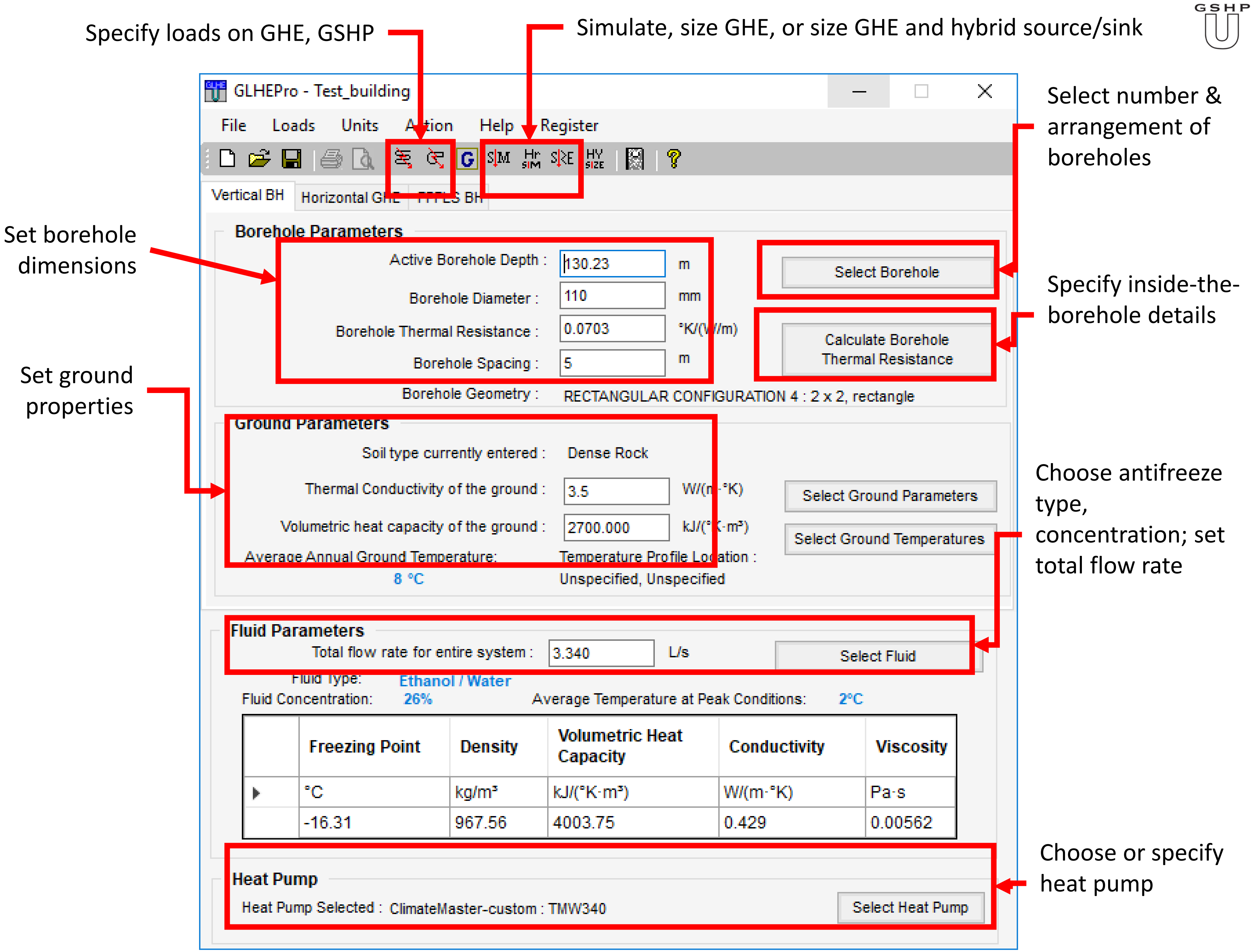
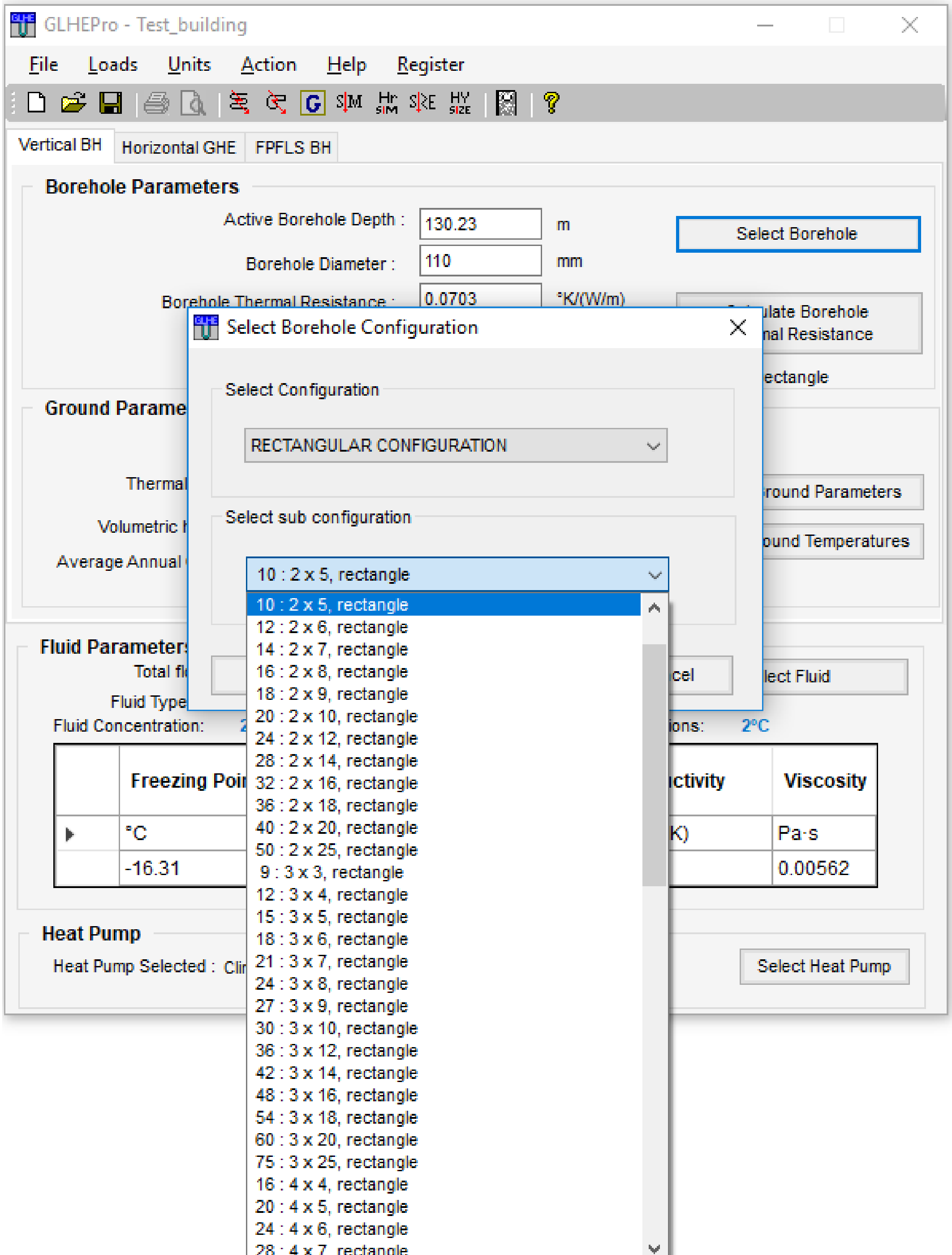
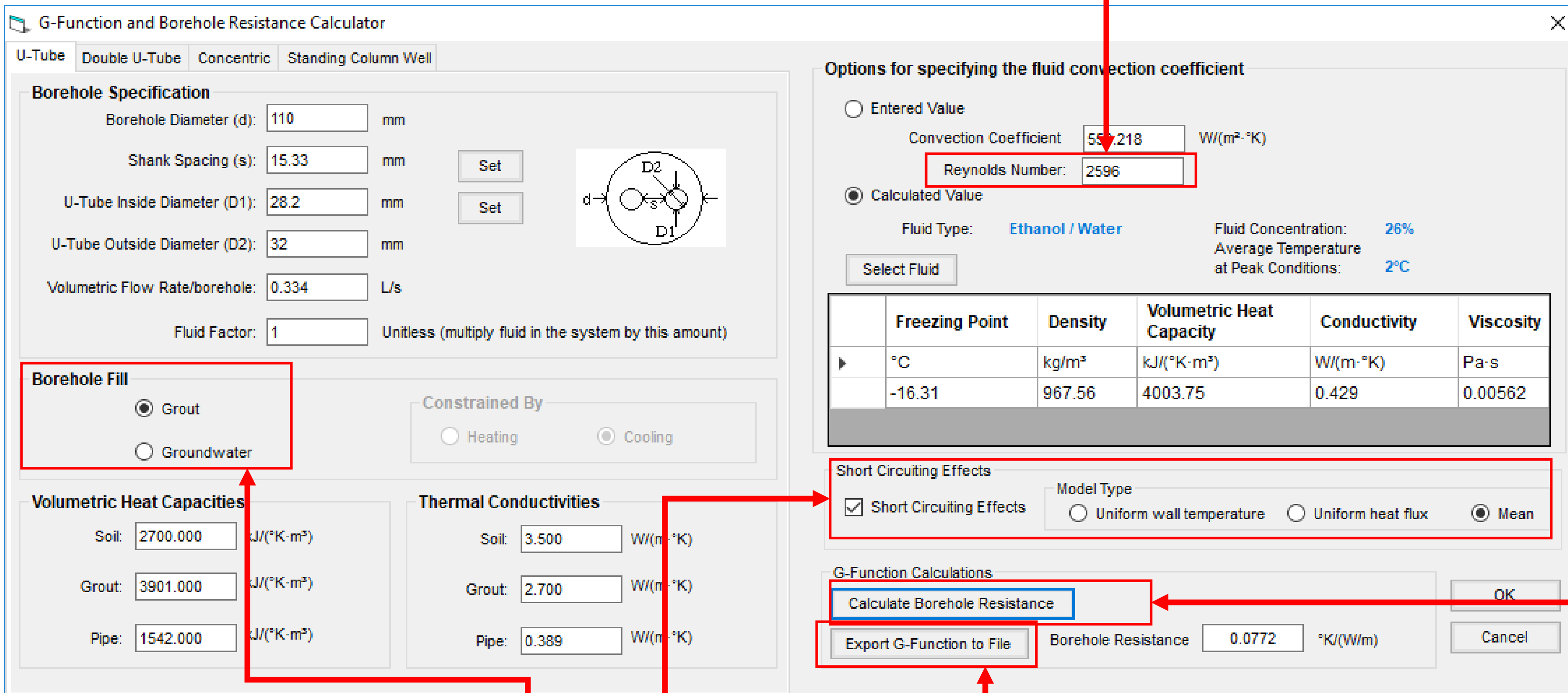

Specify loads on GHE, GSHP
Simulate, size GHE, or size GHE and hybrid source/sink
GSHP U
GLHEPro - Test_building
File Loads Units Action Help Register
Vertical BH
Horizontal GHE
PPFLS BH
Set borehole dimensions
Borehole Parameters
Active Borehole Depth : 130.23 m
Borehole Diameter : 110 mm
Borehole Thermal Resistance : 0.0703 °K/(W/m)
Borehole Spacing : 5 m
Borehole Geometry : RECTANGULAR CONFIGURATION 4 : 2 x 2, rectangle
Select Borehole
Calculate Borehole Thermal Resistance
Select number & arrangement of boreholes
Specify inside-the-borehole details
Set ground properties
Ground Parameters
Soil type currently entered : Dense Rock
Thermal Conductivity of the ground : 3.5 W/(m-°K)
Volumetric heat capacity of the ground : 2700.000 kJ/(°K-m³)
Average Annual Ground Temperature:
8 °C
Temperature Profile Location :
Unspecified, Unspecified
Select Ground Parameters
Select Ground Temperatures
Choose antifreeze type, concentration; set total flow rate
Fluid Parameters
Total flow rate for entire system : 3.340 L/s
Select Fluid
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
Heat Pump
Heat Pump Selected : ClimateMaster-custom : TMW340
Select Heat Pump
Choose or specify heat pump


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)
Ground Parame
Thermal
Volumetric
Average Annual
Fluid Parameter
Total fl
Fluid Type
Fluid Concentration:
Freezing Poi
°C
-16.31
Viscosity
Pa·s
0.00562
2°C
Heat Pump
Heat Pump Selected :
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

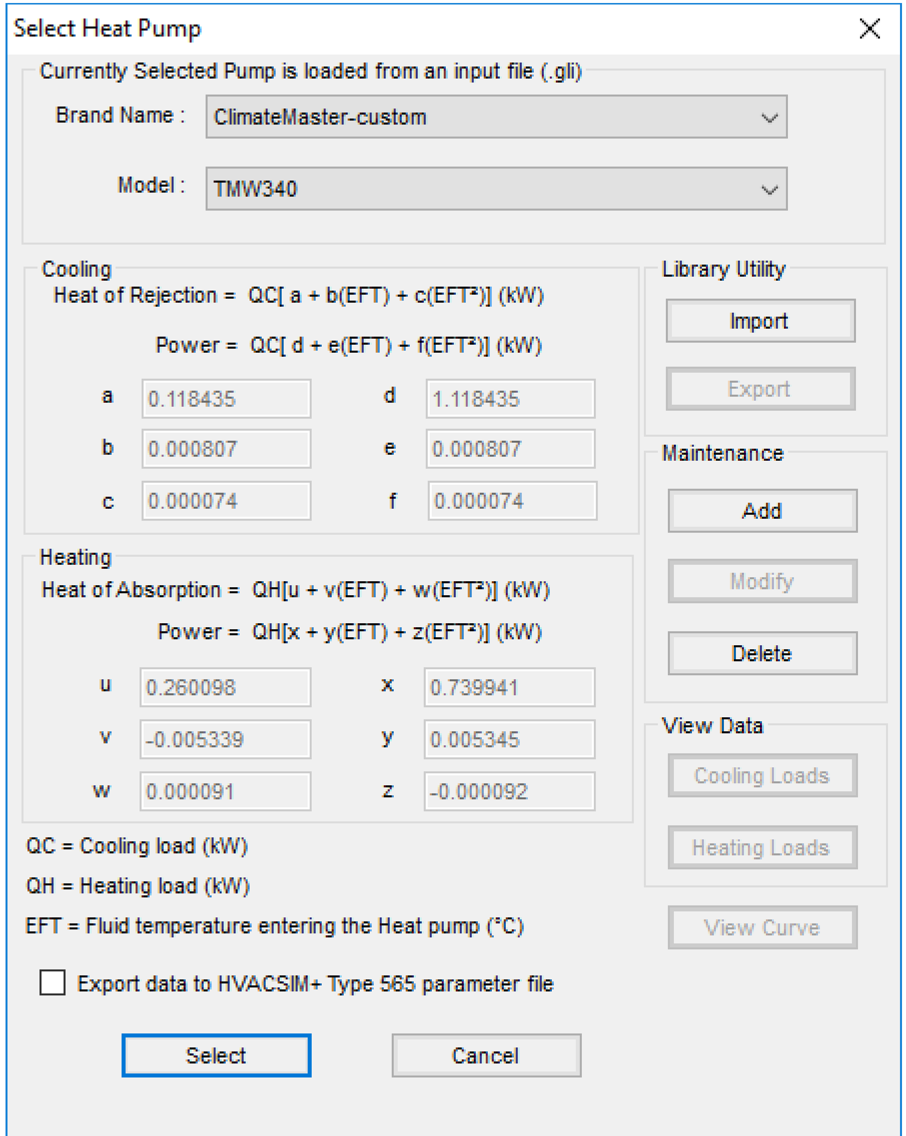
Reynolds number appears here after borehole resistance is calculated.



Choose borehole filling here.

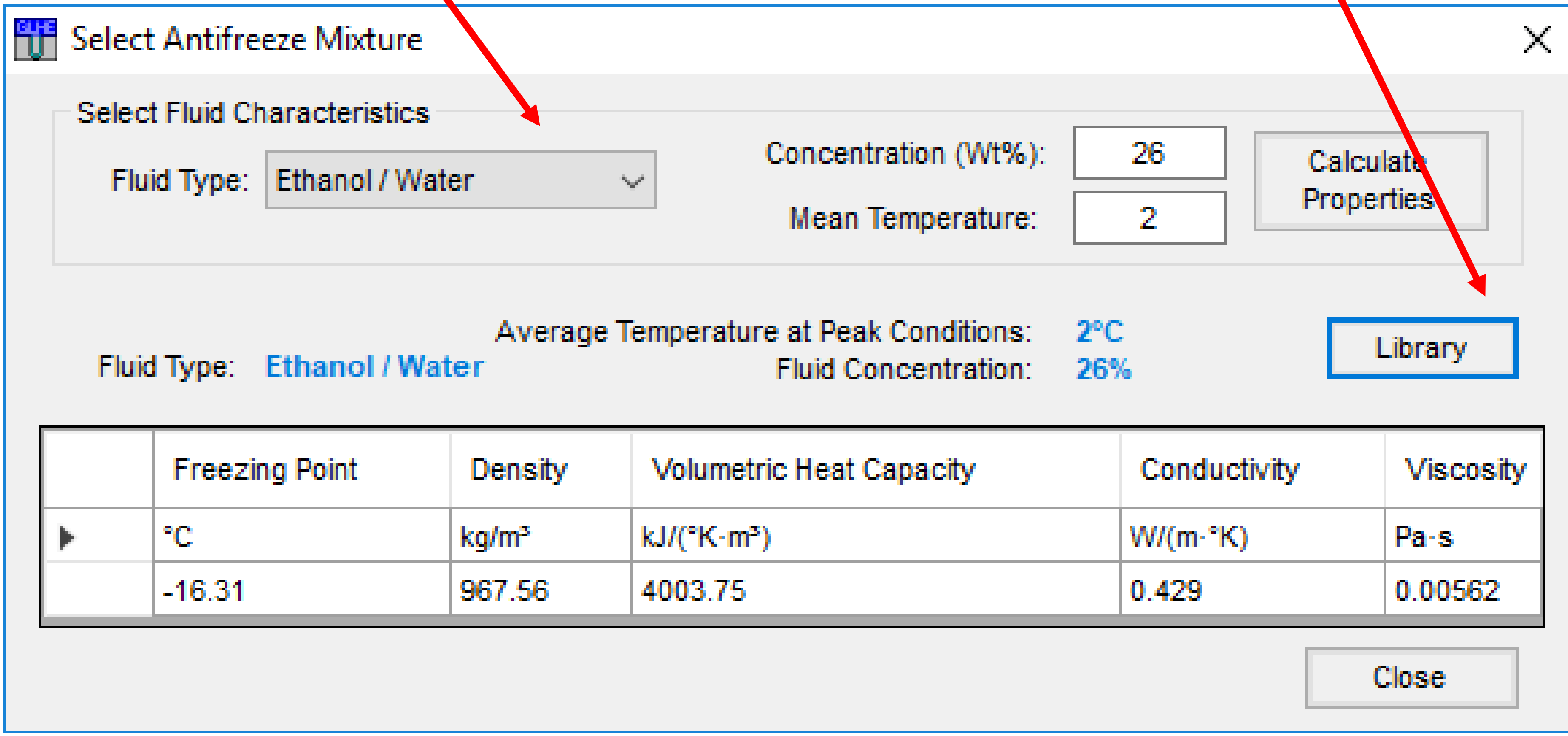
Choose treatment of short circuiting here.

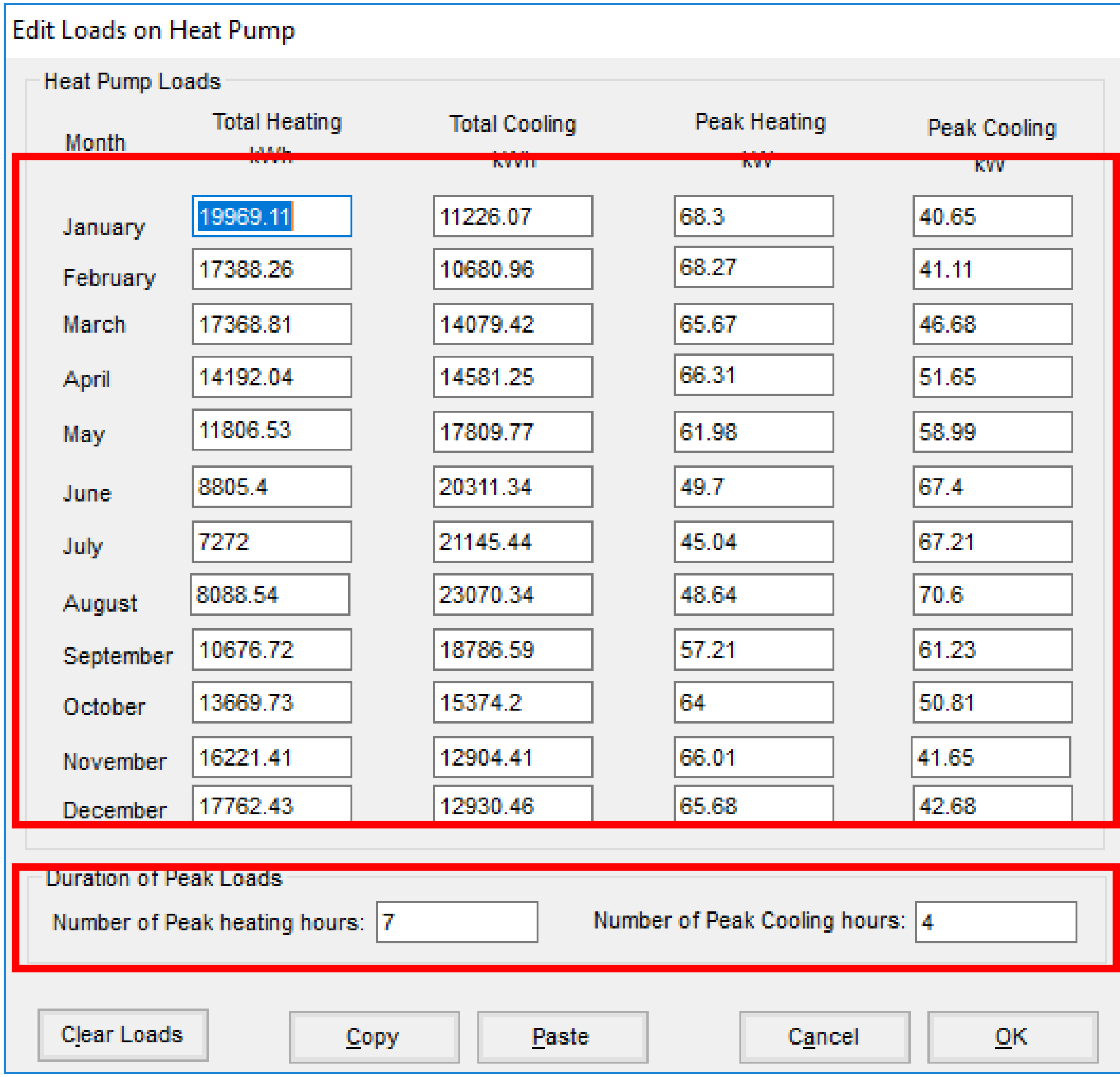
Used for simulation tools


Select Heat Pump
Currently Selected Pump is loaded from an input file (.gli)
Brand Name : ClimateMaster-custom
Model : TMW340
Cooling
Heat of Rejection = QC[a + b(EFT) + c(EFT²)] (kW)
Power = QC[d + e(EFT) + f(EFT²)] (kW)
a 0.118435
d 1.118435
b 0.000807
e 0.000807
c 0.000074
f 0.000074
Heating
Heat of Absorption = QH[u + v(EFT) + w(EFT²)] (kW)
Power = QH[x + y(EFT) + z(EFT²)] (kW)
u 0.260098
x 0.739941
v -0.005339
y 0.005345
w 0.000091
z -0.000092
QC = Cooling load (kW)
QH = Heating load (kW)
EFT = Fluid temperature entering the Heat pump (°C)
Export data to HVACSIM+ Type 565 parameter file
Library Utility
Import
Export
Maintenance
Add
Modify
Delete
View Data
Cooling Loads
Heating Loads
View Curve
Select
Cancel

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

Library for potassium acetate, salt and calcium chloride brines





Edit Loads on Heat Pump

Heat Pump Loads

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

Duration of Peak Loads

Number of Peak heating hours: 7

Number of Peak Cooling hours: 4

Clear Loads | Copy | Paste | Cancel | OK

Loads are pasted in from peak load analysis tool.

Durations are manually entered.

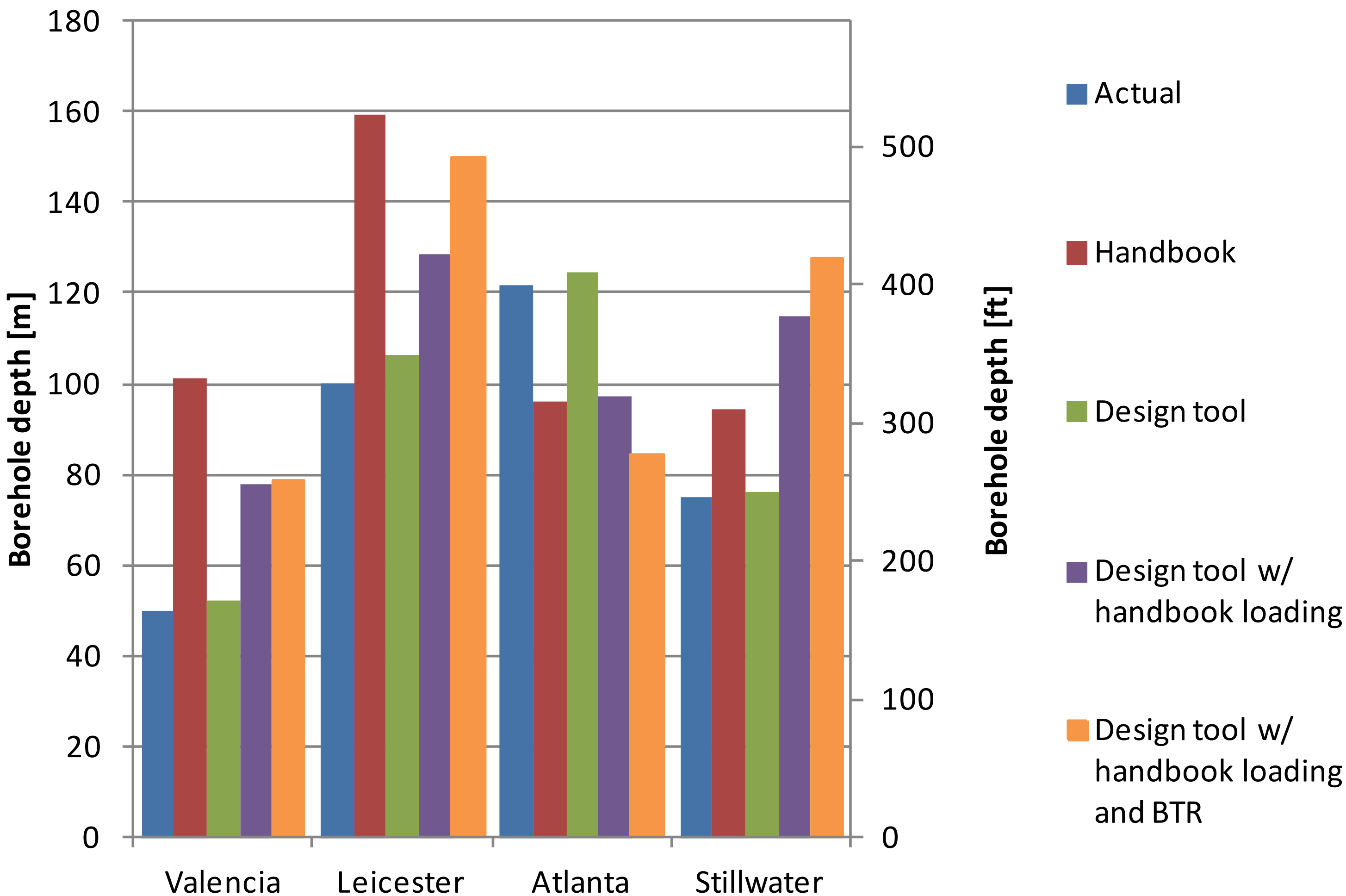
Other features

- 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



180
160
140
120
100
80
60
40
20
0
Borehole depth [m]
500
400
300
200
100
0
Borehole depth [ft]
Valencia
Leicester
Atlanta
Stillwater
Actual
Handbook
Design tool
Design tool w/ handbook loading
Design tool w/ handbook loading and BTR

Conclusions

- Three studies that give uncertainties in design, when loads are known:
  - Study just discussed: ±5%
  - Study looking at monthly/monthly peak loads: ±8% (Cullin and Spitler 2011)
  - Study looking at uncertainty in TRT results: ±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