Loopfields and Piping Design Workshop

Week 1 – GLD2014 Loopfield System Design

- **Welcome!**

Instructor: Dan Bernstein

Geothermal Training Institute

Welcome! Week 1: Loopfield System Design

The objective of this workshop is to provide the geothermal designer with an in-depth look at designing efficient, cost-effective loopfields using the industry leading Ground Loop Design (GLD) 2014 Software Suite.

You are encouraged to interact with your instructor. We are seeking to provide the geothermal professional with the tools and familiarity that he/she needs to optimize a wide range of GSHP systems.

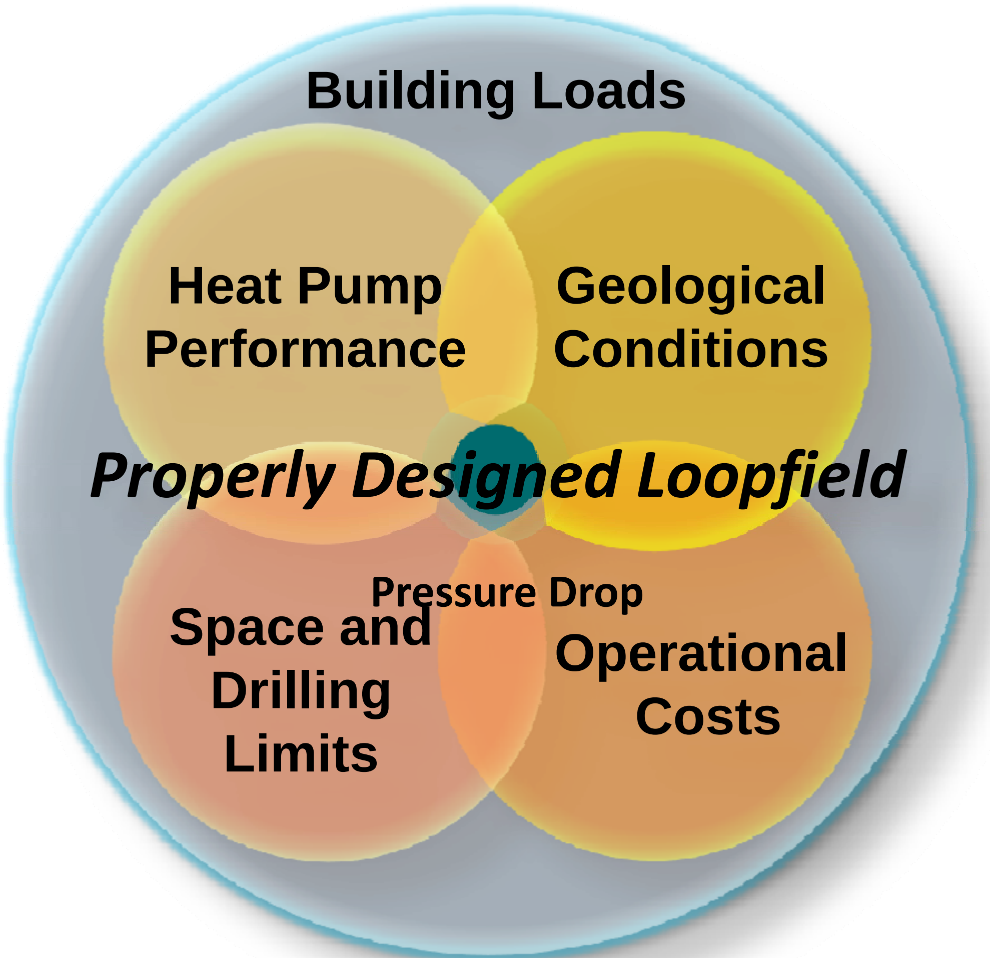
By extending the user's mastery of the GLD program, multiple design solutions can be examined for any project. Designers will quickly discover that while there are many possible ways to design a ground heat exchanger field and it is almost always possible to develop an optimized solution to operate in the most efficient portion of the operating curve, with the lowest possible installation cost.

GLD Course Overview – Course Outline

- **GLD Overview**
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
- Bringing Loads into GLD
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
- Linking Modules Together
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- The GSA Module and Lifecycle Costing

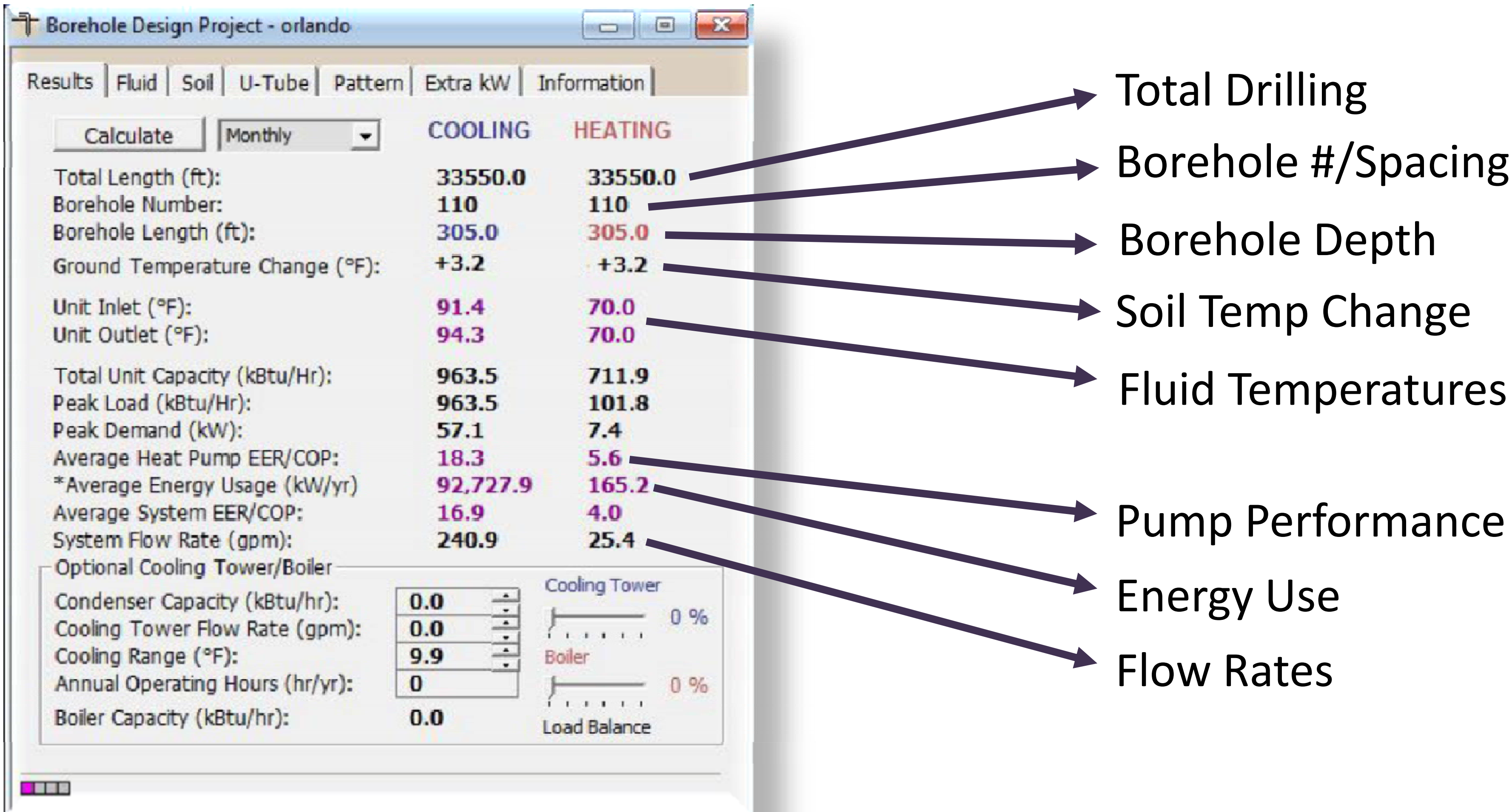
What is GLD Software?

- An advanced software suite that helps to properly size a closed loop ground heat exchanger by considering the interplay among:



What is Ground Loop Design Software?

- Basic Outputs include:



What is Ground Loop Design Software?

- More Advanced Outputs Include:

Optimized Headers | GHX System Pressure Drop | Purging Flow Rates

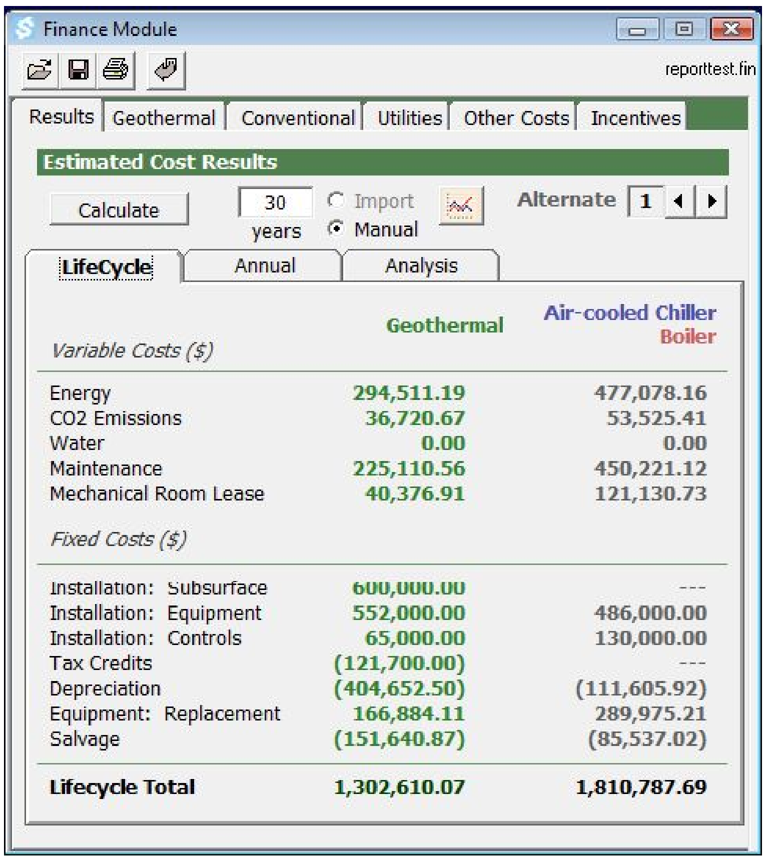
- GHX Module - Supply-Return Runout | 3" | 100.0 ft | 35.40 gpm | 13253 | [9.6 ft. hd] |
  - Circuit #01 | 1" | 278.0 ft | 3.38 gpm | 3367 | [6.3 ft. hd] |
  - GHX Header Section #01 | 3" | 20.0 ft | 32.02 gpm | 11989 | [0.0 ft. hd] |
    - Circuit #02 | 1" | 278.0 ft | 3.52 gpm | 3507 | [6.8 ft. hd] |
    - GHX Header Section #02 | 3" | 20.0 ft | 28.51 gpm | 10673 | [0.0 ft. hd] |
      - Circuit #03 | 1" | 278.0 ft | 3.59 gpm | 3584 | [7.0 ft. hd] |
      - GHX Header Section #03 | 2" | 20.0 ft | 24.91 gpm | 13749 | [0.0 ft. hd] |
        - Circuit #04 | 1" | 278.0 ft | 3.61 gpm | 3604 | [7.1 ft. hd] |
        - GHX Header Section #04 | 2" | 20.0 ft | 21.30 gpm | 11755 | [0.0 ft. hd] |
          - Circuit #05 | 1" | 278.0 ft | 3.60 gpm | 3593 | [7.1 ft. hd] |
          - GHX Header Section #05 | 2" | 20.0 ft | 17.70 gpm | 9768 | [0.0 ft. hd] |
            - Circuit #06 | 1" | 278.0 ft | 3.60 gpm | 3593 | [7.1 ft. hd] |
            - GHX Header Section #06 | 2" | 20.0 ft | 14.10 gpm | 7780 | [0.0 ft. hd] |
              - Circuit #07 | 1" | 278.0 ft | 3.61 gpm | 3604 | [7.1 ft. hd] |
              - GHX Header Section #07 | 1 1/2" | 20.0 ft | 10.49 gpm | 7235 | [0.0 ft. hd] |
                - Circuit #08 | 1" | 278.0 ft | 3.59 gpm | 3584 | [7.0 ft. hd] |
                - GHX Header Section #08 | 1 1/4" | 20.0 ft | 6.89 gpm | 5441 | [0.0 ft. hd] |
                  - Circuit #09 | 1" | 278.0 ft | 3.52 gpm | 3507 | [6.8 ft. hd] |
                  - GHX Header Section #09 | 1" | 20.0 ft | 3.38 gpm | 3367 | [0.0 ft. hd] |
                    - Circuit #10 | 1" | 278.0 ft | 3.38 gpm | 3367 | [6.3 ft. hd] |

Fluid Velocities | Purge Pump Requirements | Vaults and Manifolds

What is Ground Loop Design Software?

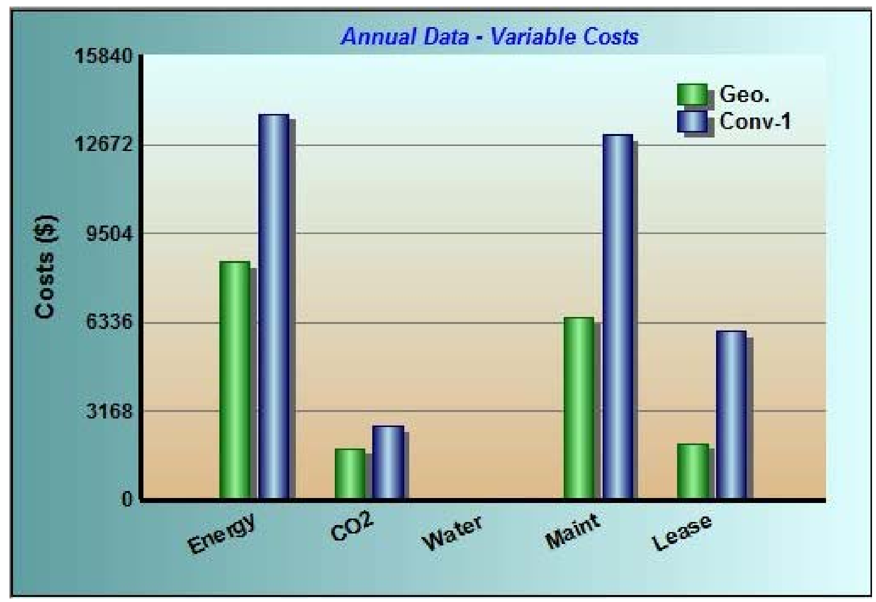
- More Advanced Outputs Include:

Net Present Value Lifecycle Cost Analysis



	Geothermal	Air-cooled Chiller Boiler
Variable Costs ($)		
Energy	294,511.19	477,078.16
CO2 Emissions	36,720.67	53,525.41
Water	0.00	0.00
Maintenance	225,110.56	450,221.12
Mechanical Room Lease	40,376.91	121,130.73
Fixed Costs ($)		
Installation: Subsurface	600,000.00	---
Installation: Equipment	552,000.00	486,000.00
Installation: Controls	65,000.00	130,000.00
Tax Credits	(121,700.00)	---
Depreciation	(404,652.50)	(111,605.92)
Equipment: Replacement	166,884.11	289,975.21
Salvage	(151,640.87)	(85,537.02)
Lifecycle Total	**1,302,610.07**	**1,810,787.69**

Emissions Analysis



What is Ground Loop Design Software?

- **1990s:** Version 1.0 – training tool for engineers
- **2001:** Version 2.7 – horizontal module release
- **2003:** Version 3.0 – dongle-based license
- **2005:** Version 4.0 – development tool
- **2007:** Version 5.0 – Monthly model added
- **2008:** Version 5.0 – Residential Edition
- **2009:** Version 6.0 – Finance/Emissions Module
- **2010:** Version 7.0 – CFD Module and Hourly Sim Engine
- **2014:** Version 8.0 – Gridbuilder, Geothermal System Analysis

Today: 54 countries, 1000's of engineering customers

What is Ground Loop Design Software?

Goal: To turn research advances into practical design tools

Developed in conjunction with:

- Oakridge National Lab
- University of Alabama
- Oklahoma State University
- Lund University, Sweden
- University of Valencia
- Oregon Institute of Technology- “GeoHeat Center”
- Major Heat Pump Companies- WFI, Climatemaster, FHP, etc
- 100’s of Design and engineering firms

What is Ground Loop Design Software?

- **Heat transfer models (boreholes only):**
  - Design Day Method
  - Monthly Method
  - Hourly Method

- **GLD strength: all three models included**
  - Calculate heat exchangers with all models
  - Compare three results from one loads profile
  - Optimize design
  - Enhance design confidence

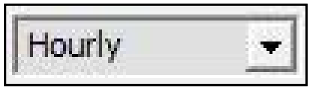
What is Ground Loop Design Software?

Design Day Method

- Models borehole as cylinder
- Borehole thermal interaction analysis limited
- Provides estimate of ground temperature change
- Good for quick and "prelim" modeling
- Only for rectangular or square configurations with equidistant spacing

Monthly Method (g function)

- Borehole modeled as line
- More advanced borehole interaction model
- More advanced simulations of fluid temps and COP/EER values
- No ground temp change estimates at present
- Any loopfield configuration



Hourly Method (g function)

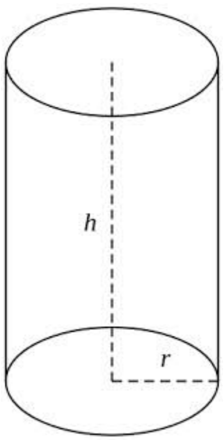
- More advanced 8760 simulations
- Requires computational resources
- No ground temp change estimates at present

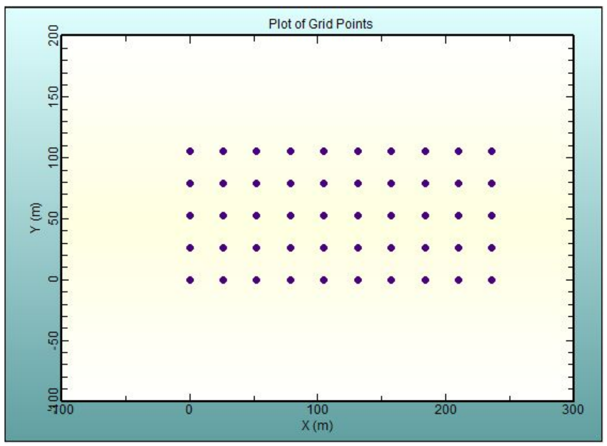
What is Ground Loop Design Software?

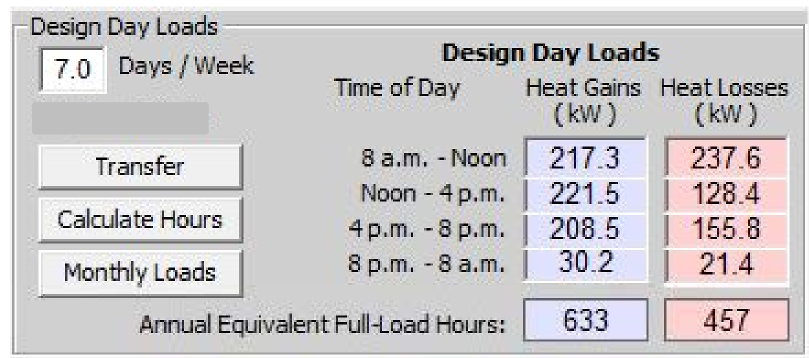
Method	Model	Building Loads Requirements	Loopfield Designs	Usefulness
Design Day	2D Cylinder	Minimal	Square/ Rectangle	Preliminary Modeling
Monthly	1D Line G function	Moderate	Any	Optimized Modeling
Hourly	1D Line G function	Detailed	Any	Optimized Modeling

What is Ground Loop Design Software?

Design Day Method Basic Inputs:



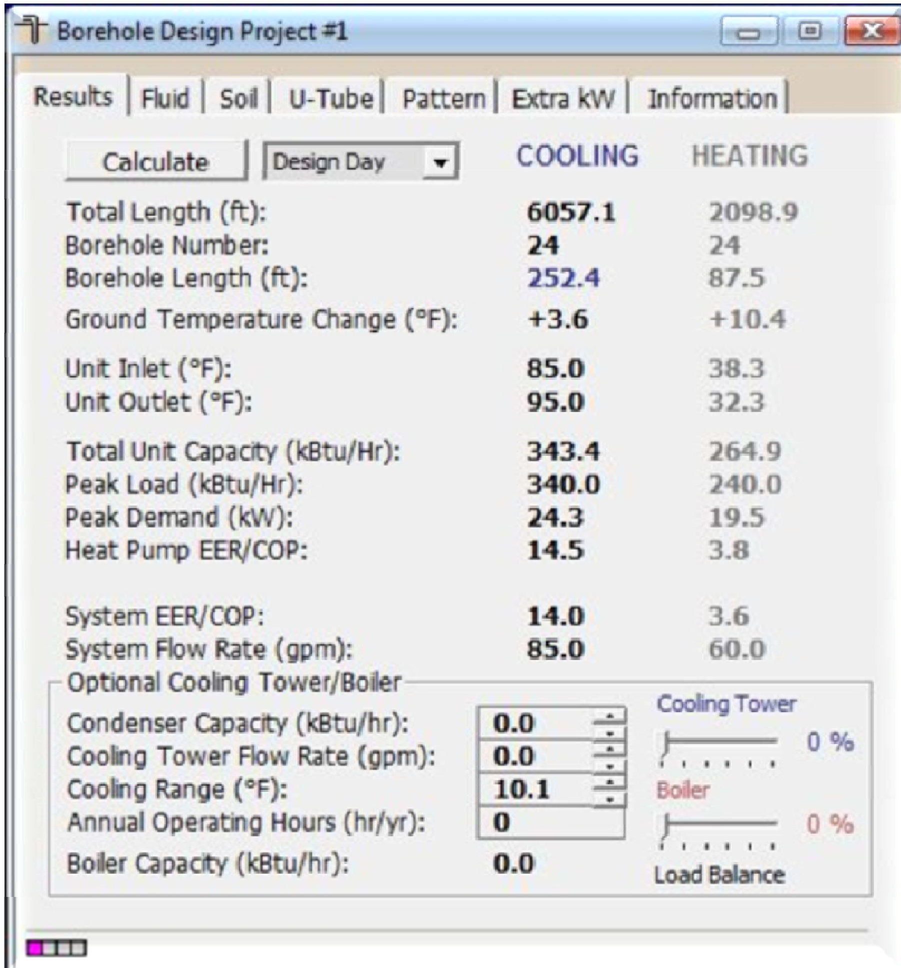




What is Ground Loop Design Software?

Design Day

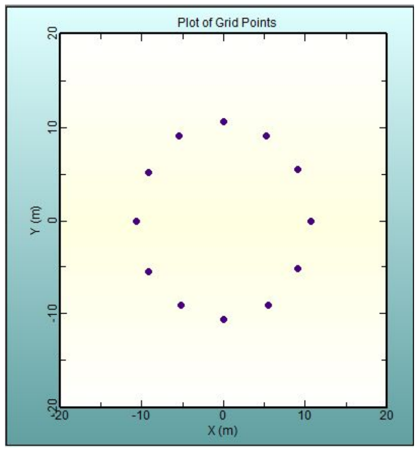
Design Day Method Outputs:

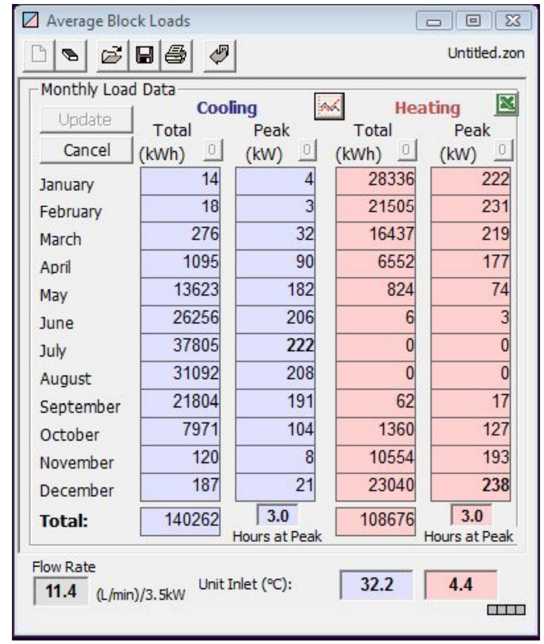


What is Ground Loop Design Software?

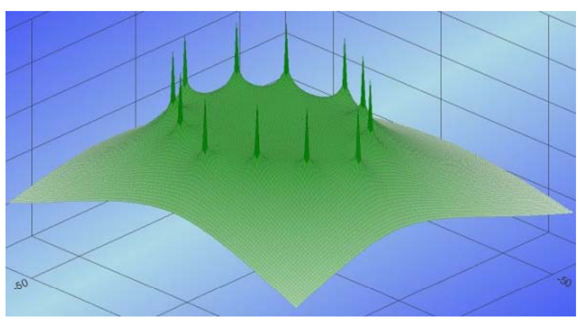
Monthly

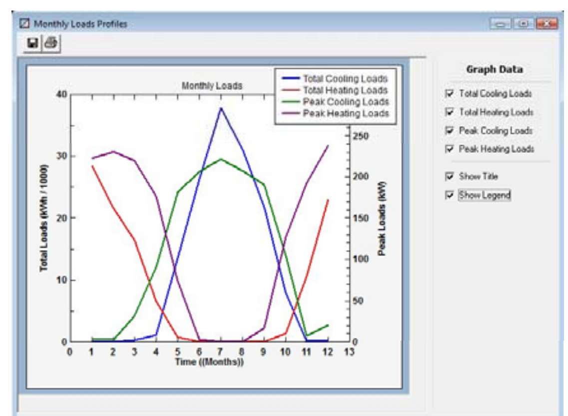
Monthly Method Inputs:





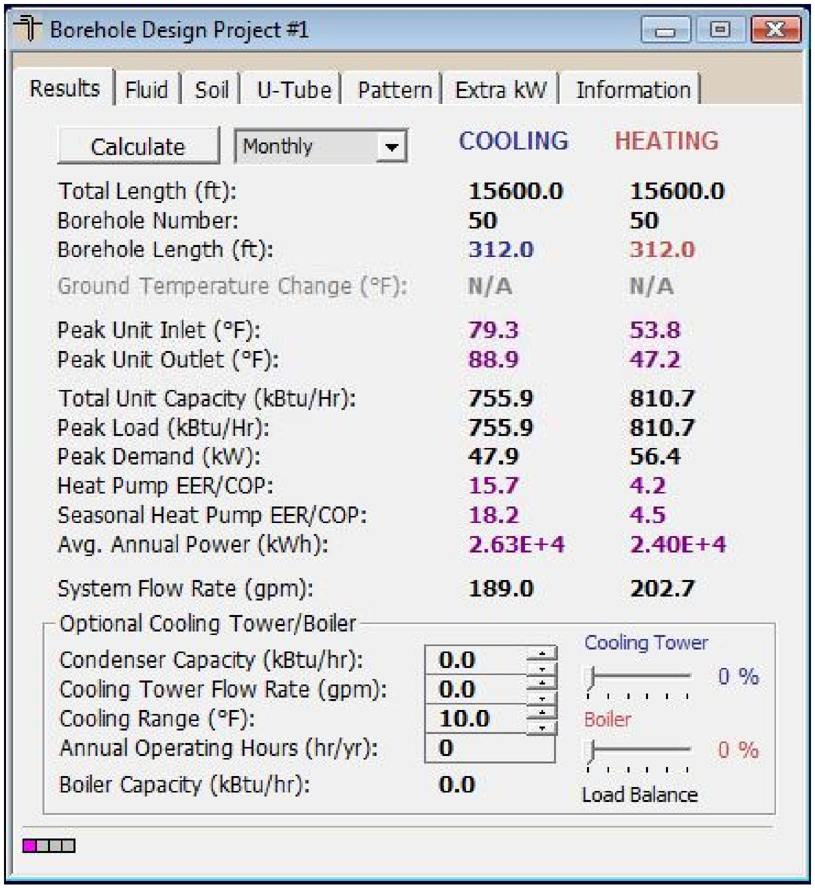
	Cooling Total (kWh)	Cooling Peak (kW)	Heating Total (kWh)	Heating Peak (kW)
January	14	4	28336	222
February	18	3	21505	231
March	276	32	16437	219
April	1095	90	6552	177
May	13623	182	824	74
June	26256	206	6	3
July	37805	222	0	0
August	31092	208	0	0
September	21804	191	62	17
October	7971	104	1360	127
November	120	8	10554	193
December	187	21	23040	238
Total:	140262	3.0 Hours at Peak	108676	3.0 Hours at Peak

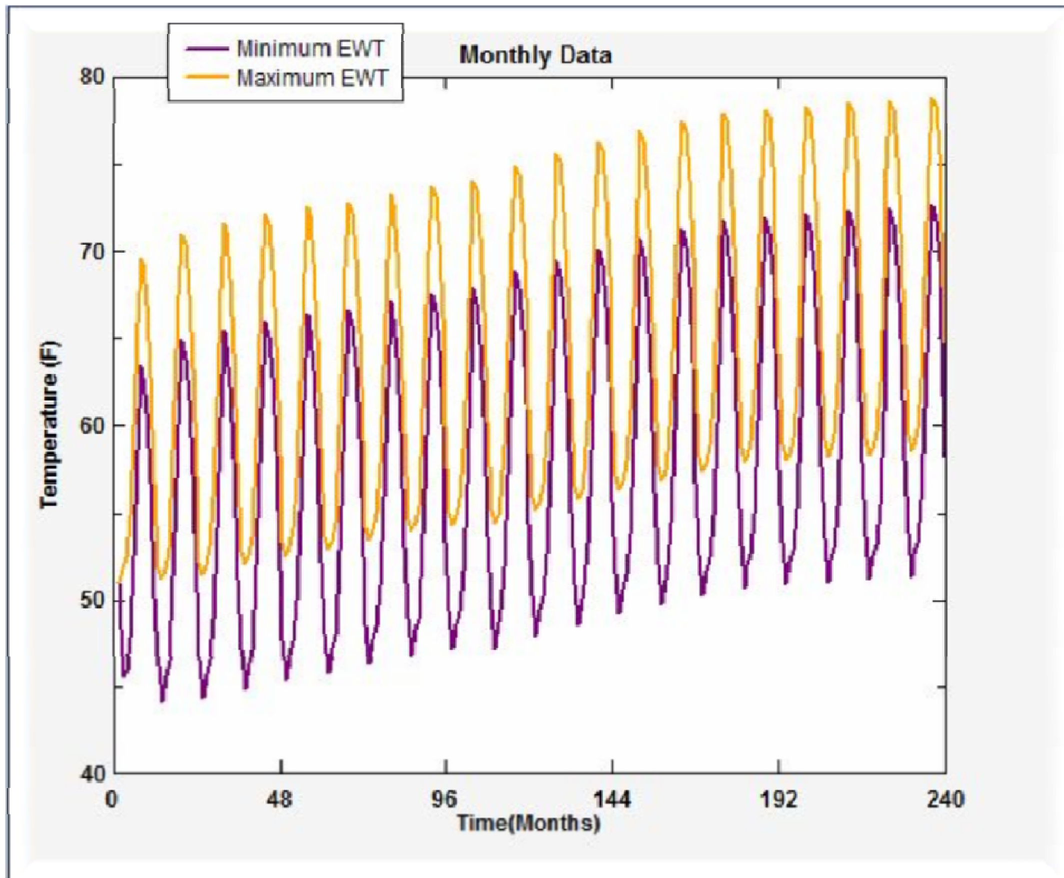




What is Ground Loop Design Software?

Monthly Method Outputs:





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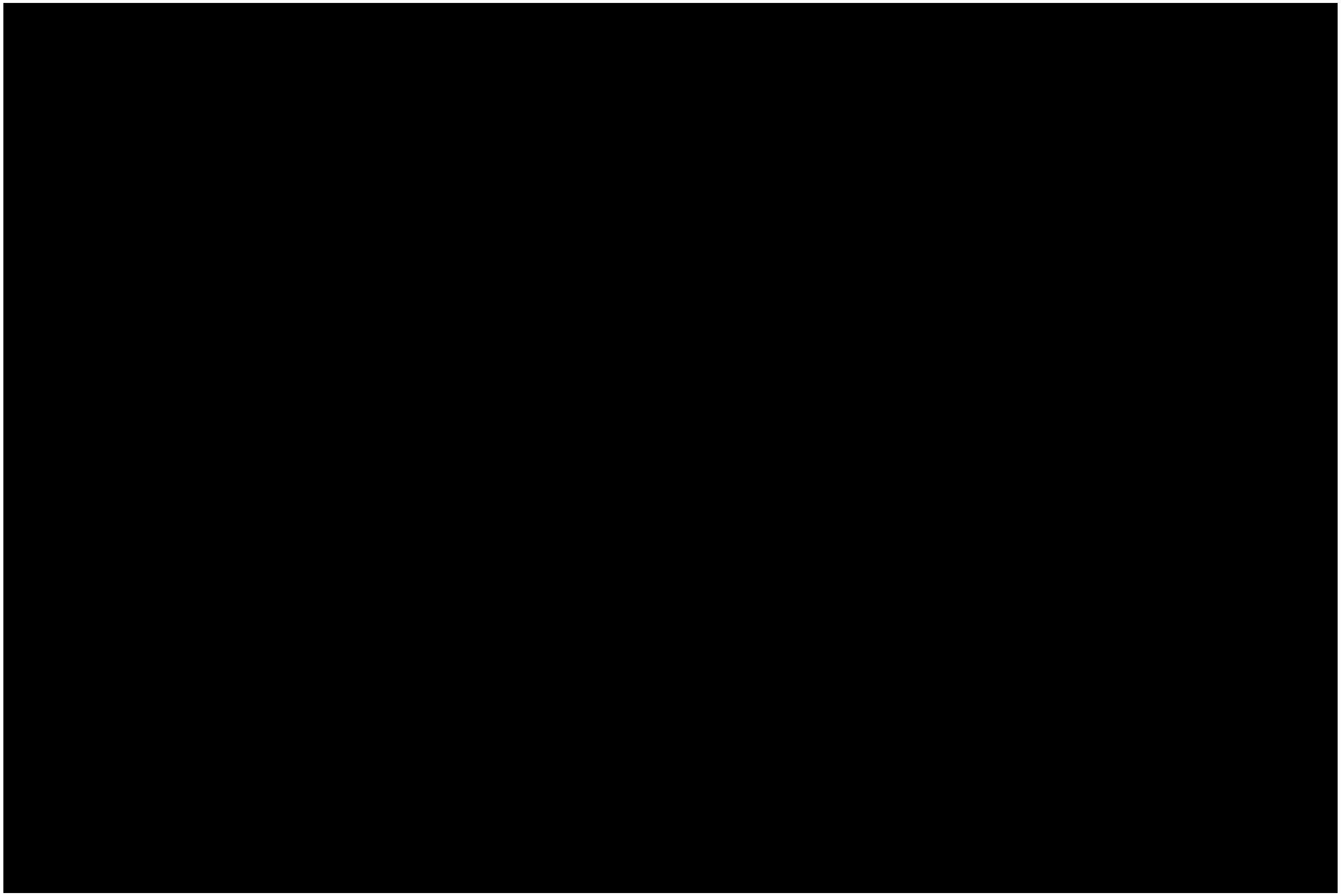

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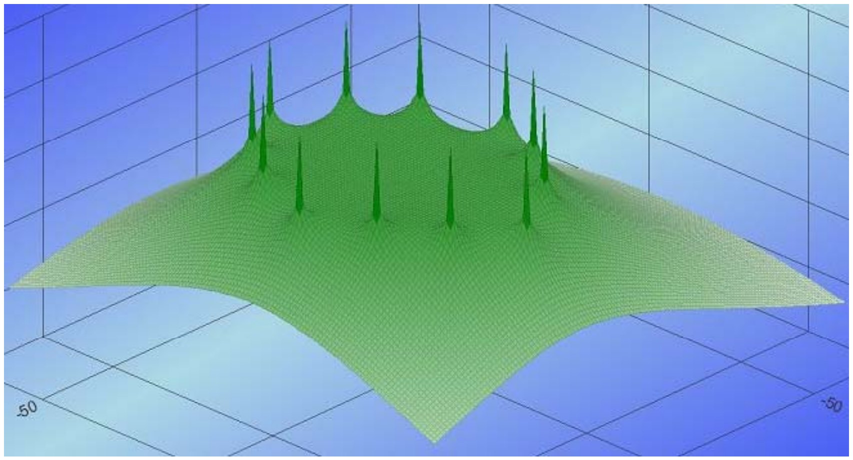
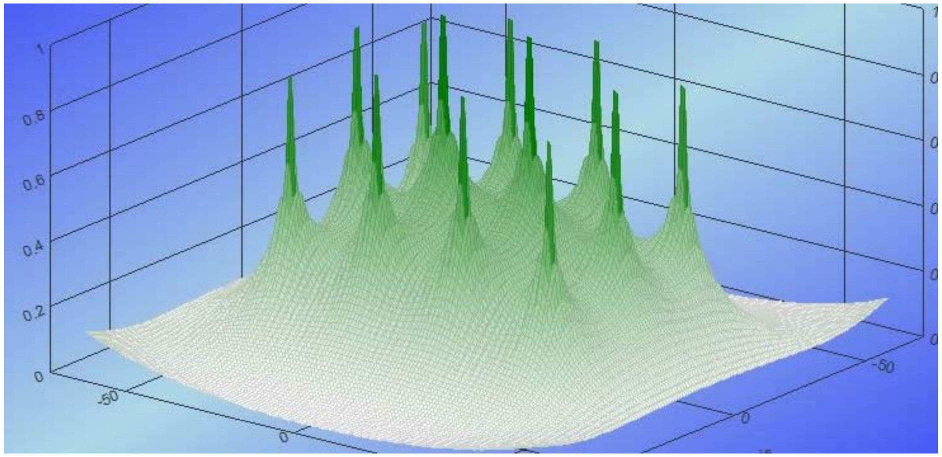
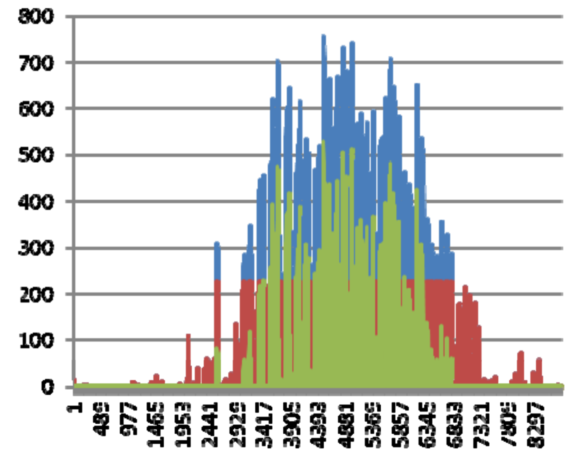


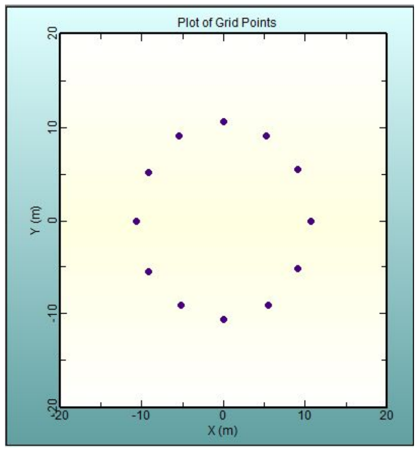


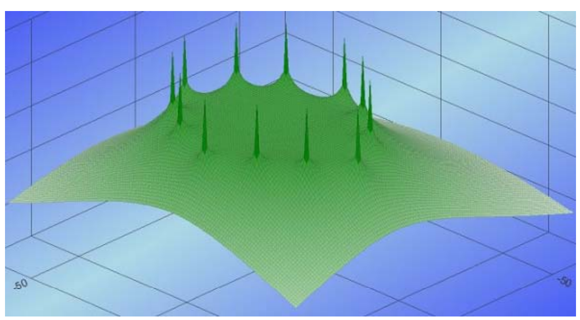
What is Ground Loop Design Software?

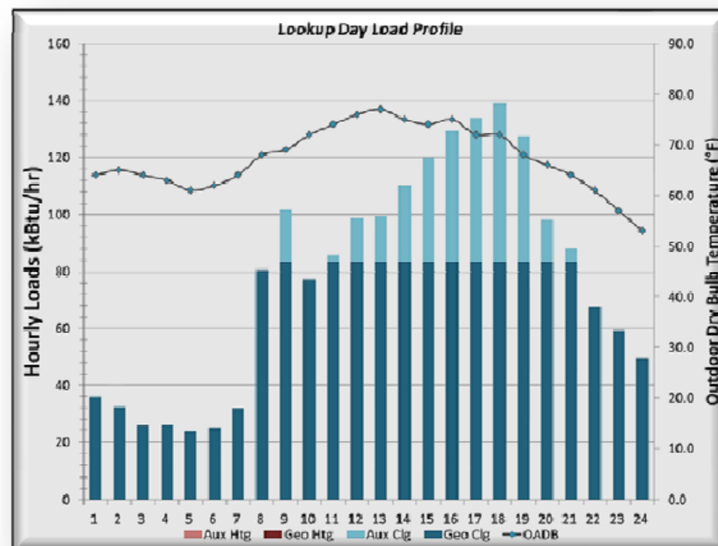
Monthly

Hourly Method Inputs:



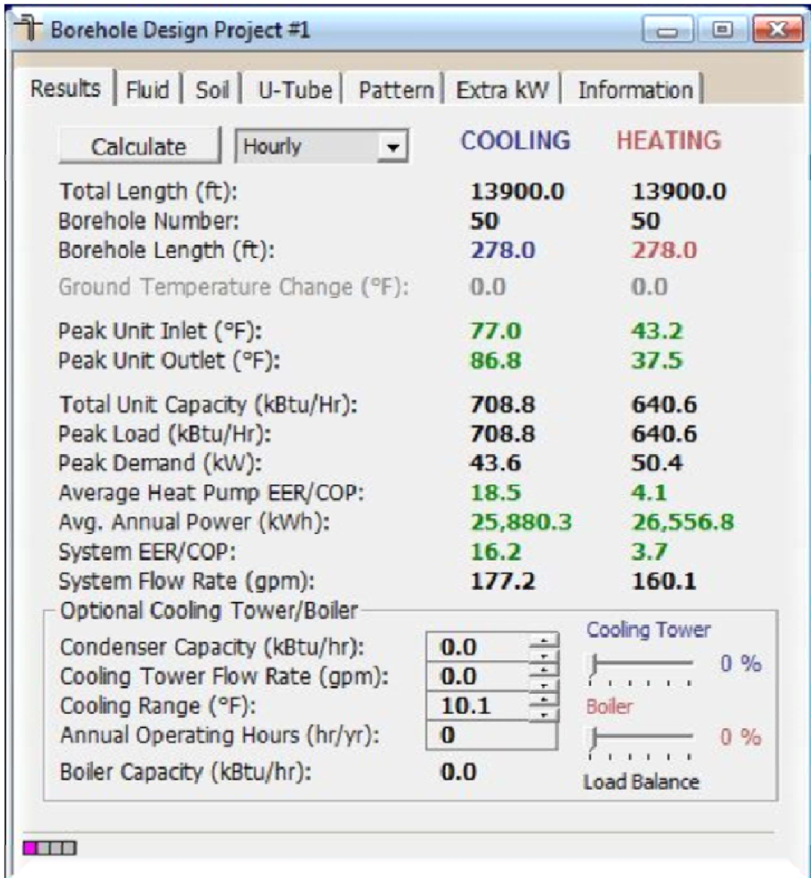


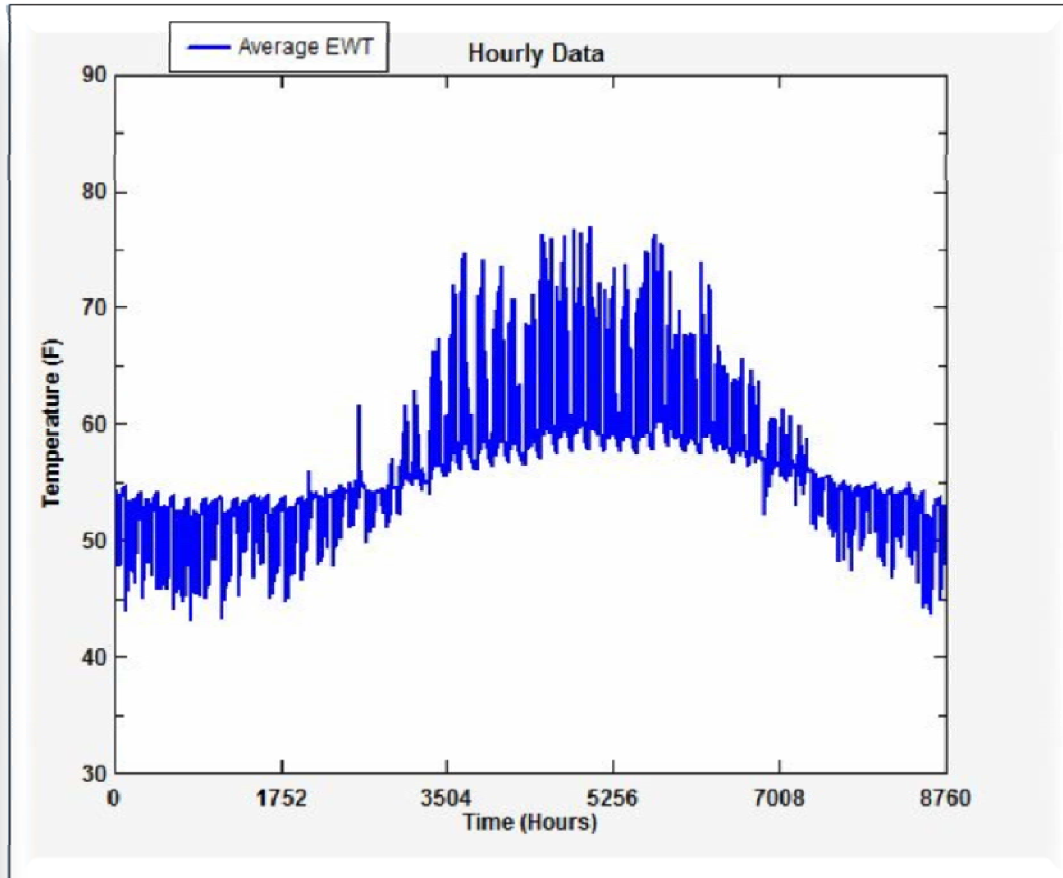




What is Ground Loop Design Software?

Hourly Method Outputs:





What is Ground Loop Design Software?

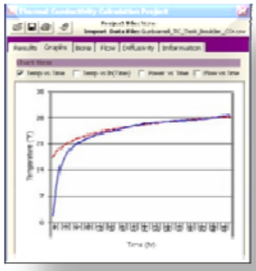
- Heat Exchanger Modules



- Average Block and Zone Manager Loads Modules


- Piping Module/GSA & CO2 Module/TC Module





What is Ground Loop Design Software?

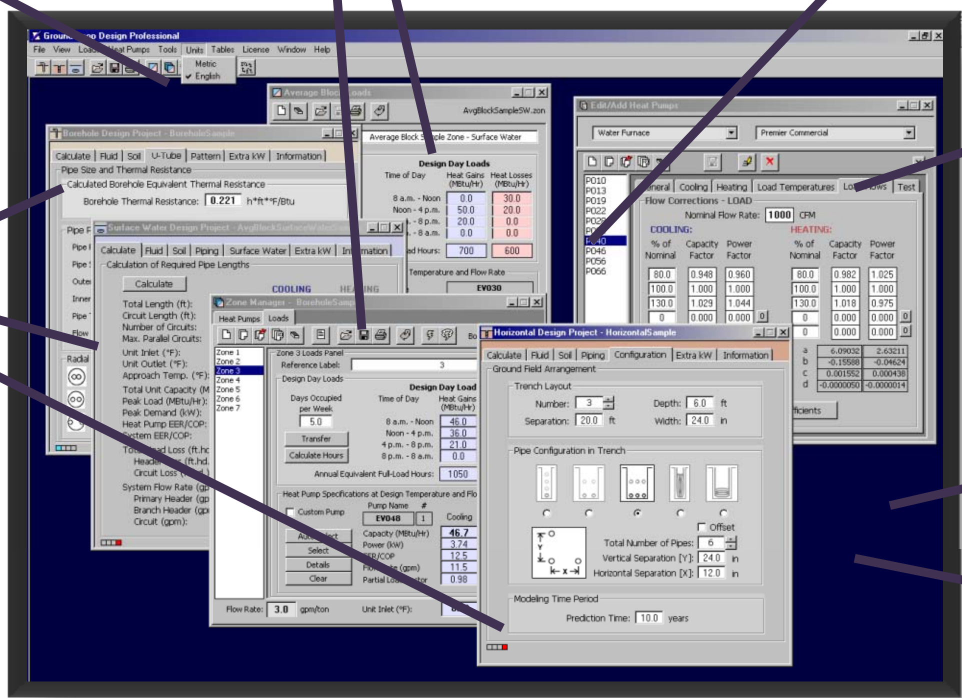
Import Module

Loads Modules

Reports

Edit/Add Heat Pumps Module

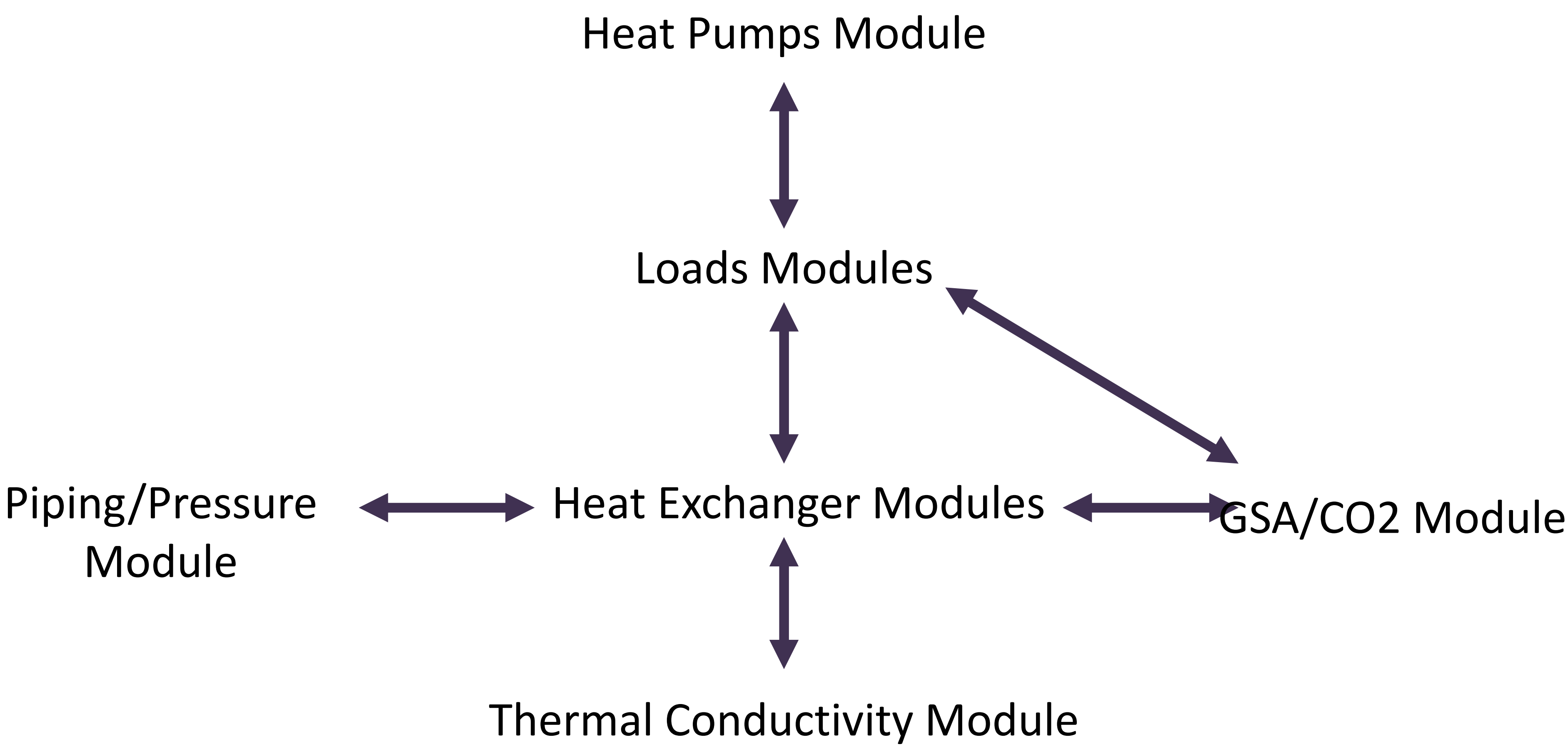
Design Modules



References

Help Files

What is Ground Loop Design Software?



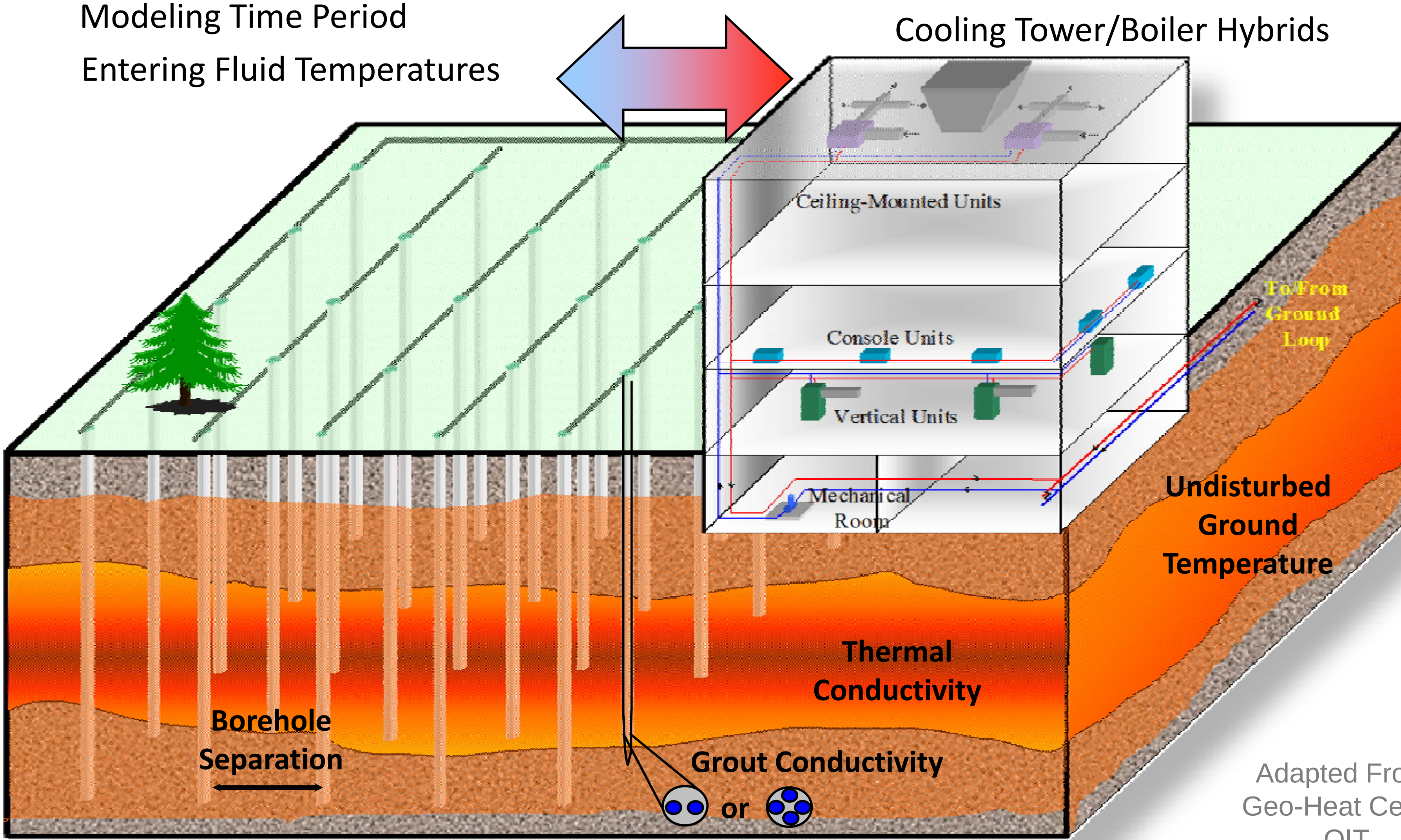
Why Use GLD Software?

- To ensure long-term, thermally stable systems
- To understand the ins and outs of heat transfer
- To efficiently explore scenarios and quickly optimize designs
- To accurately balance installation cost/system performance tradeoffs
- To save your clients money
- To avoid risky "rule of thumb" designs
- To think holistically about energy efficiency

Section - System Design Inputs and their Impact

- GLD Overview
- **System Design Inputs and their Impact**
- Average Block vs. Zone Manager Loads Module
- Bringing Loads into GLD
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
- Linking Modules Together
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- The GSA Module and Lifecycle Costing

System Design Inputs and their Impact



Adapted From:
Geo-Heat Center
OIT

System Design Inputs and their Impact

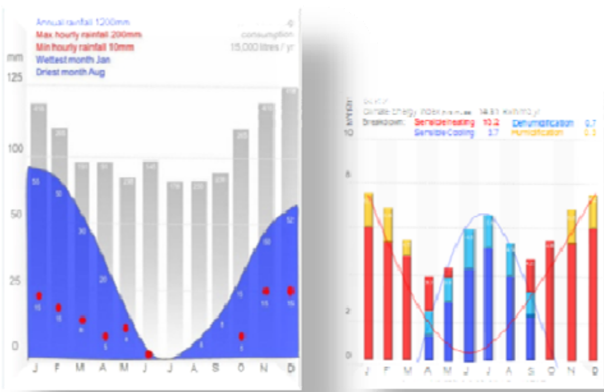
Key Components:

- Loads
- Entering Water Temperatures
- Pipe/Borehole Spacing
- Field Layout
- Ground Temperature
- Thermal Conductivity
- Grout Conductivity
- Modeling Time Period

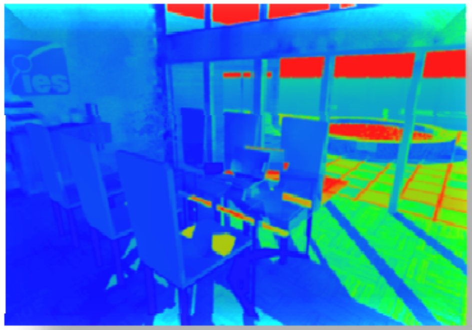
Loads

Loads are THE foundation of a geothermal system:

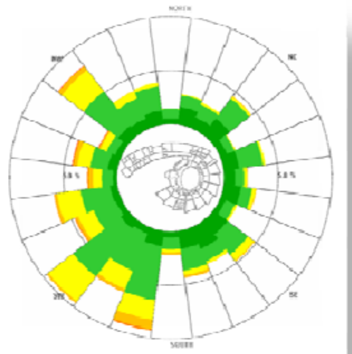
- Loads Overview
- Required Loads Data



Monthly Energy Output*



Daylight contours

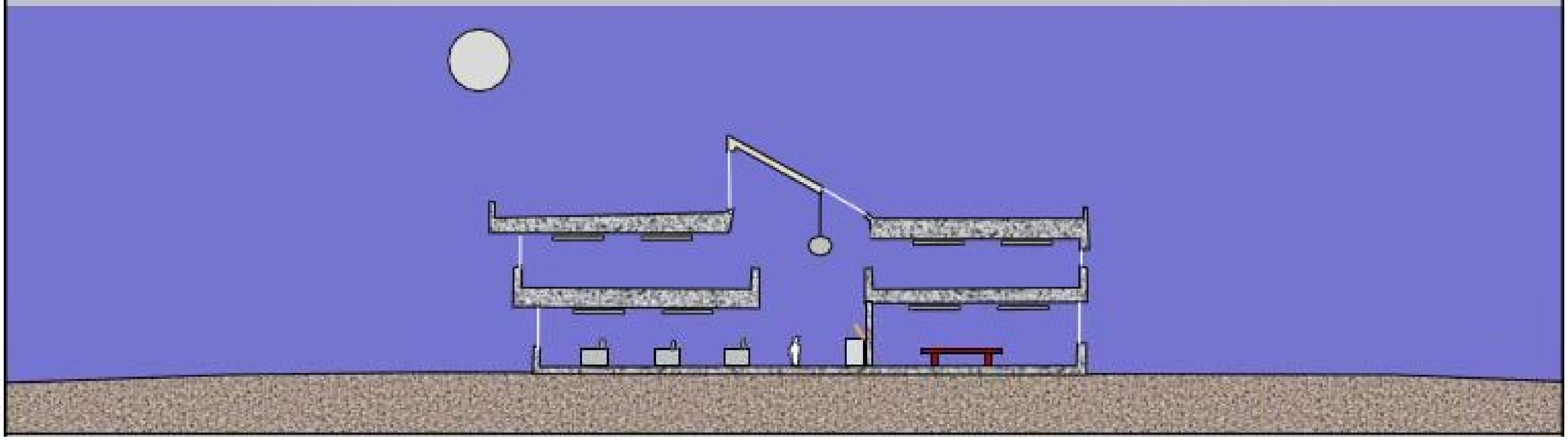


Climate Understanding

Loads

Building loads are dynamic

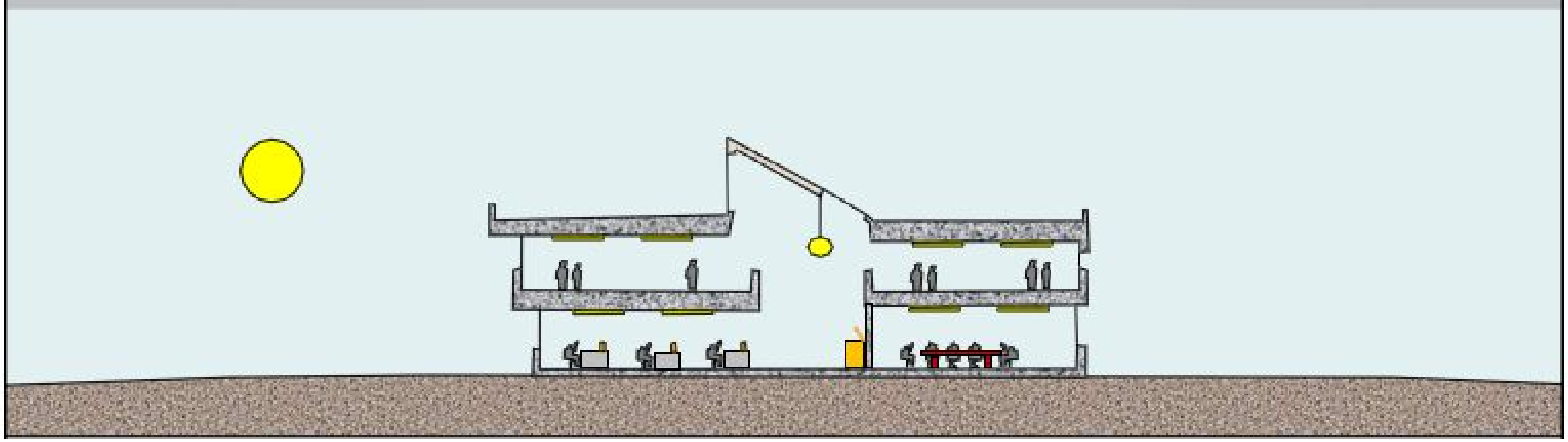
At night most buildings are unoccupied, lights & electrical equipment are shut off, there are no solar gains, outdoor temperature is lower & ventilation rates are reduced. Cooling loads at night are typically lower.



Loads

The building in the morning

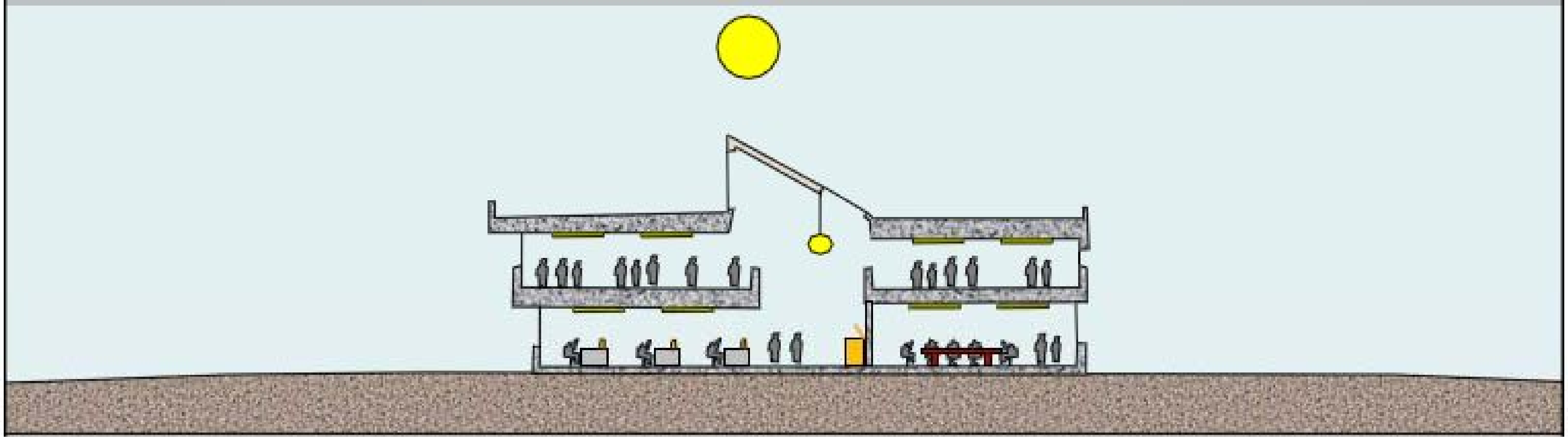
As people arrive at work, lights, computers & copiers are turned on, the sun warms the east side of the building & ventilation rates are increased. Heating loads can be reduced because of internal & solar gains, or could increase because of increased ventilation.



Loads

The building during the day

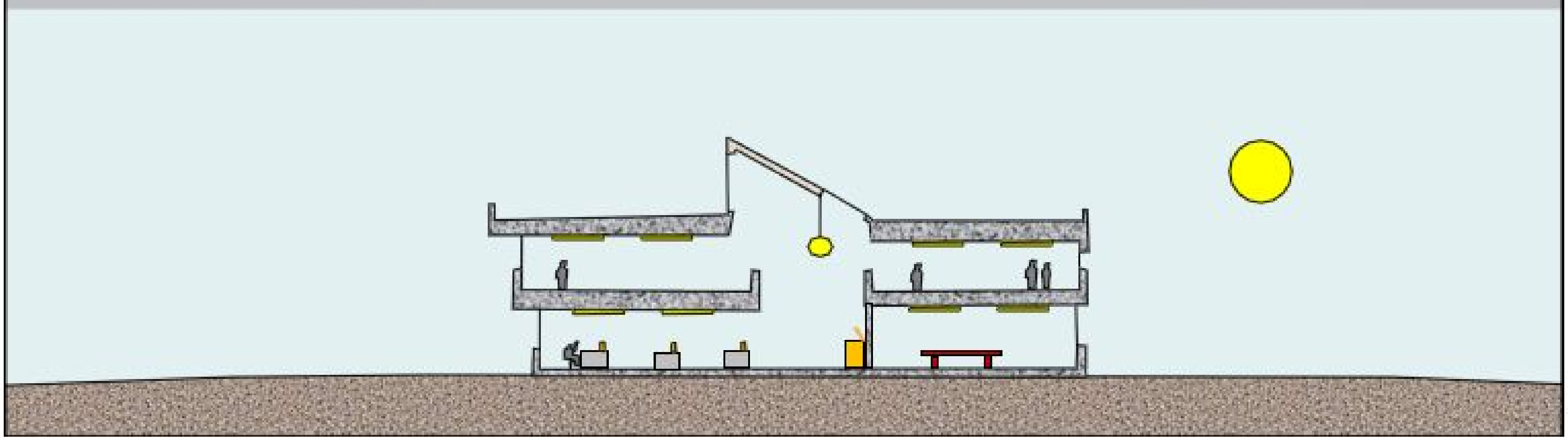
As the day progresses, outdoor air temperatures increase, more people occupy the building, the mass of the building gradually increases in temperature, and solar gains shift to other parts of the building, cooling loads typically increase and heating loads are further reduced.



Loads

The building in the late afternoon

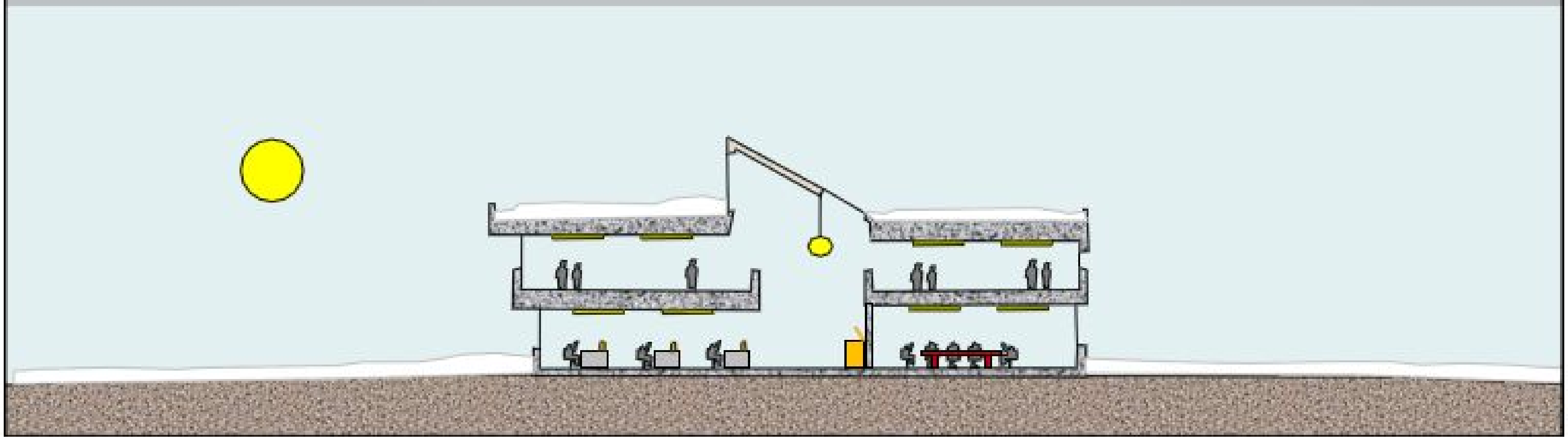
By late afternoon solar gains have shifted and outdoor temperatures gradually increase the cooling loads typically have increased and heating loads are further reduced. Building mass that has warmed during the day may begin radiating heat to the air in the building.



Loads

Seasonal changes

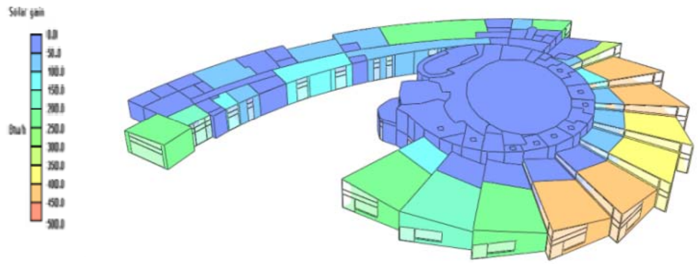
An accurate energy model calculates the hourly heating and cooling loads, based on 8,760 hourly weather data. The occupancy and use of the building is overlaid on the building schedule you input into the software.



Loads: Overview

Building loads depend on:

- Climate/Location
- Building Envelope
- Building Insulation Values
- Window Specifications
- Daylighting with natural light
- Solar shading
- Lighting controls and specs
- White roof/green roof options
- Building Use
- Architects and engineers should be using software that can do this type of analysis!

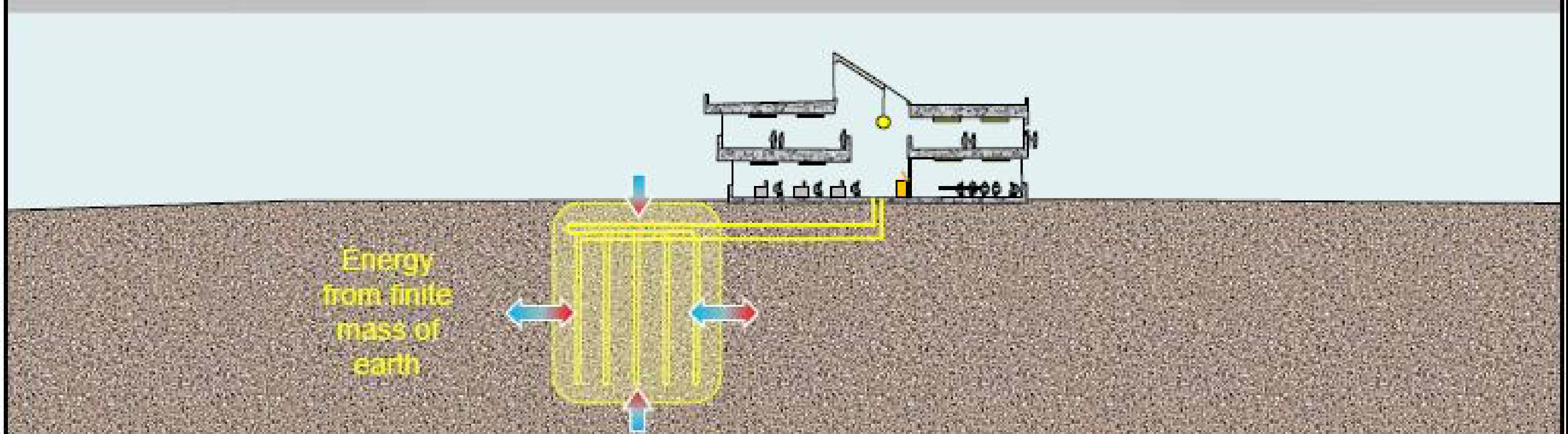


Loads: Overview

- For a geothermal system to function, the design must guarantee that the equipment can utilize the ground all year round.

GHX is connected to finite piece of earth

A GHX is only connected to a finite mass of soil and rock. When too much energy is withdrawn from or rejected to the GHX it will freeze or overheat. The ability to provide or absorb energy from the building is limited by the temperature range of the heat pump equipment connected to it.



Loads: Overview

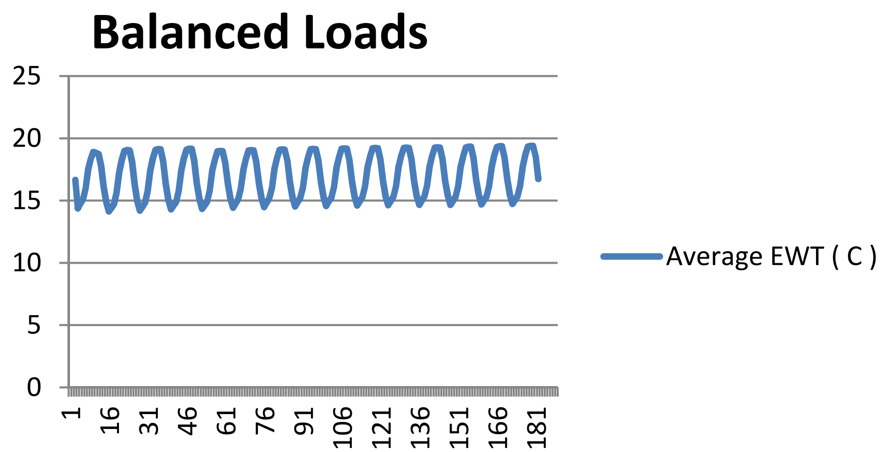
- Designers need to know the building loads going into the ground and coming out of the ground on a daily basis.

GHX is like a bank account

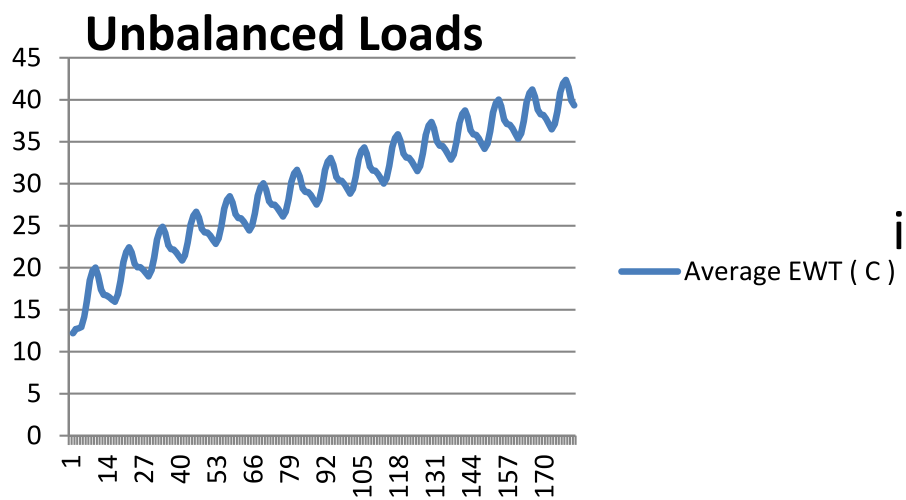
If all you do is take money from a bank account, eventually it will run out of money. If the amount of money deposited is approximately equal to the amount of money withdrawn, the process can go on forever.

Loads: Overview

- We want loads that allow the process to go on year after year after year.



efficient and sustainable



inefficient and unsustainable

Loads: Required Loads Data

- Minimum (Design Day Method)
- Better (Monthly Method)
- Best (Hourly Method)

Loads: Required Loads Data

Design Day ▾ Method: Required Loads Data

1) **Peak Loads** (kW)

2) **Annual Energy Loads** (total kWh)

Design Day Loads

7.0 Days / Week

Transfer | Calculate Hours | Monthly Loads

Design Day Loads Time of Day	Heat Gains (kW)	Heat Losses (kW)
8 a.m. - Noon	0.0	237.6
Noon - 4 p.m.	221.5	0.0
4 p.m. - 8 p.m.	0.0	0.0
8 p.m. - 8 a.m.	0.0	0.0
Annual Equivalent Full-Load Hours:	633	457

Annual Equivalent Full-Load Hours = Energy Load/Peak Load

Peak Cooling: 221.5kW

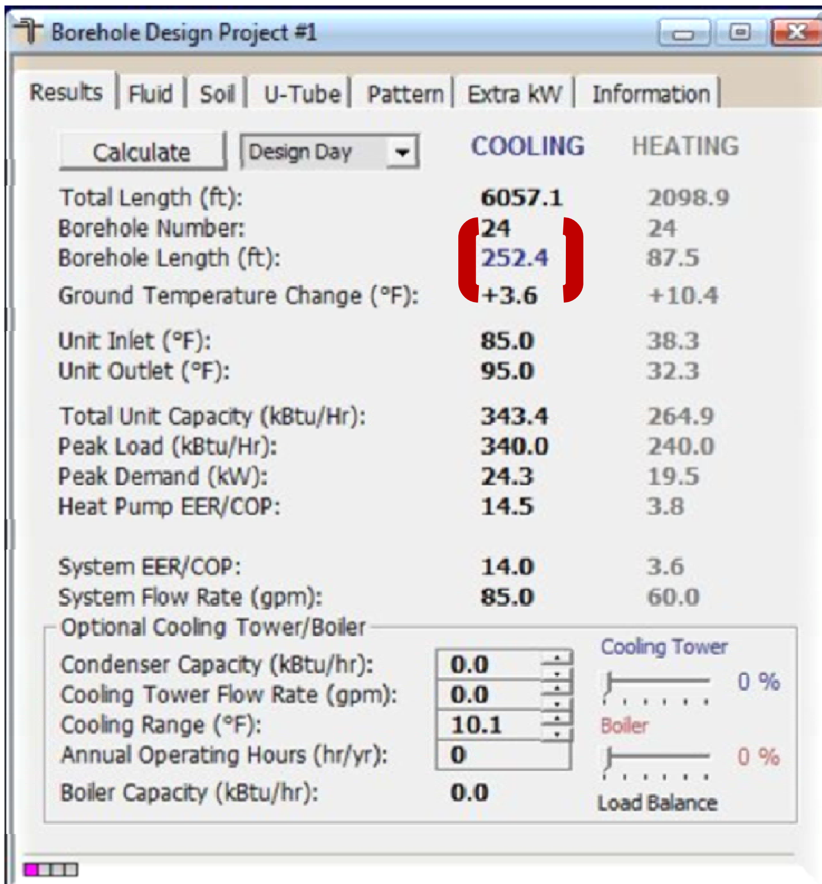
Annual Cooling Energy Load: 140262kWh

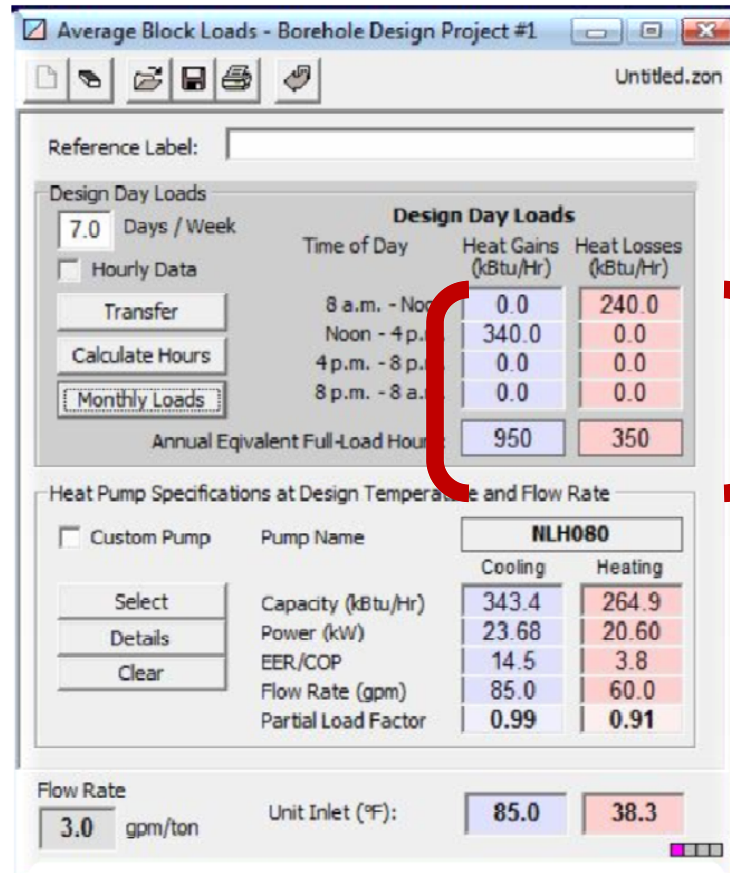
AEFLH = 140262/221.5 = 633 hours cooling

Loads: Required Loads Data

What happens if we don't have Annual Energy loads and we guess?

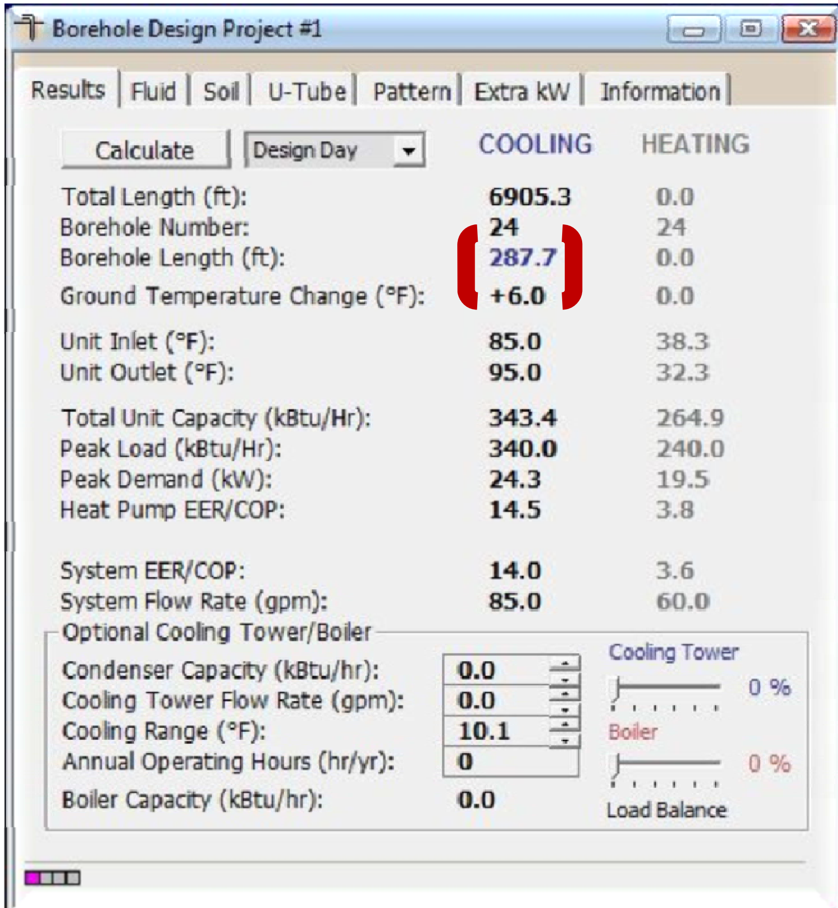
GUESS #1:

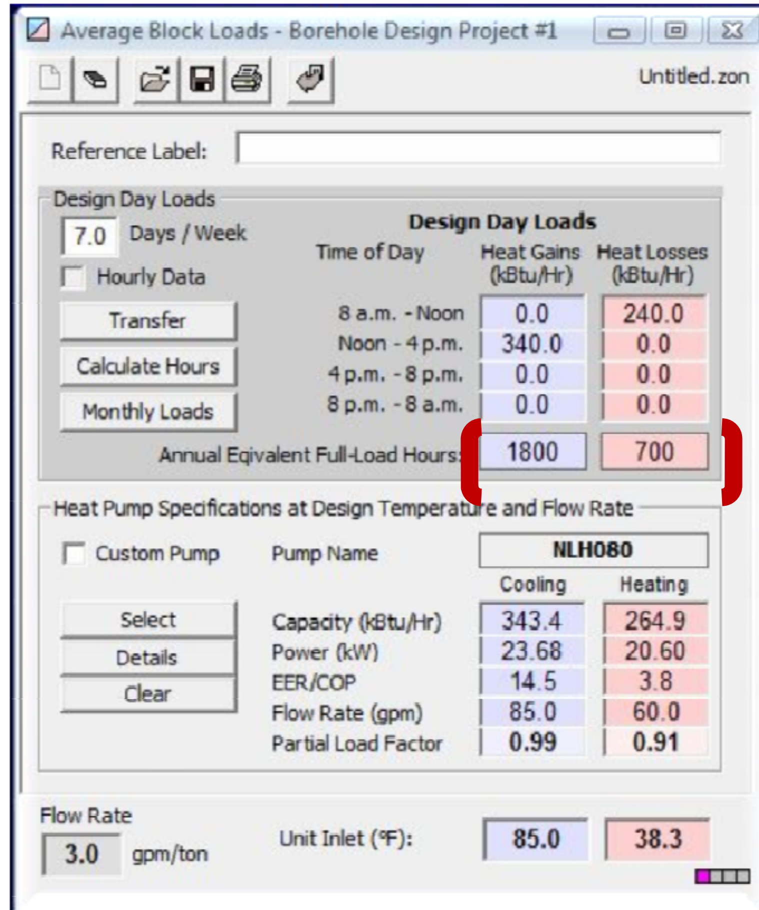




Loads: Required Loads Data

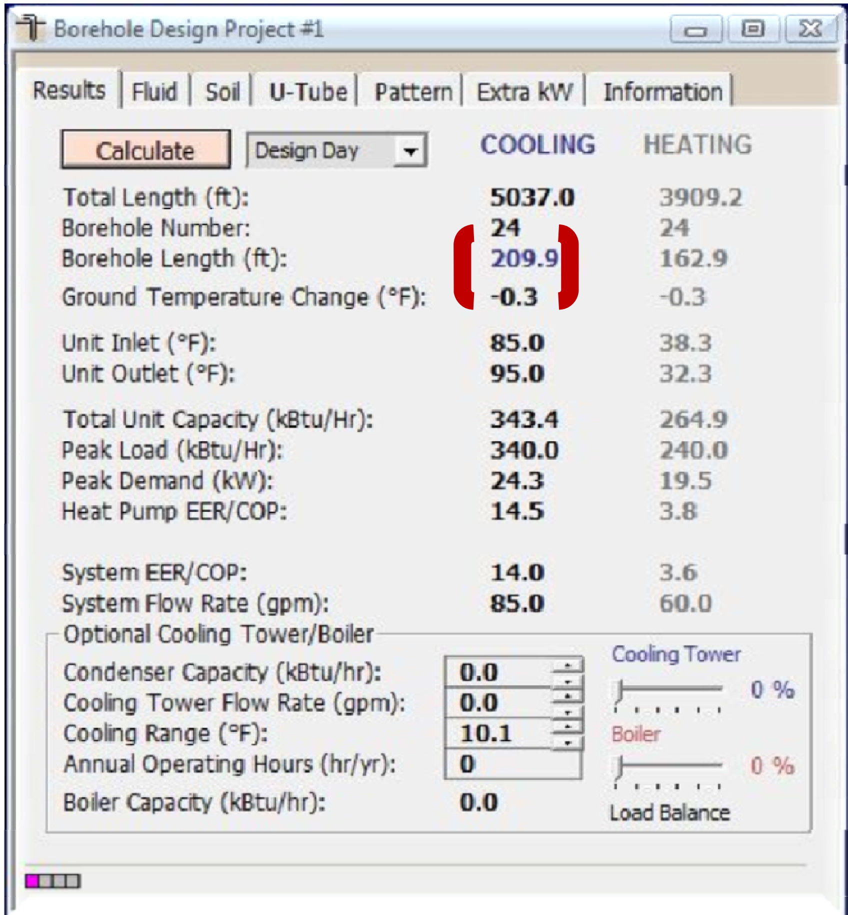
Guess #2:

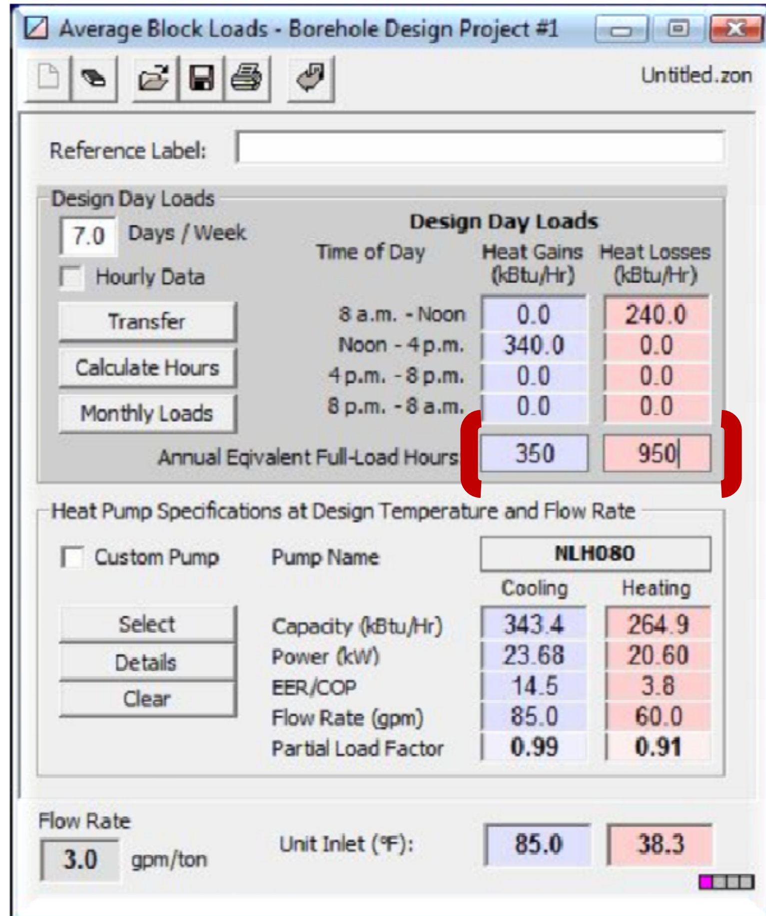




Loads: Required Loads Data

Guess #3:





Loads: Required Loads Data

What happens if you guess the number of hours?

Guess	Cooling Hours/Heating Hours	Calculated Length
Guess #1	350/950	209 ft
Guess #2	950/350	252 ft
Guess #3	1800/700	288 ft

209 to 288 is a 40% difference! Guessing can be very dangerous!

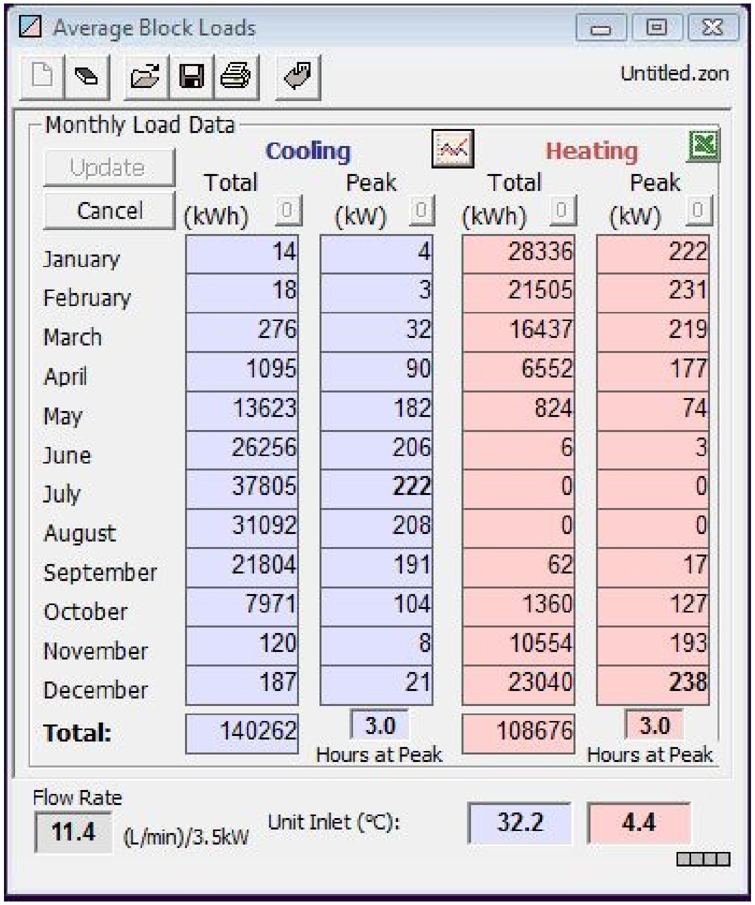
Don't guess! Use software tools to accurately calculate loads.

Loads: Required Loads Data

Monthly Method : Required Loads Data

Peak Loads (kW)

Monthly total loads (kWh)



	Cooling Total (kWh)	Cooling Peak (kW)	Heating Total (kWh)	Heating Peak (kW)
January	14	4	28336	222
February	18	3	21505	231
March	276	32	16437	219
April	1095	90	6552	177
May	13623	182	824	74
June	26256	206	6	3
July	37805	222	0	0
August	31092	208	0	0
September	21804	191	62	17
October	7971	104	1360	127
November	120	8	10554	193
December	187	21	23040	238
Total:	140262	3.0 Hours at Peak	108676	3.0 Hours at Peak

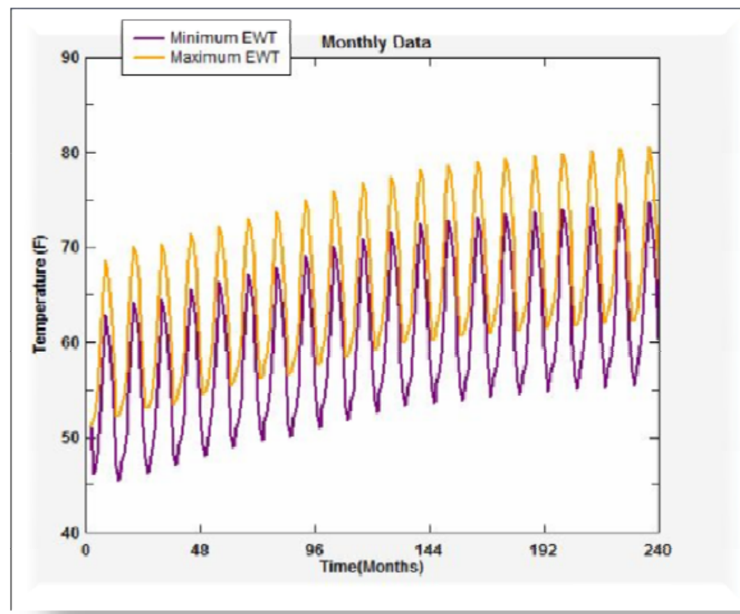
Loads: Required Loads Data

<u>What can you do with Monthly Simulation Method Loads Data?</u>

Estimate fluid temps for each month over many years, calculate average COPs/EERs and annual power consumption.

With balanced loads, you may be able to calculate reduce your drilling.

	COOLING	HEATING
Total Length (ft):	14658.0	14658.0
Borehole Number:	60	60
Borehole Length (ft):	244.3	244.3
Ground Temperature Change (°F):	0.0	0.0
Peak Unit Inlet (°F):	80.5	45.5
Peak Unit Outlet (°F):	88.8	36.5
Total Unit Capacity (kBtu/Hr):	708.8	640.6
Peak Load (kBtu/Hr):	708.8	640.6
Peak Demand (kW):	10.0	9.2
Average Heat Pump EER/COP:	18.4	4.4
Avg. Annual Power (kWh):	25,974.2	24,671.4

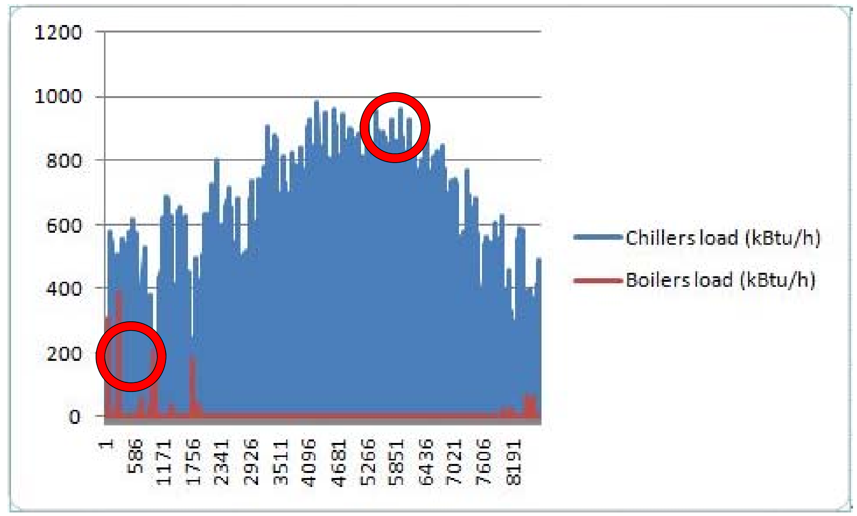


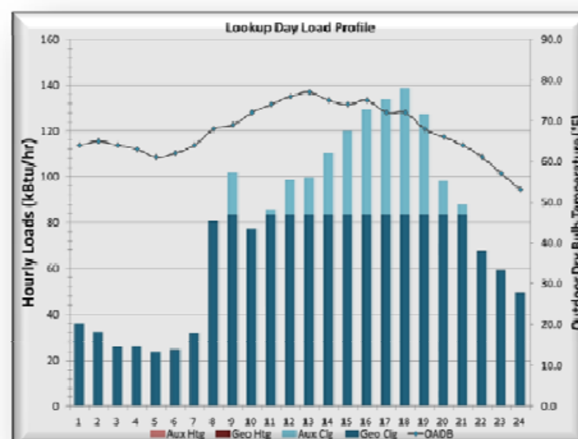
Loads: Required Loads Data

Hourly

Method: Required Loads Data

Hour	Chillers load (kBtu/h)	Boilers load (kBtu/h)
1	0	1.932
2	0	1.929
3	0	1.976
4	0	2.35
5	0	3.217
6	0	3.16
7	0	2.963
8	0	310.514
9	1.205	124.741
10	13.375	76.599
11	29.946	38.911
12	46.029	11.067
13	62.112	4.25
14	74.821	0.006
15	87.88	0
16	96.815	0
17	100.01	0
18	100.982	0.19
19	105.067	2.846
20	0.024	0
21	0.695	0
22	2.384	0
23	5.343	0
24	6.568	0





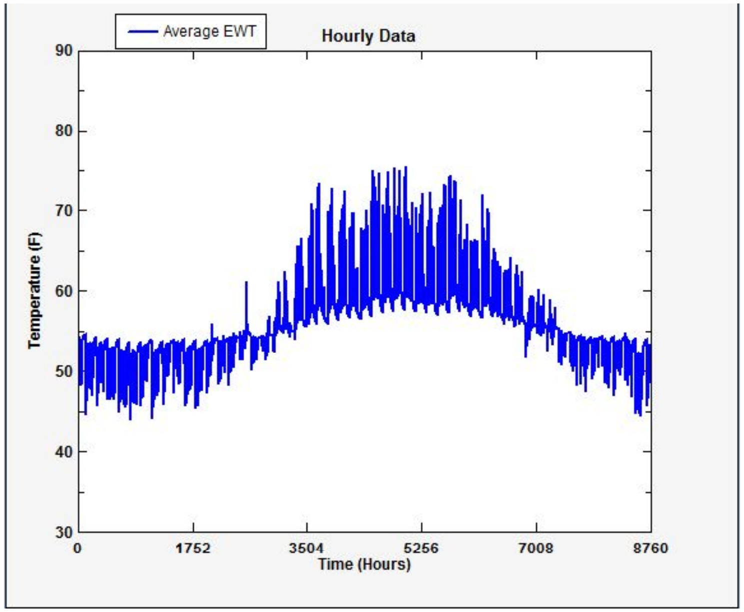
Loads: Required Loads Data

What can you do with Hourly Simulation Method Loads Data?

Estimate fluid temps hour by hour and calculate average COPs/EERs and annual power consumption.

Optimize your design, compare your design to data collected from installed system

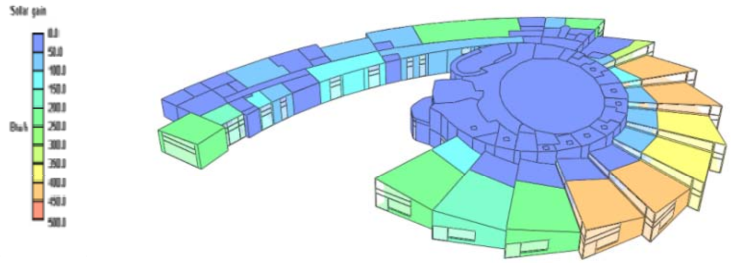
	COOLING	HEATING
Total Length (ft):	14640.0	14640.0
Borehole Number:	60	60
Borehole Length (ft):	244.0	244.0
Ground Temperature Change (°F):	0.0	0.0
Peak Unit Inlet (°F):	75.6	43.9
Peak Unit Outlet (°F):	85.4	38.2
Total Unit Capacity (kBtu/Hr):	708.8	640.6
Peak Load (kBtu/Hr):	708.8	640.6
Peak Demand (kW):	42.7	50.2
Average Heat Pump EER/COP:	18.7	4.1
Avg. Annual Power (kWh):	25,571.1	26,516.0
System EER/COP:	16.5	3.7



Loads: Overview

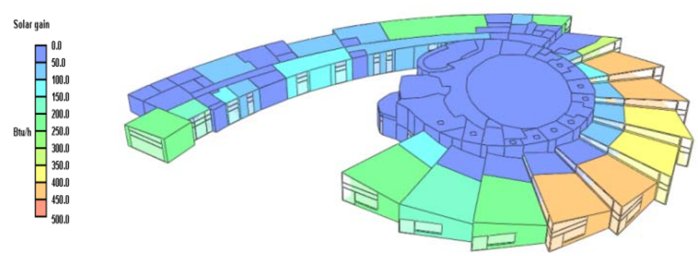
A thorough understanding of the loads is essential for determining how much energy must be transferred to and from the ground. The designer must consider:

- Climate and Structure
- Energy Reclamation
- Internal gains (occupancy, electrical, process)
- Solar gains
- Energy loads
- Energy Balance



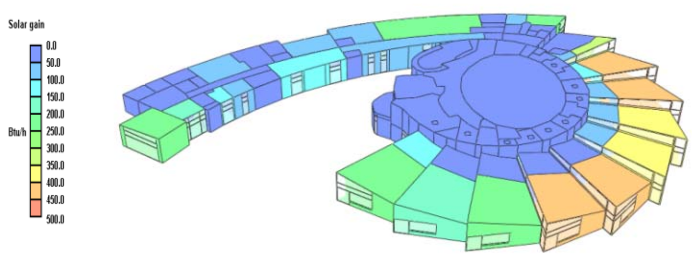
Loads: Overview

- Conventional loads calculations require only the cooling load on the hottest day of summer when the building is fully occupied.
- Conventional loads calculations require only the heating load on the coldest night of the year
- With these two numbers, the building will have the “right” conventional equipment capacity



Loads: Overview

- For a geothermal system to function, the design must guarantee that the equipment can utilize the ground all year round.
- Designing a geothermal system involves the design of a system and an energy source. The GHX must be the right size.
- If it is too big it costs too much. If it is too small it underperforms and gives geothermal technologies a bad reputation.
- More detailed loads data are required. They take more time to calculate and are more valuable. Designers should charge clients for these calculations.



Loads: Overview

- Example: Church vs. Office

  - Same peak load, same location, same geology
  - Church used 2x a week
  - Office used 12 hours a day, 5 days a week
  - Office loopfield >> Church Loop

Loads: Software

- With loads programs, it is easy to have oversized loads
- Avoid oversized loads with geothermal design

With most commercial loads programs:

- the heat gain from the mechanical room is added to cooling load (for example, a chiller plant). This doesn't exist with geothermal systems.
- Lighting must be adjusted for scheduled use to avoid extra loads
- Eliminate any backup heat sources in the loads calculations
- Include energy recovery for outside air ventilation

Loads: Reality Check

PEAK LOADS

New Construction Office Buildings:

20-30 btu/sq ft cooling

Less for heating

Retrofit:

25-30 btu/sq ft cooling

Heating may be as high

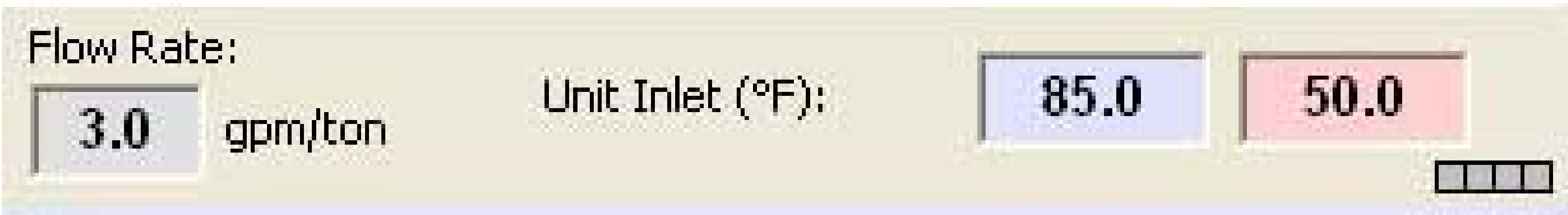
ANNUAL HOURS

Cooling annual loads over 2000 hours = double check

Loads: Conclusion

- **Loads are really important!**
- **Calculate them accurately!**

Entering Water Temperatures



- **Definition:**

  Entering Water Temperatures (EWTs)/Unit Inlet Temperatures are the temperatures coming into the heat pump from the ground source heat exchanger.

- **Range:**

  Cooling: 85^{o}-95^{o} F (25^{o} -35^{o} above ground temp)

  Heating: 30^{o} -40^{o} F (15^{o} below ground temp)

- **Impact**

  Heat Exchanger Length

Example 1

Borehole Spacing

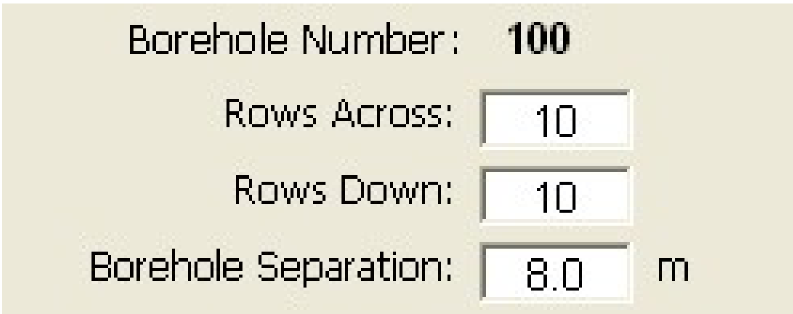
- **Definition:**
  Center-to-center distance between adjacent boreholes

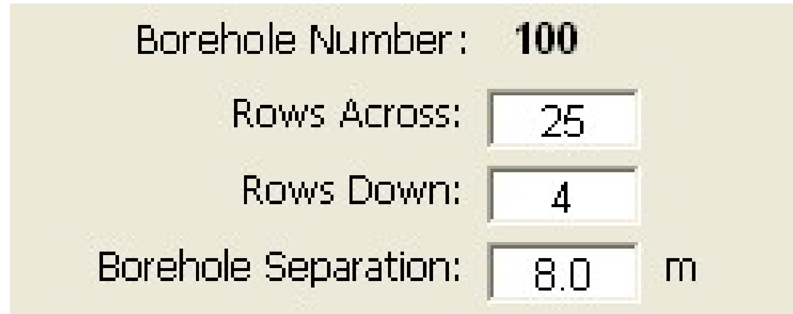
- **Range:**
  15 ft minimum, no maximum

- **Impact**
  more separation = less heat build-up in soil = less drilling
  less separation = more heat build-up in soil = more drilling

Example 1 (cooling dominant)
Example 2 (heating dominant)

Borehole Geometry



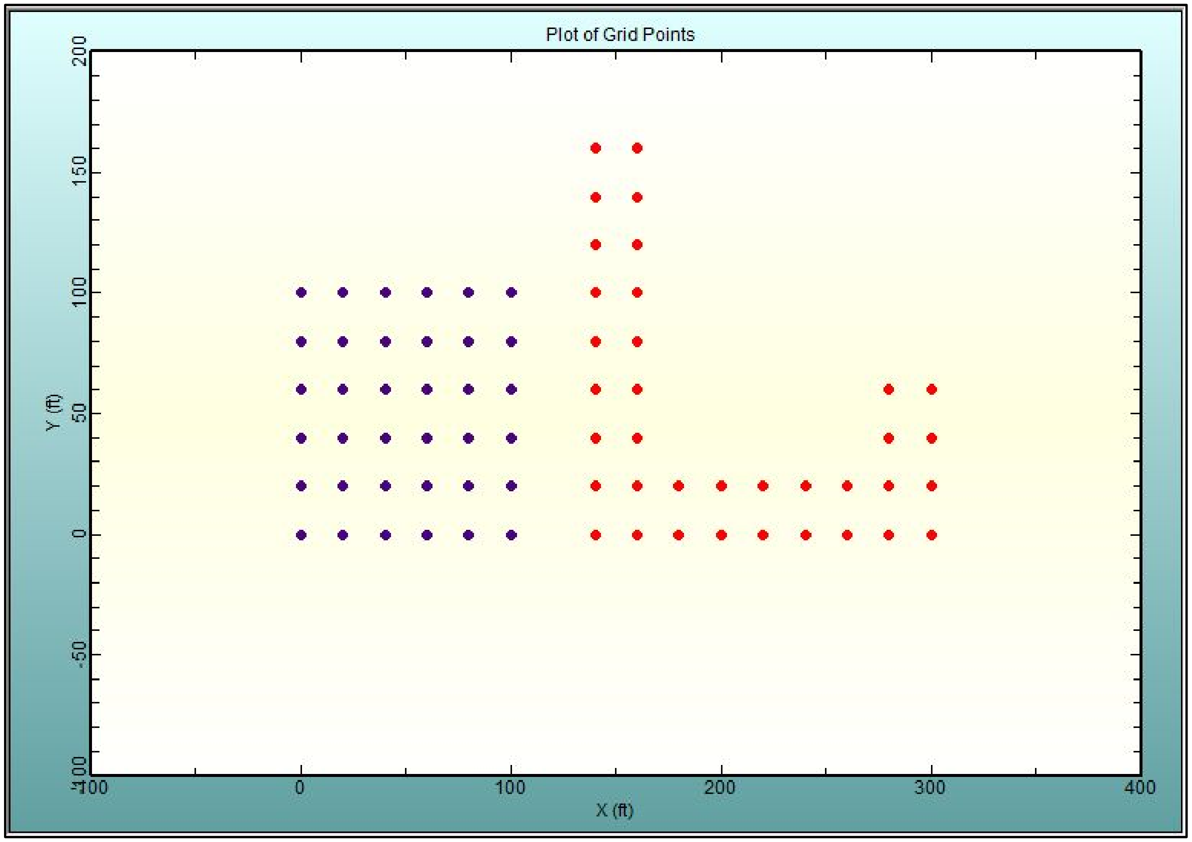


- **Definition:**
  Geometry of the loopfield

- **Range:**
  Depends on space

- **Impact**
  High Density Systems = More Drilling
  Low Density Systems = Less Drilling

Borehole Geometry



36 boreholes x 437ft

36 boreholes x 406ft

~ 1111 ft less drilling

Ground Temperature

- **Definition:**
  Subsurface undisturbed ground temperature

- **Range:**
  35^{o}F (+/)- to 68^{o}F (+/-)

- **Impact:**
  Maximize the Delta T between the Soil and EWTs to minimize drilling

Example 1

Thermal Conductivity

Thermal Conductivity: 1.08 Btu/(h*ft*°F)

Thermal Diffusivity: 0.75 ft^2/day

- **Definition:**
  Ability of soil to transport heat

- **Range:**
  0.6 to 1.5 +

- **Impact:**
  higher conductivity = more efficient heat transfer = less drilling

Example 1

Thermal Conductivity

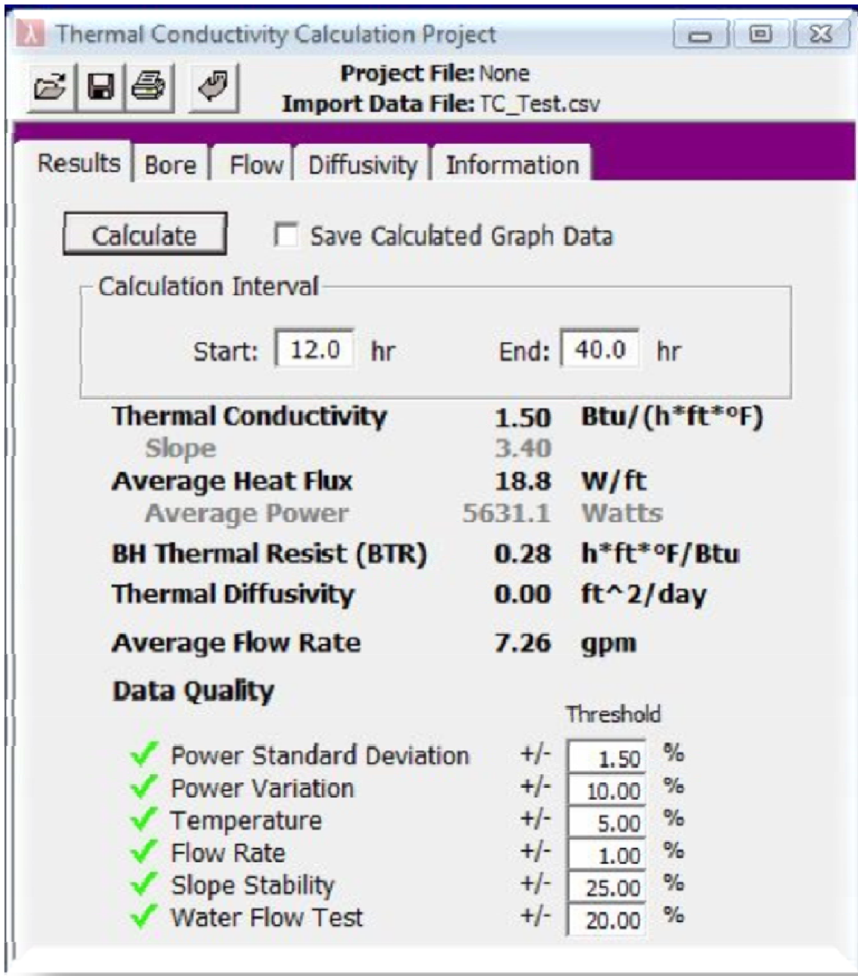
- **What?**
  - A test to determine the average thermal conductivity of the ground.
  - Usually for vertical systems. Can be performed for horizontal systems as well;
  - Measures:
    - Ground temperature (undisturbed)
    - Conductivity (k) –how much heat flows through the soil
    - Diffusivity (α =k/pc)
      - » Ratio of thermal conductivity to volumetric heat capacity. How rapidly heat flows through soil.

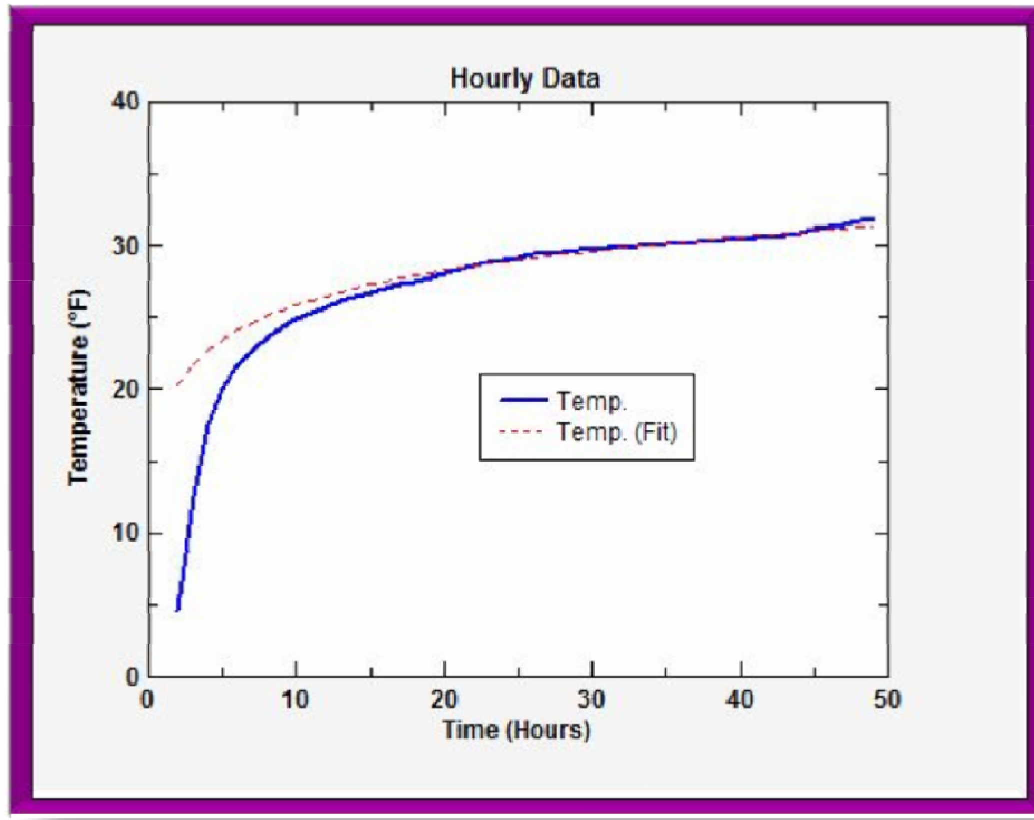
- **Why?**
  - Allows you to design accurately

Thermal Conductivity

- **When?**
  - Should be performed if the TC test cost is less than the difference between the best case and worst case design scenarios
- **How?**
  - Transfer known amount of heat into a test loop and measure how much heat is absorbed by soil
  - Use depth and pipe size that you plan on using for final installation.
  - The TC test borehole can be used in the final installation

Thermal Conductivity





Grout Conductivity

- **Definition:**
  Ability of grout to transport heat

- **Range:**
  varies

- **Impact**
  higher conductivity = more efficient heat transfer = less drilling

Example 1

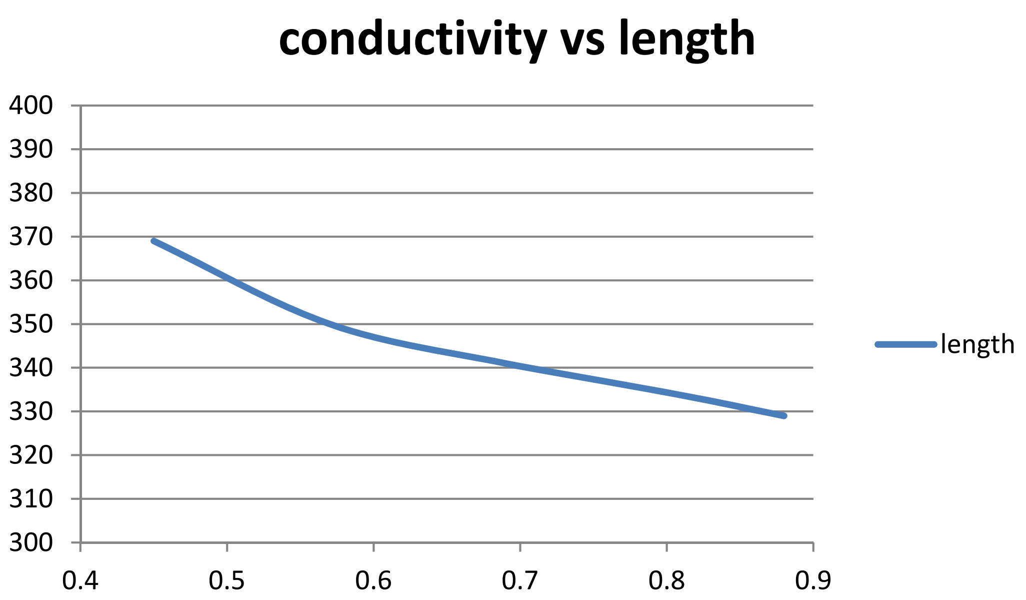
Grout Conductivity

100 borehole system

Grout Conductivity	Bore length	Total length	Cost ($12/ft)
0.00	6039ft	603900ft	$7,246,800
0.45	369ft	36900ft	$442,800
0.57	350.3ft	35030ft	$420.360
0.69	341ft	34100ft	$409,200
0.79	335ft	33500ft	$402,000
0.88	329ft	32900ft	$394,800

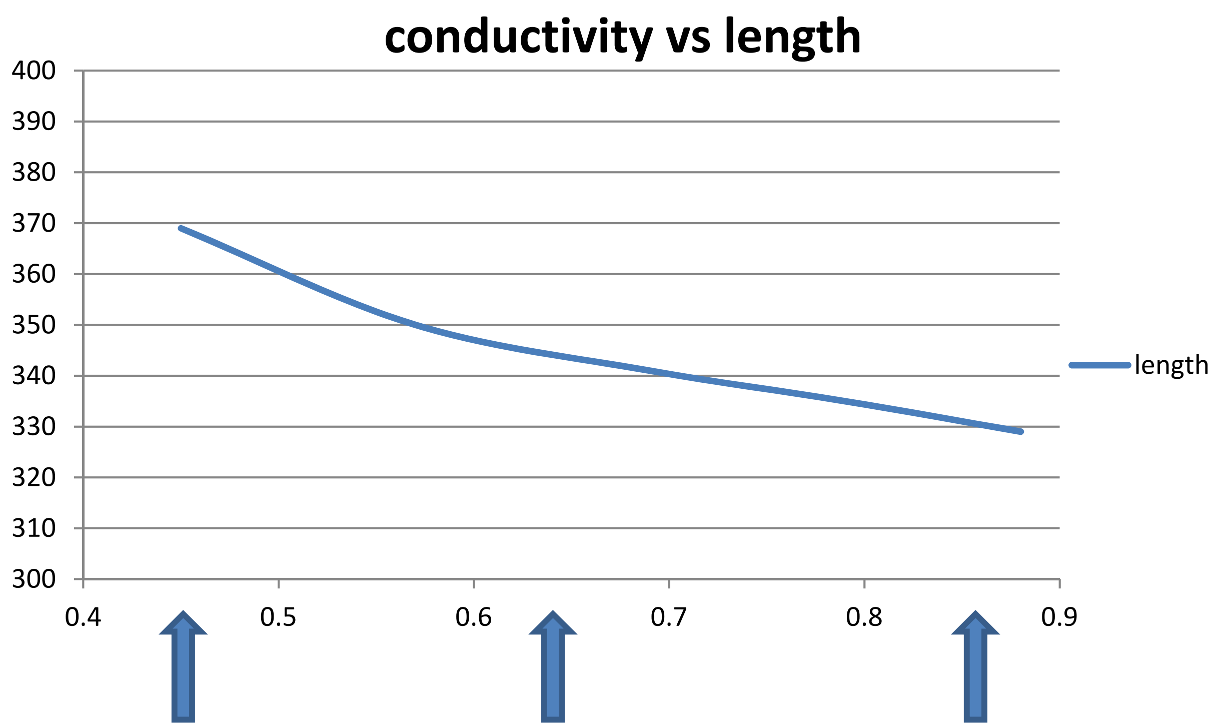
Example 1

Grout Conductivity



Example 1

Grout Conductivity



$3700 to drill	$3450 to drill	$3300 to drill
$190 to grout	$220 to grout	$290 to grout
$3890	$3670	$3590

▲$220 ▲$90

- 1 bag bentonite: $10/ 1 bag of sand: $3
- 1:1 ratio costs $13 for 25 ft of grouting with ~ 0.45 conductivity
- 4:1 ratio costs $22 for 25 ft of grouting with ~ 0.88 conductivity

Example 1

Modeling Time Period

Prediction Time: 15.0 years

- **Definition:**
  The length of time required for the ground temperature to stabilize
- **Range:**
  Vertical system: 10-25 years
  Horizontal system: 5-10 years
  Pond system: N/A
- **Impact:**
  Balanced systems, ground temperature stabilizes quickly
  Unbalanced systems: required stabilization time increases

Example 1

Modeling Time Period

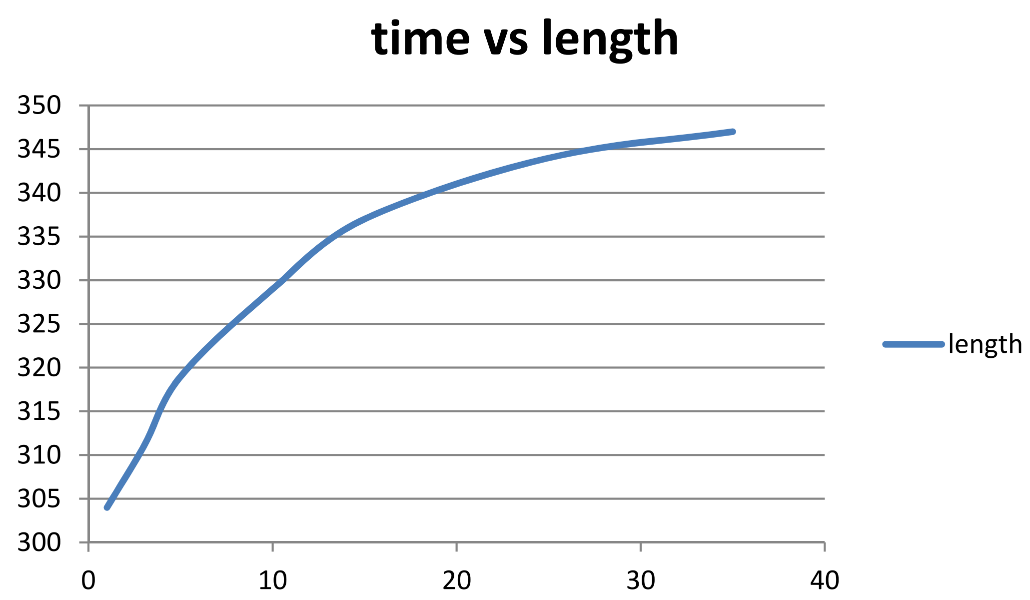
100 borehole system

Time	Bore length	Total length	Ground Temp Change
1 year	304ft	30400ft	0.9F
3 years	311.5ft	31150ft	1.8F
5 years	319.3ft	31930ft	2.2F
10 years	329ft	32900ft	2.8F
15 years	336.7ft	33670ft	3.2F
25 years	344.1ft	34410ft	3.6F
35 years	347.2ft	34720ft	3.8F

Example 1

Modeling Time Period

Prediction Time: 15.0 years

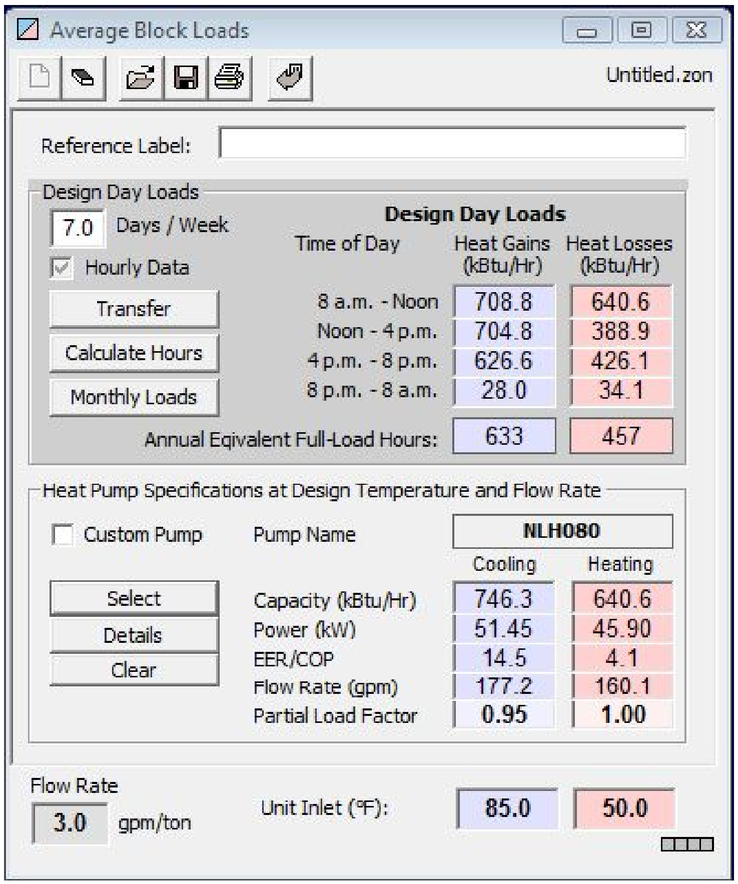


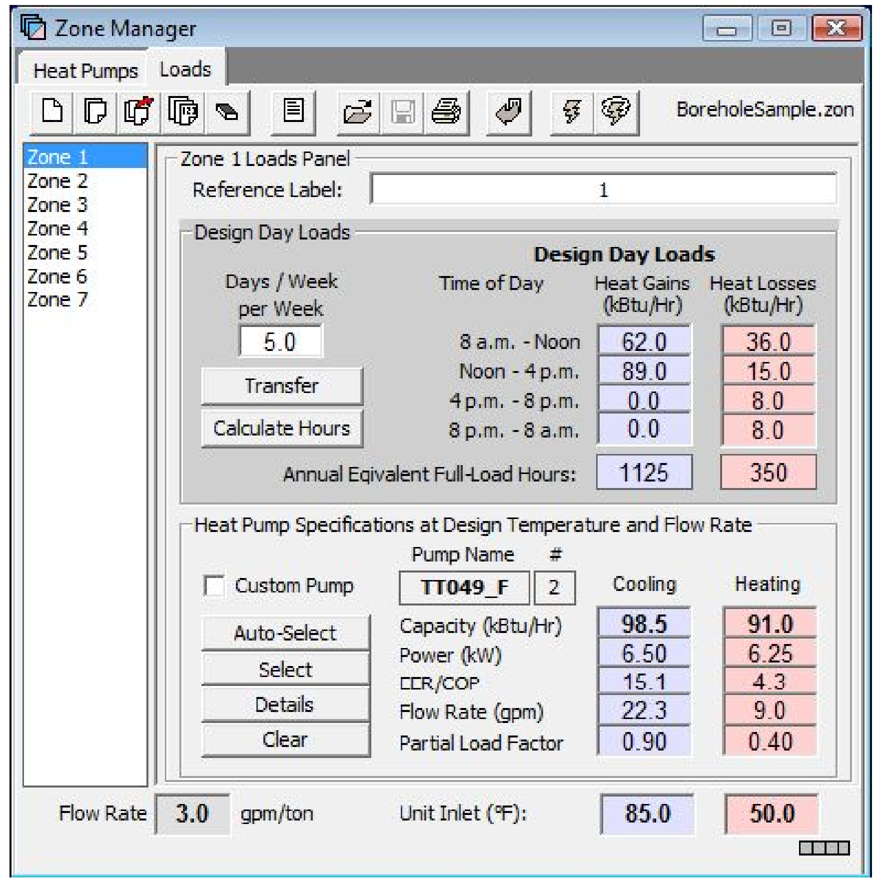
Example 1

Section – Average Block/Zone Manager Module

Average Block vs. Zone Manager

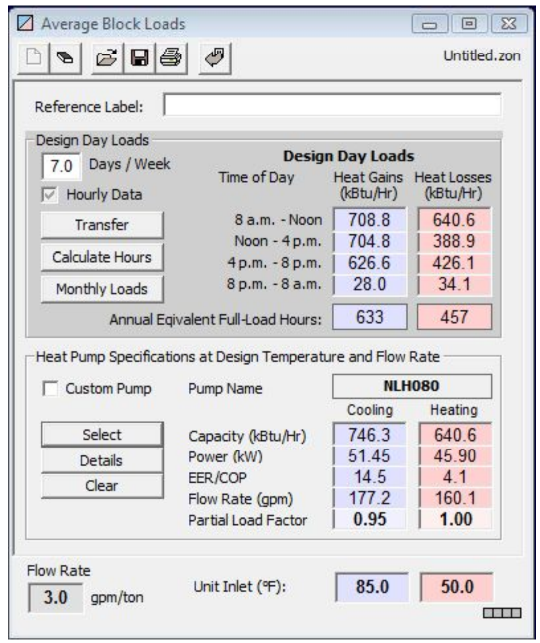
The Average Block and Zone Manager Loads modules provide identical heat exchanger lengths assuming the inputs are identical.

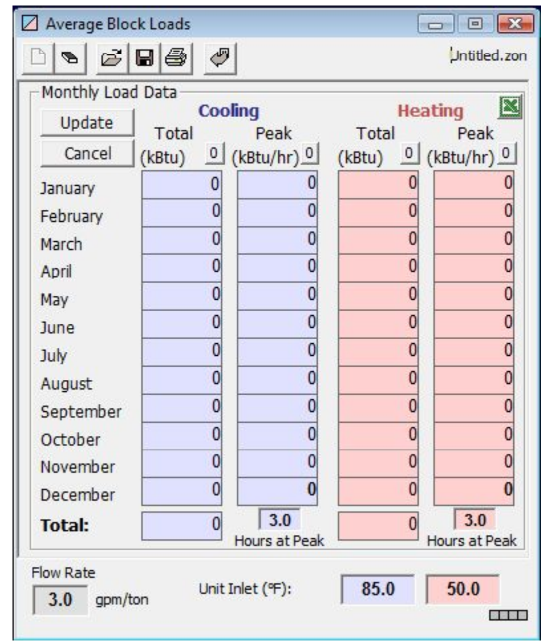




Average Block vs. Zone Manager

- Rapid method of entering enter system info into one block load and quickly designing a system
- Uses a particular "style" of pump (or COP) and matches it in an average way to the entire load
- Can be used to perform monthly or hourly simulations

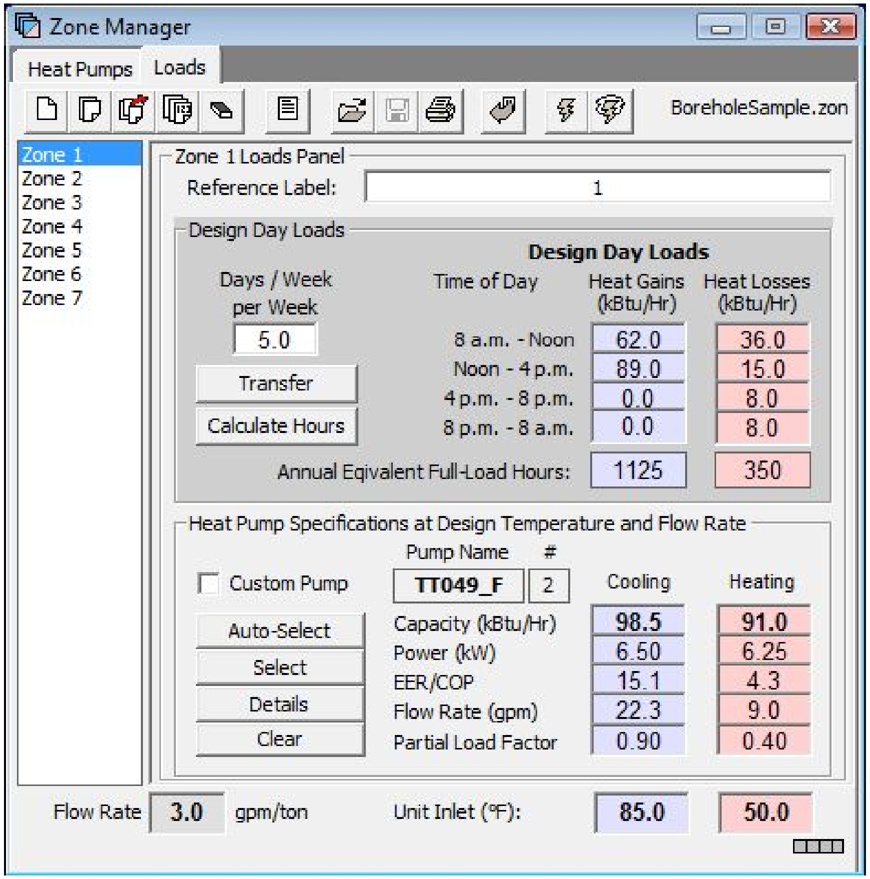




Average Block Loads Module

Average Block vs. Zone Manager

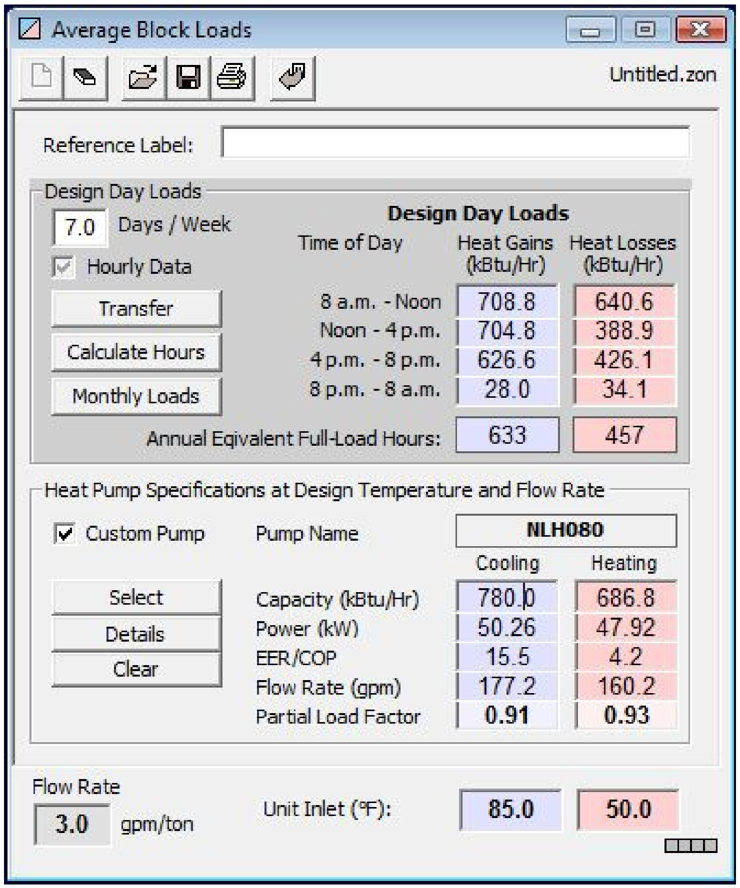
- Loads are input in separate zones
- Each zone precisely matched to pumps
- Can mix and match heat pumps
- Can not do monthly/hourly sims



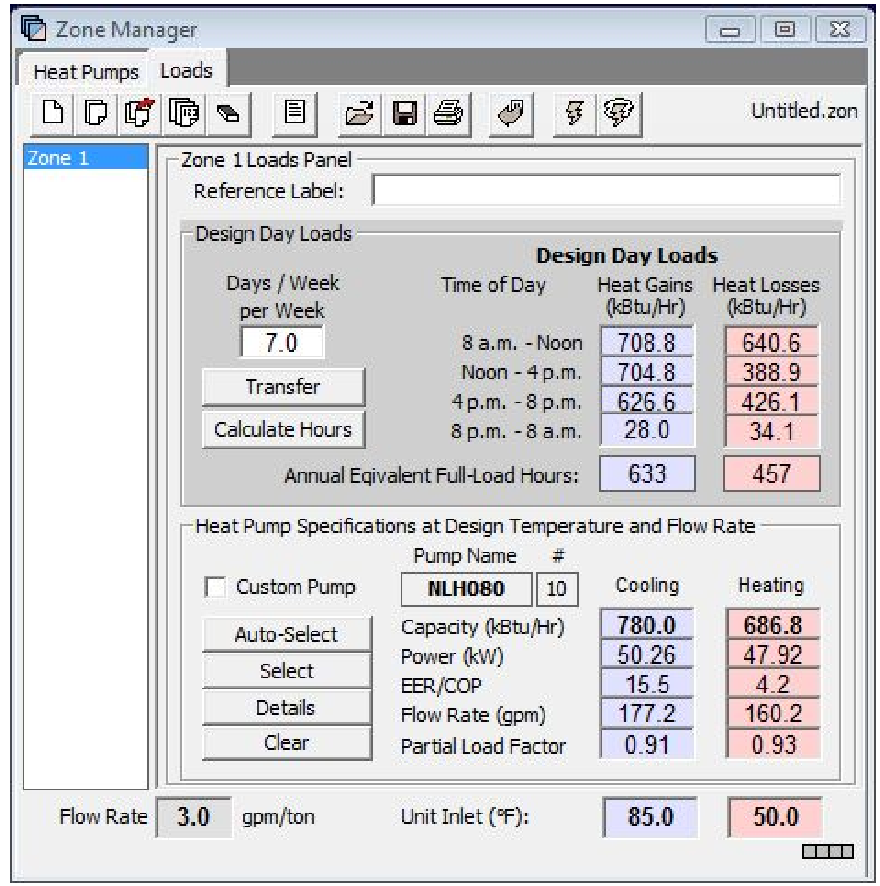
Zone Manager Loads Module

Average Block vs. Zone Manager

Inputs are identical



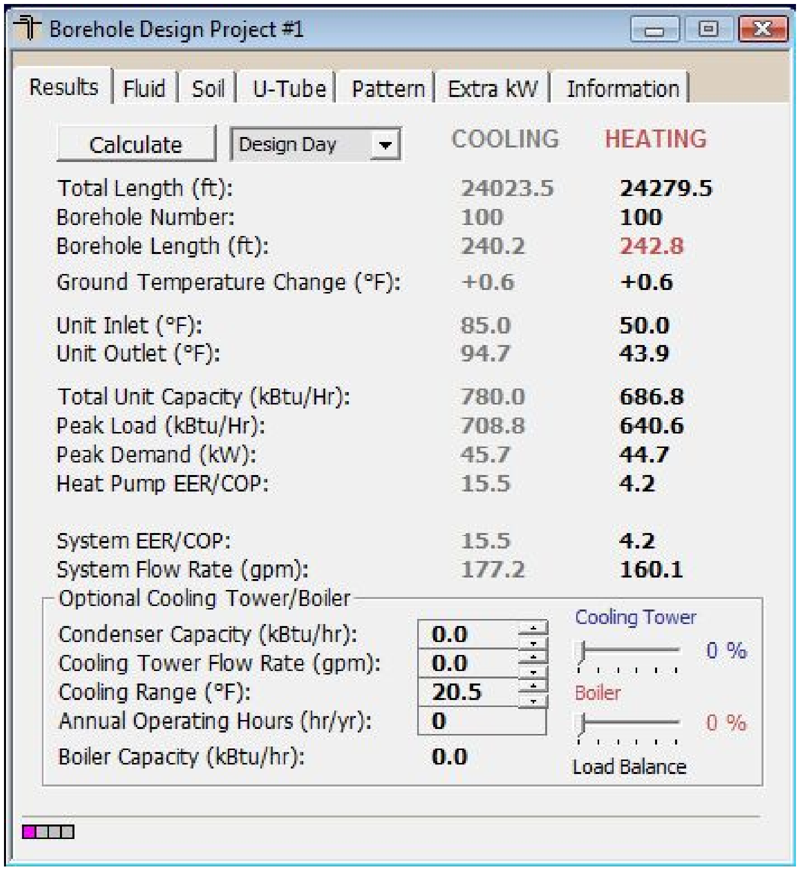
Average Block Loads Module



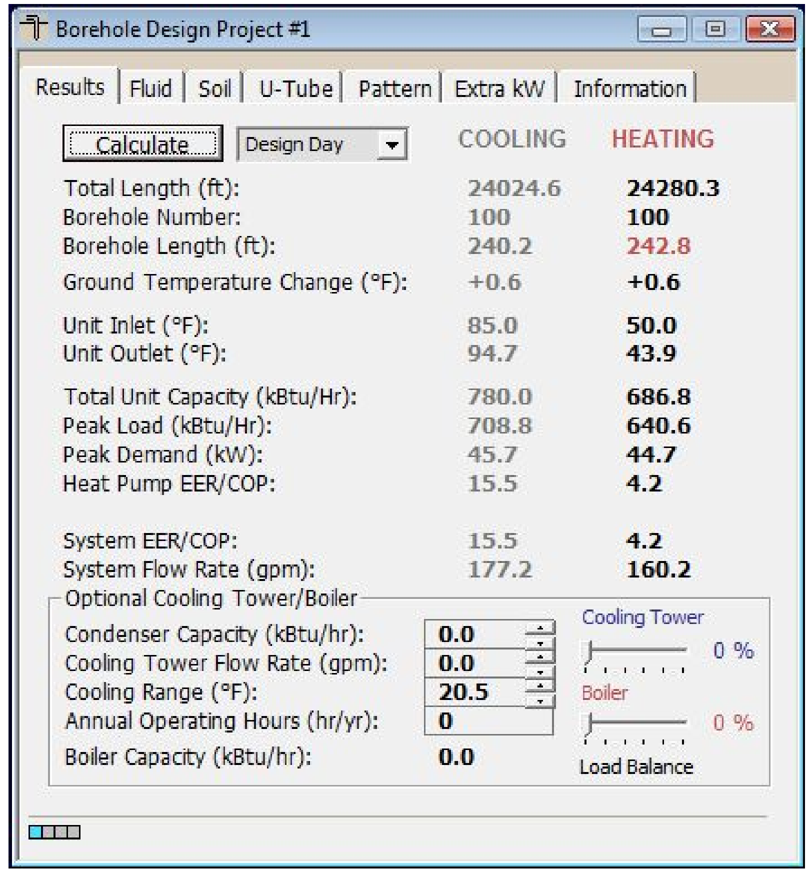
Zone Manager Loads Module

Average Block vs. Zone Manager

Therefore results are identical



Linked to Average Block Loads Module



Linked to Zone Manager Loads Module

Section – Bringing Loads into GLD

- GLD Overview
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
- **Bringing Loads into GLD**
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
- Linking Modules Together
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- Surface Water GHX Design
- The GSA Module and Lifecycle Costing

Bringing Loads Data into GLD

- **Design Day Loads**
  - Manual Entry
  - Copy/Paste from Excel

- **Monthly Simulation Loads**
  - Manual Entry
  - Copy/Paste from Excel
  - Import CSV and Proprietary Files

- **Hourly Simulation Loads**
  - Import CSV and Proprietary Files (IES “APS” files and Trace “GT” files)

Section – Adding/Editing Heat Pumps

- GLD Overview
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
- Bringing Loads into GLD
- **Adding/Editing Heat Pumps**
- Selecting Heat Pumps
- Linking Modules Together
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- The GSA Module and Lifecycle Costing

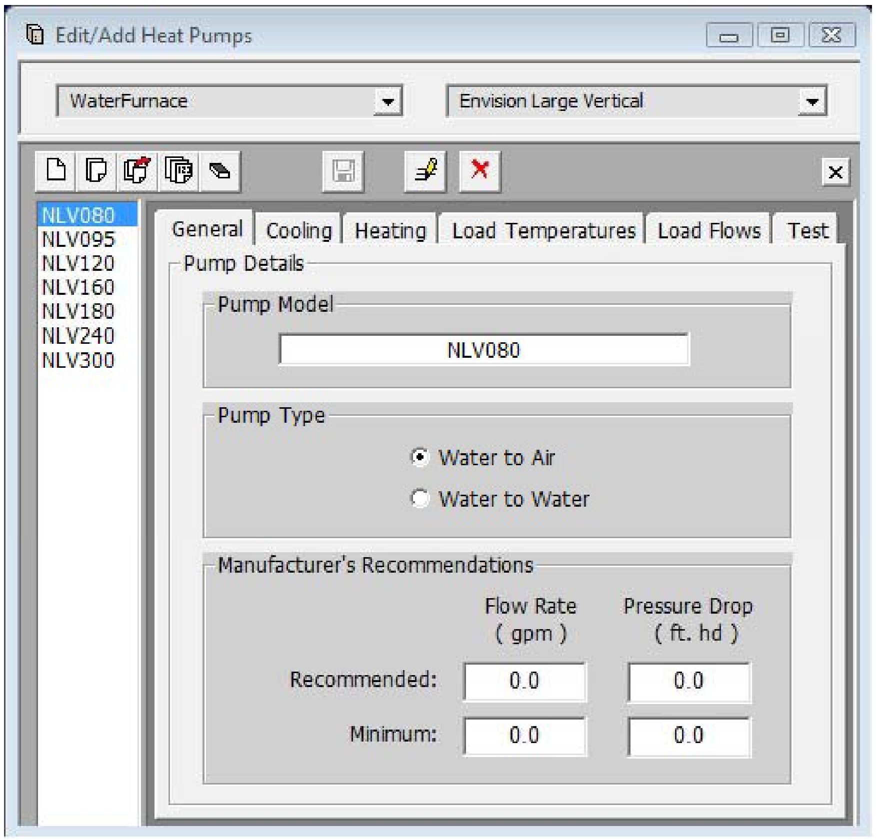
Adding/Editing Heat Pumps

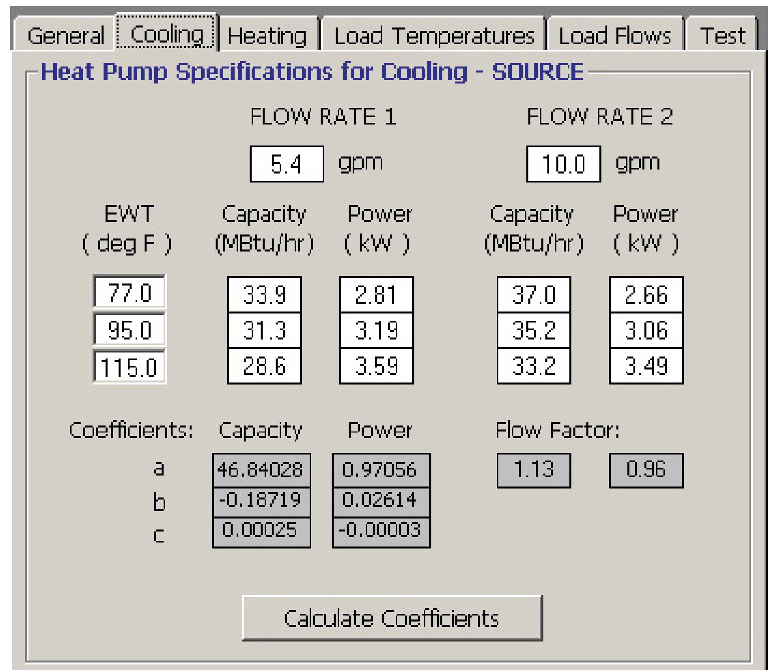
The heat pump database in GLD dynamically models heat pump capacity and power as load and source side temperatures and flow rates vary. In conjunction with detailed loads data, the database can predict energy consumption hour by hour or month by month.

Users can enter their own heat pumps into the database with as much detail as they like. Note that a full model requires nearly 80 unique data points.

Some small manufacturers don't have detailed performance data and as a result, these heat pumps can't be accurately modeled in GLD.

Adding/Editing Heat Pumps





Adding/Editing Heat Pumps

General | Cooling | Heating | **Load Temperatures** | Load Flows | Test

Temperature Corrections - LOAD

COOLING:

EAT-WB (deg F)	Capacity Factor	Power Factor
61.0	0.910	0.960
64.0	0.960	0.980
67.0	1.000	1.000
70.0	1.050	1.020
73.0	1.090	1.040

	Capacity	Power
a	-0.35784	0.55333
b	0.02563	0.00667
c	-0.000079	0.000000
d	0.0000000	0.0000000

HEATING:

EAT-DB (deg F)	Capacity Factor	Power Factor
60.0	1.050	0.980
70.0	1.000	1.000
80.0	0.940	1.020
0.0	0.000	0.000
0.0	0.000	0.000

	Capacity	Power
a	1.08301	1.10387
b	0.00398	-0.00860
c	-0.000086	0.000152
d	0.0000002	-0.0000007

Calculate Coefficients

General | Cooling | Heating | Load Temperatures | **Load Flows** | Test

Flow Corrections - LOAD

Nominal Flow Rate 1140 CFM

COOLING:

% of Nominal	Capacity Factor	Power Factor
80.0	0.974	0.965
90.0	0.987	0.981
100.0	1.000	1.000
110.0	1.012	1.020
120.0	1.025	1.042

	Capacity	Power
a	0.78510	0.98010
b	0.00388	-0.00240
c	-0.000026	0.000034
d	0.0000001	-0.0000001

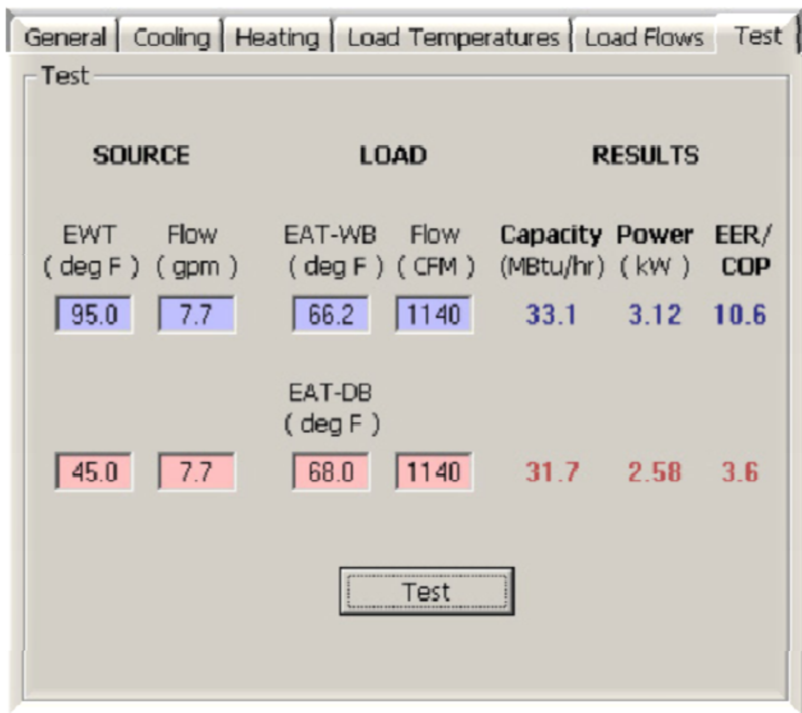
HEATING:

% of Nominal	Capacity Factor	Power Factor
80.0	0.972	1.032
90.0	0.986	1.016
100.0	1.000	1.000
110.0	1.020	0.984
120.0	1.042	0.968

	Capacity	Power
a	0.82300	1.16000
b	0.00354	-0.00160
c	-0.000034	0.000000
d	0.0000002	0.0000000

Calculate Coefficients

Adding/Editing Heat Pumps



Adding/Editing Heat Pumps

600 CFM Nominal Airflow

Performance capacities shown in thousands of Btuh

EWT °F	GPM	WPD		COOLING - EAT 80/67°F						HEATING - EAT 70°F				
		PSI	FT	TC	SC	Sens/Tot Ratio	KW	HR	EER	HC	KW	HE	LAT	COP
60	2.3	2.1	4.8	20.2	14.8	0.73	1.37	24.8	14.7	19.9	1.54	14.6	100.7	3.78
	3.4	3.0	7.0	20.9	15.1	0.72	1.28	25.3	16.4	20.7	1.57	15.4	102.0	3.87
	4.5	4.3	9.8	21.3	15.2	0.71	1.24	25.6	17.2	21.1	1.58	15.7	102.6	3.90
†70	2.3	2.0	4.6	19.3	14.4	0.75	1.48	24.4	13.1	21.6	1.60	16.1	103.3	3.95
	3.4	2.9	6.7	20.0	14.7	0.74	1.39	24.7	14.3	22.4	1.63	16.8	104.6	4.03
	4.5	**4.1**	**9.5**	20.3	14.9	0.73	1.36	24.9	14.9	**22.7**	**1.64**	**17.1**	**105.1**	**4.06**
80	2.3	1.9	4.5	18.3	13.8	0.75	1.58	23.7	11.5	23.1	1.65	17.4	105.6	4.09
	3.4	2.8	6.5	19.1	14.3	0.75	1.50	24.2	12.7	23.8	1.68	18.1	106.8	4.15
	4.5	4.0	9.2	19.4	14.4	0.74	1.47	24.4	13.2	24.1	1.69	18.3	107.2	4.17
†85	2.3	1.9	4.4	17.6	13.4	0.76	1.63	23.1	10.8	23.7	1.68	18.0	106.6	4.14
	3.4	2.8	6.4	18.6	14.0	0.75	1.56	23.9	11.9	24.4	1.71	18.6	107.6	4.19
	4.5	**3.9**	**9.1**	**18.9**	**14.2**	**0.75**	**1.52**	**24.1**	**12.4**	24.7	1.72	18.8	108.1	4.20
90	2.3	1.9	4.4	16.7	12.9	0.77	1.67	22.4	10.0	24.3	1.70	18.5	107.5	4.18
	3.4	2.7	6.3	17.9	13.6	0.76	1.61	23.4	11.2	24.9	1.73	19.0	108.5	4.22
	4.5	3.9	9.0	18.3	13.8	0.75	1.58	23.7	11.6	25.3	1.74	19.4	109.0	4.25
95	2.3	1.9	4.3	15.7	12.3	0.78	1.72	21.5	9.1	Operation Not Recommended				
	3.4	2.7	6.3	17.1	13.1	0.77	1.65	22.7	10.3					
	4.5	3.8	8.9	17.6	13.4	0.76	1.63	23.2	10.8					

Rev: 04/29/02 B

Interpolation is permissable, extrapolation is not.

All entering air conditions are 80°F DB and 67°F WB in cooling and 70°F DB in heating.

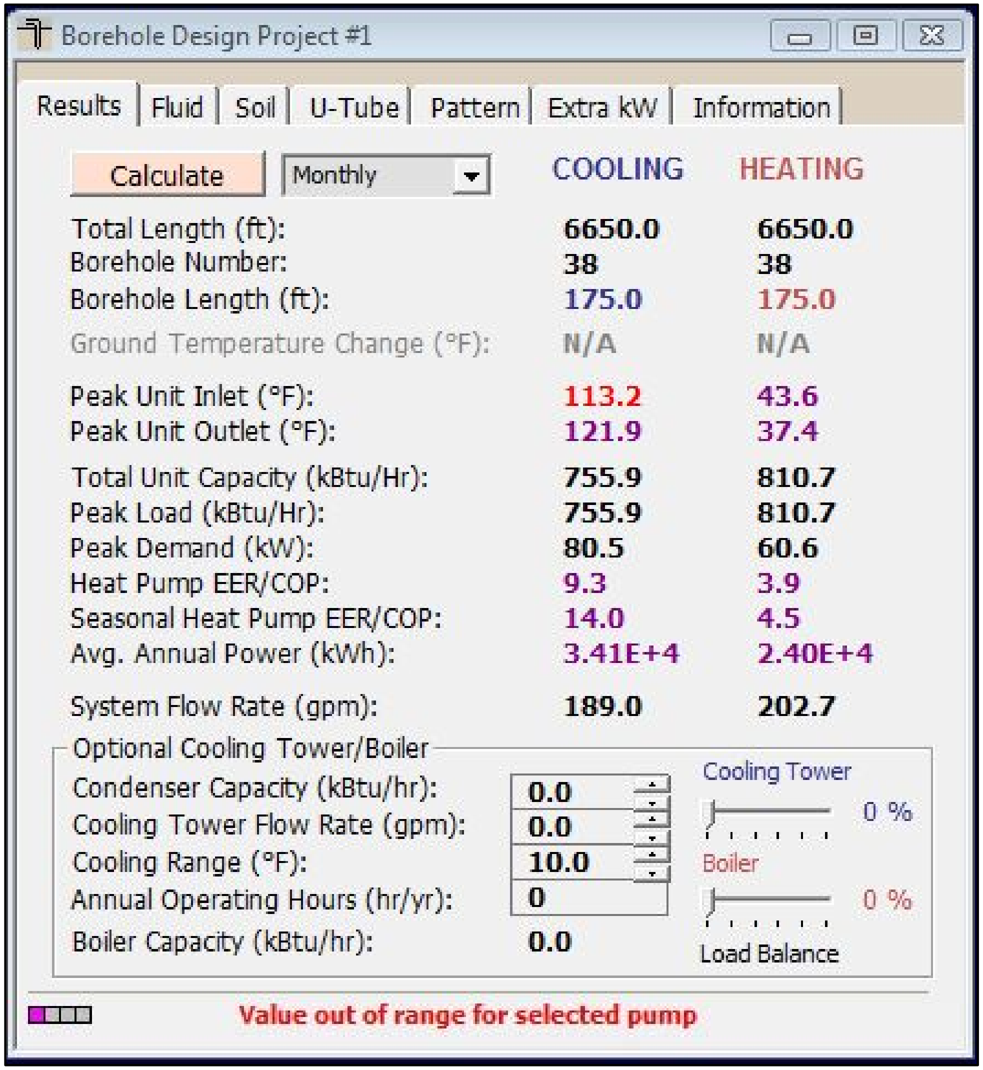
Adding/Editing Heat Pumps

Cooling Corrections										
Ent Air WB °F	Total Clg Cap	Sens Clg Cap Multiplier - Entering DB °F							Power	Heat of Rej
		70	75	80	80.6	85	90	95		
60	0.858	0.812	1.062	1.217	1.229	*	*	*	0.982	0.886
65	0.964	0.622	0.876	1.076	1.098	1.240	*	*	0.996	0.971
66.2	0.986	0.577	0.822	1.032	1.055	1.214	*	*	0.999	0.989
67	1.000	0.547	0.785	1.000	1.024	1.192	1.362	1.508	1.000	1.000
70	1.049		0.630	0.864	0.891	1.086	1.236	1.399	1.004	1.039
75	1.113			0.580	0.609	0.814	1.027	1.218	1.007	1.089

Airflow		Heating			Cooling			
CFM Per Ton of Clg	% of Nominal	Htg Cap	Power	Heat of Ext	Total Cap	Sens Cap	Power	Heat of Rej
300	75%	0.966	1.051	0.939	0.970	0.899	0.953	0.967
325	81%	0.976	1.037	0.956	0.979	0.924	0.966	0.976
350	88%	0.985	1.023	0.973	0.987	0.949	0.979	0.985
375	94%	0.993	1.012	0.987	0.994	0.975	0.990	0.993
400	100%	1.000	1.000	1.000	1.000	1.000	1.000	1.000
425	106%	1.006	0.991	1.010	1.005	1.026	1.008	1.005
450	113%	1.011	0.982	1.020	1.009	1.051	1.016	1.010
475	119%	1.014	0.975	1.027	1.011	1.077	1.022	1.013
500	125%	1.017	0.968	1.033	1.013	1.102	1.027	1.016

Heating Corrections			
Ent Air DB °F	Htg Cap	Power	Heat of Ext
45	1.044	0.803	1.123
50	1.042	0.847	1.107
55	1.037	0.888	1.086
60	1.028	0.927	1.062
65	1.016	0.965	1.033
68	1.007	0.986	1.014
70	1.000	1.000	1.000
75	0.980	1.033	0.963
80	0.957	1.065	0.921

Pumps: Out of Range Warnings

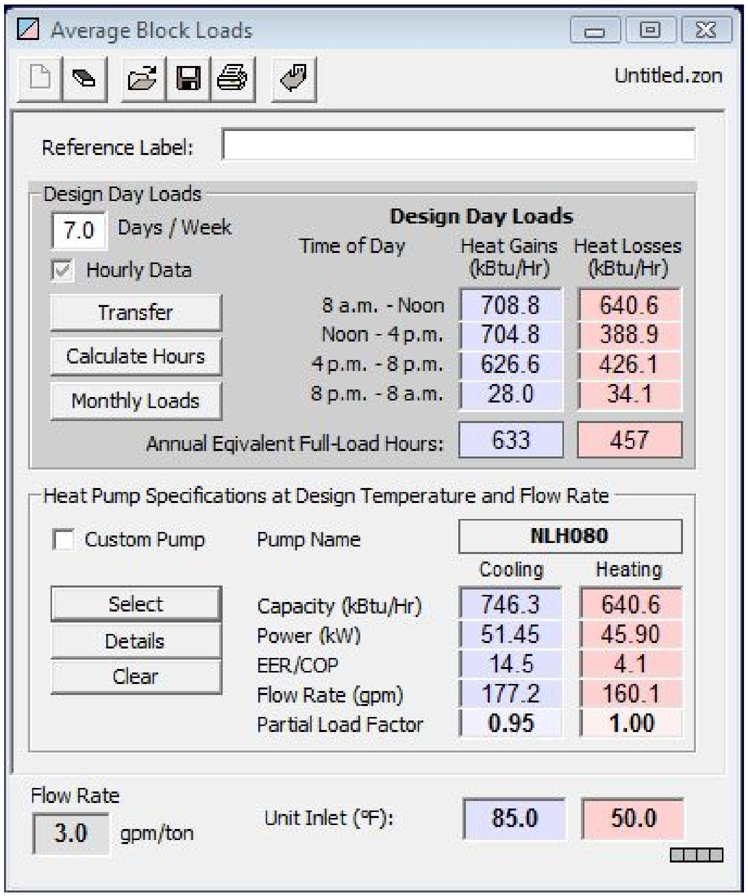


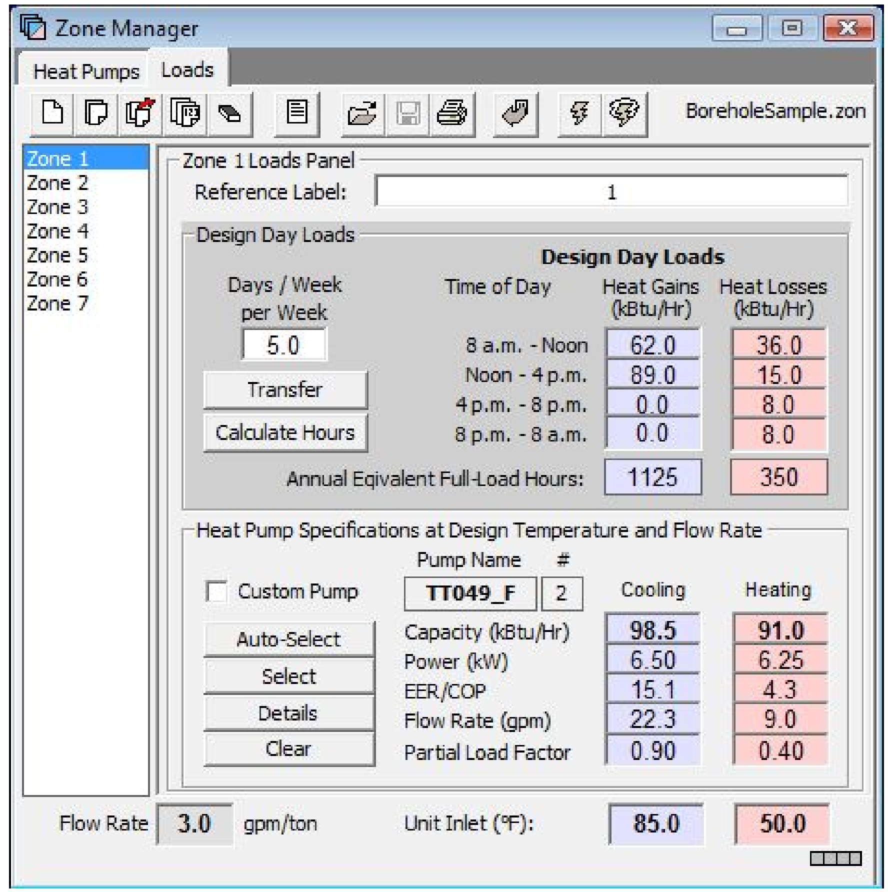
Section – Selecting Heat Pumps

- GLD Overview
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
- Bringing Loads into GLD
- Adding/Editing Heat Pumps
- **Selecting Heat Pumps**
- Linking Modules Together
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- The GSA Module and Lifecycle Costing

Selecting Heat Pumps

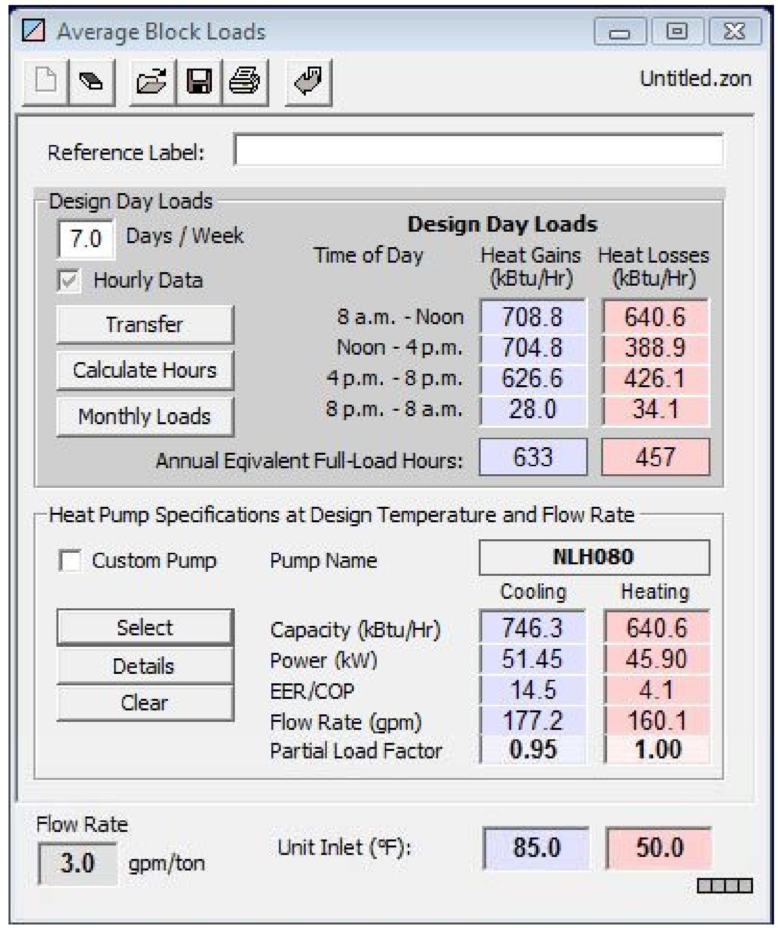
The Average Block and ZM Loads modules offer different types of options





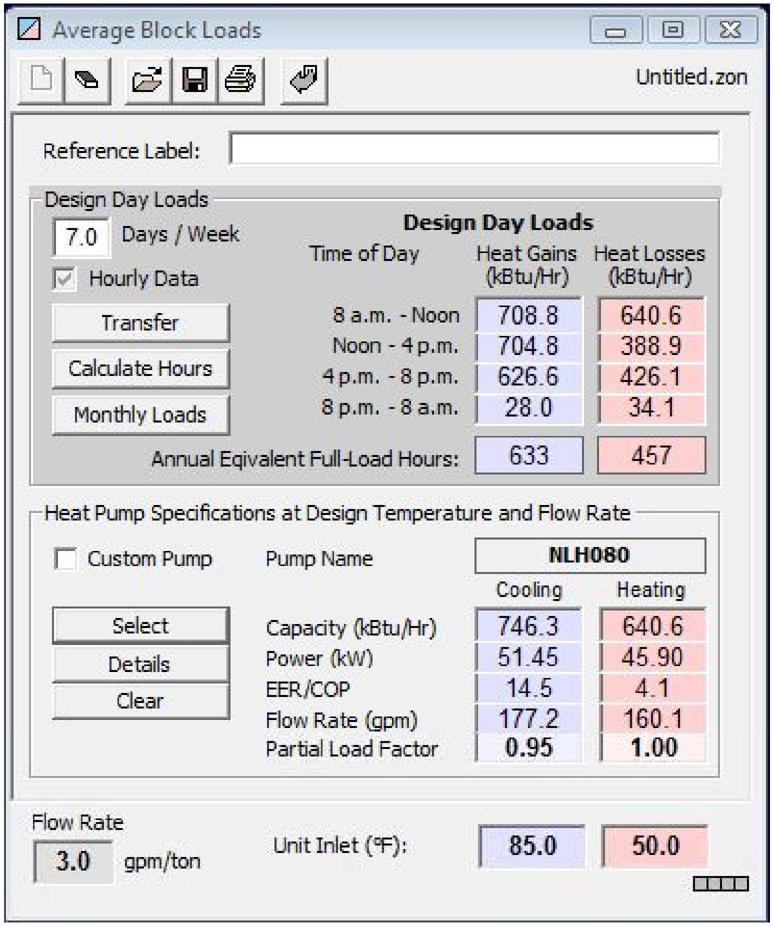
Selecting Heat Pumps: Average Block

- Select one type of heat pump
- This pump should be the "average" type of pump in a design. For example, if you are designing a school and you plan on having 16 four ton pumps and two six ton pumps, you could select a four ton pump
- The displayed pump performance values are applied in an average way to the overall load.
- In reality of course the loads are broken up into zones and you have multiple pumps but because you have selected the "average" pump, design results are the same



Selecting Heat Pumps: Average Block

- You can override any values and thereby have a “custom” pump. This enables you to use a pump that is not in the standard database. However, by doing so you can’t model the pump dynamically and therefore can’t do advanced monthly/hourly simulations.
- You can also input load side correction factors (flow rates/temperatures) to provide greater accuracy. Note that this is more important for w-w pumps than for w-a pumps.



Selecting Heat Pumps: Average Block

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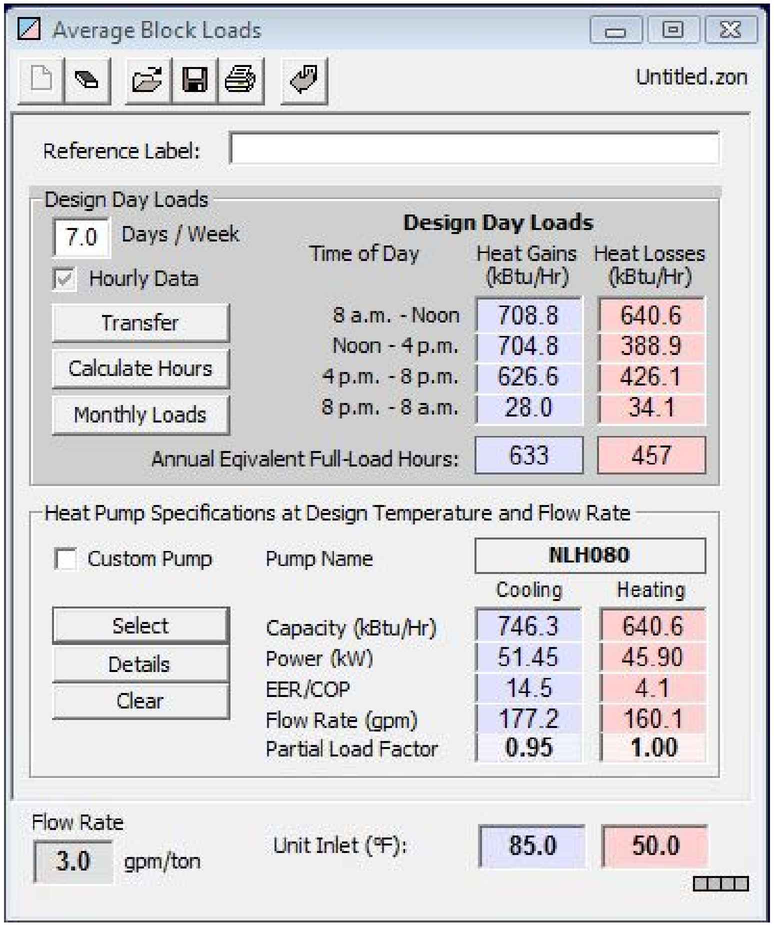
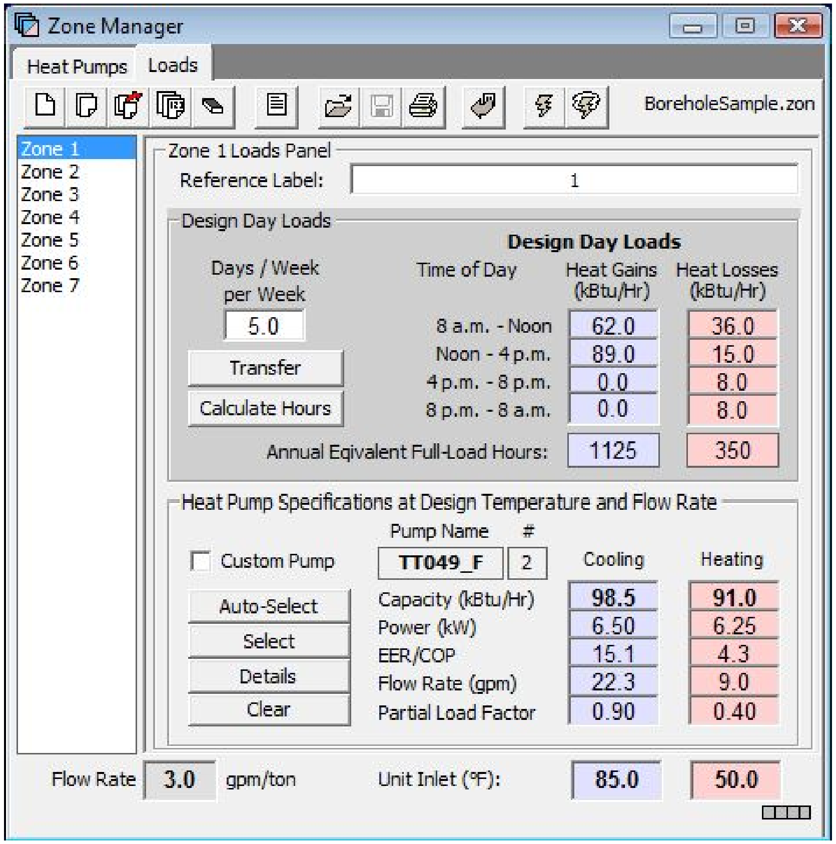
- You can also input load side correction factors (flow rates/temperatures) to provide greater accuracy. Note that this is more important for w-w pumps than for w-a pumps.



Selecting Heat Pumps: Zone Manager

- Manually or automatically select pumps to match loads in one zone
- Manually or automatically select pumps to match loads across multiple zones
- Combine manual and automatic selection across multiple zones
- Use both w-w and w-a pumps



Section – Linking Modules Together

- GLD Overview
- System Design Inputs and their Impact
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- Bringing Loads into GLD
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
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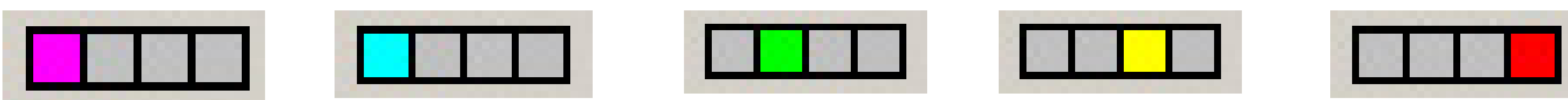
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- Surface Water GHX Design
- The GSA Module and Lifecycle Costing

Linking Modules Together

- GLD is a modular program. Each core function has its own module
- These modules communicate back and forth with each other via the **linking** system.



- With this system you can design and compare multiple systems at the same time.

Section - Vertical GHX Loopfield Design

- GLD Overview
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
- Bringing Loads into GLD
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
- Linking Modules Together
- **Vertical GHX Loopfield Design**
- Horizontal GHX Loopfield Design
- The GSA Module and Lifecycle Costing

GHX Loopfield Design Methodology

Optimize Loads → 1) Import Loads

↓

2) Select Heat Pump (s)

↓

3) Design Heat Exchanger ↔ Piping Optimization

↓

4) GSA/CO2 Analysis

Vertical GHX Loopfield Design

Design Exercise #1

Exercise Goals:

- Learn how to import loads into Average Block
- Learn how to select pump
- Learn how to use Design Day and Monthly Modes
- Learn how to compare Design Day and Monthly Modes
- Learn how to reduce borefield size with balanced loads

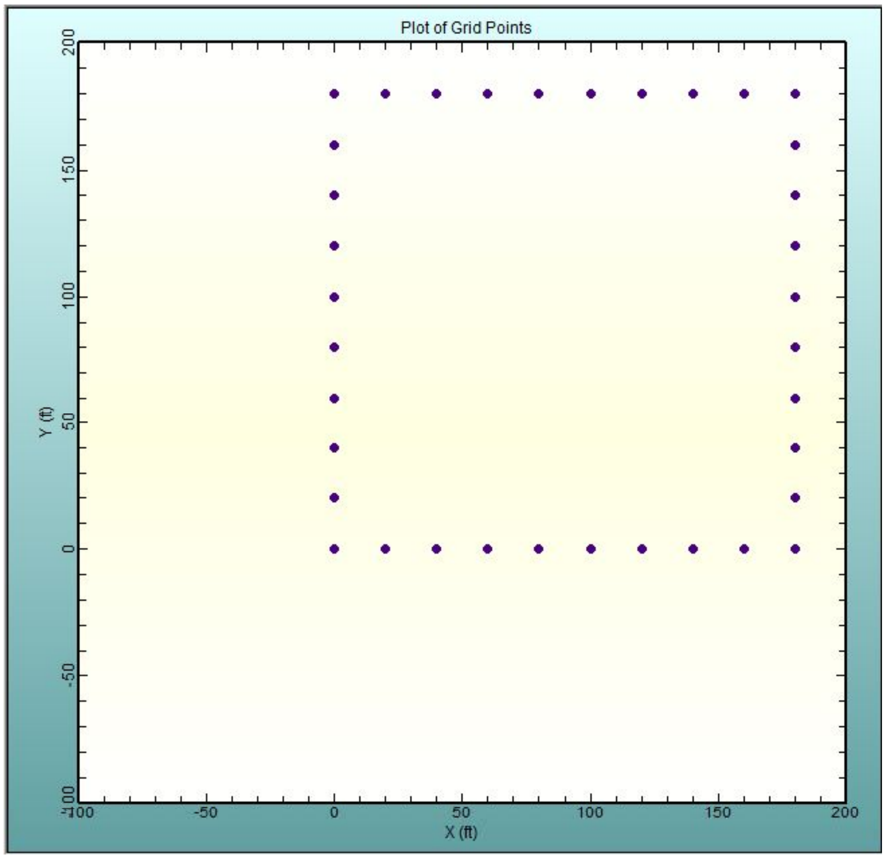
Vertical GHX Loopfield Design

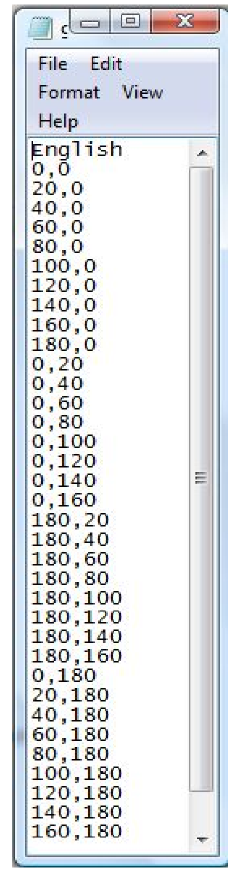
Sample Design 1

- Average Block Loads Module
- Hourly Data - **balanced load** (hourly_Denver.csv plus CO TC value)
- Look at different heat transfer models and simulations
- Look at benefits of TES
- TOU modeling overview

Vertical GHX Loopfield Design: GridBuilder

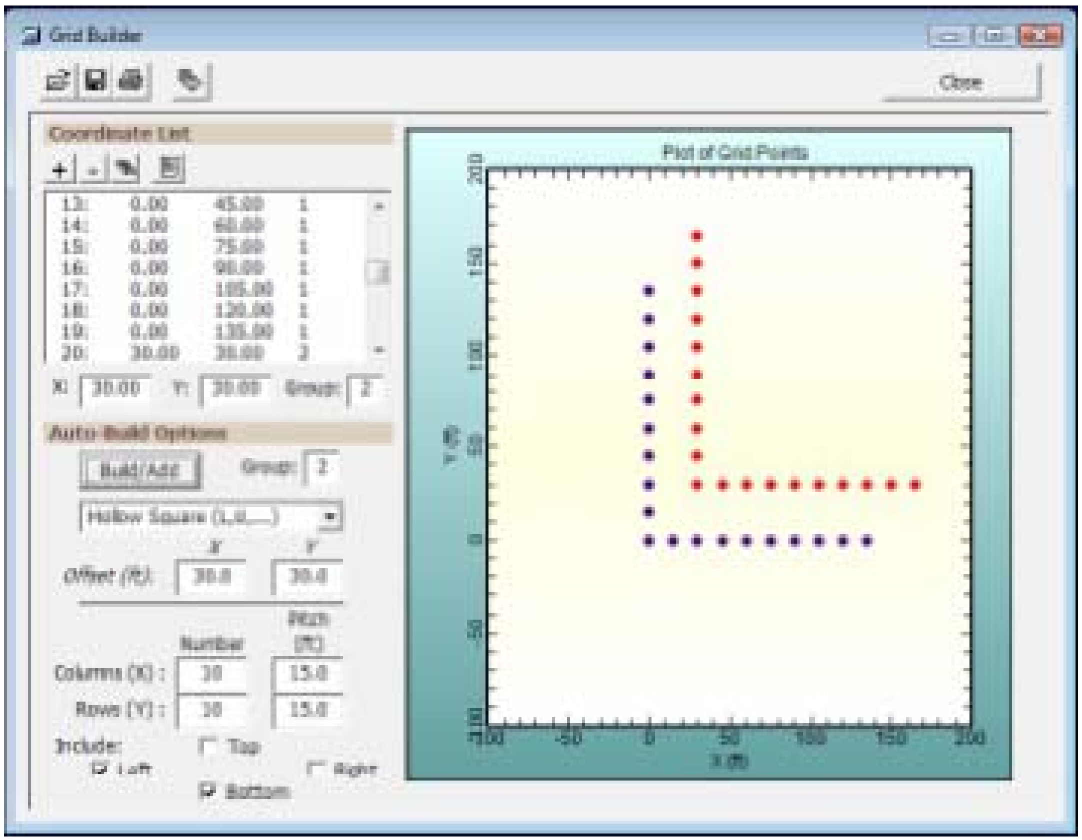
The GridBuilder builds gridfiles, which are very useful for non-standard/non-rectangular designs





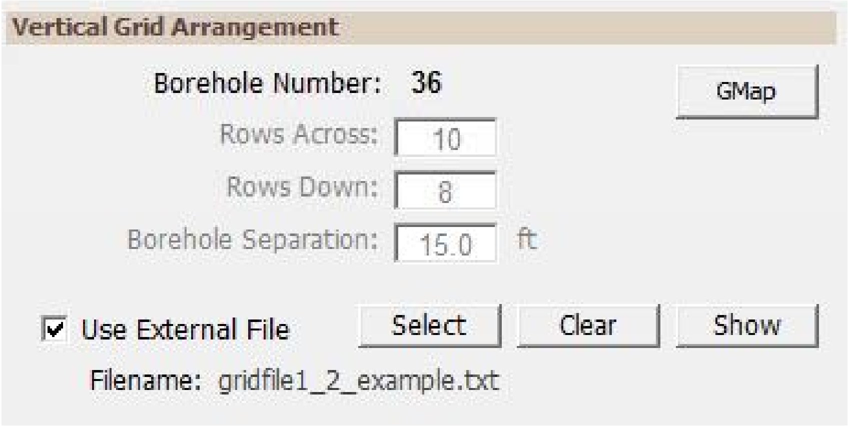
Vertical GHX Loopfield Design: GridBuilder

The GridBuilder is a design tool for easily designing and modeling any type of vertical loopfield.



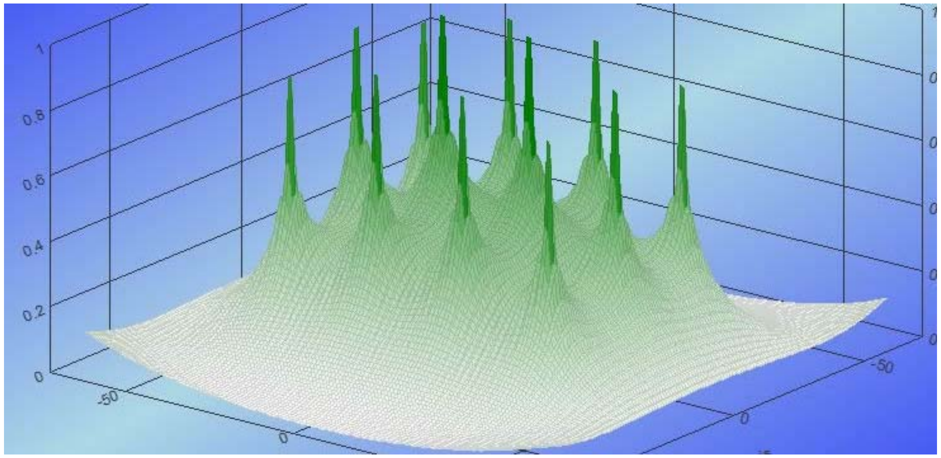
Vertical GHX Loopfield Design

When you use a gridfile in a design, it overrides the standard borehole input boxes.



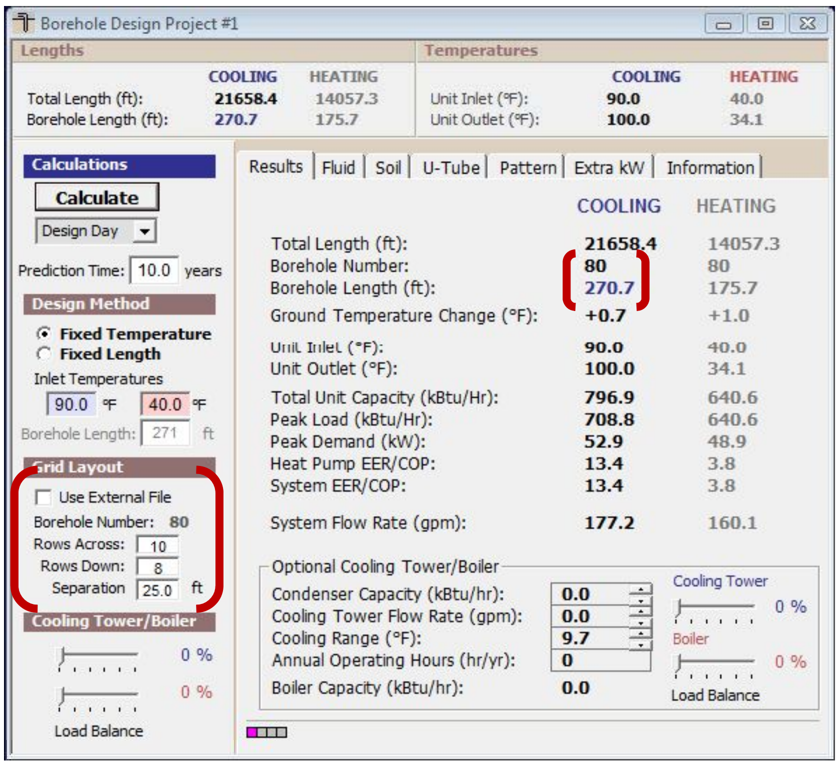
Vertical GHX Loopfield Design

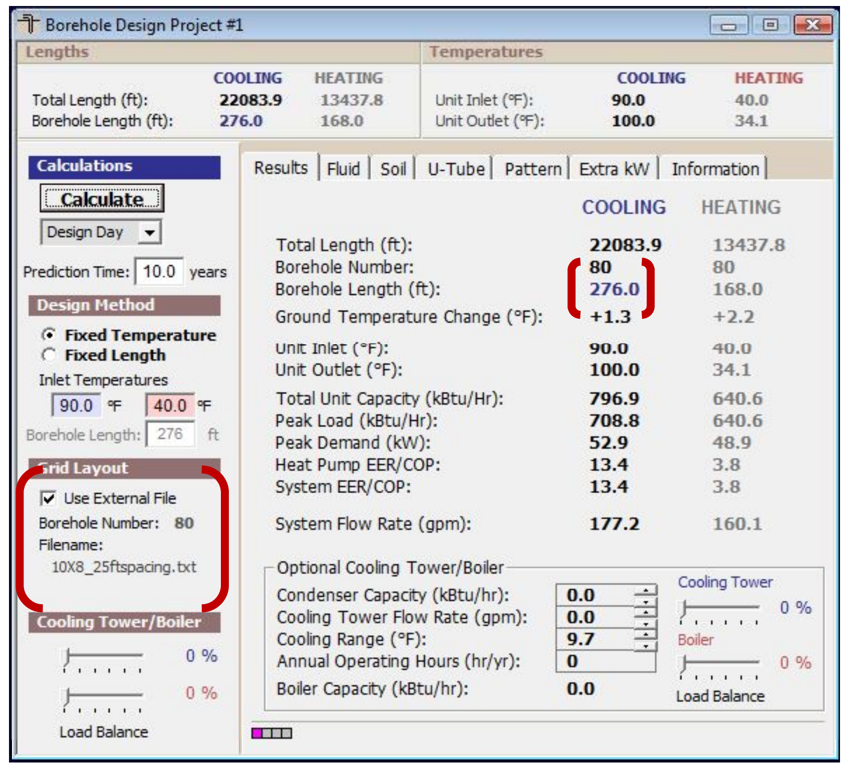
In general, using a gridfile will increase the calculated length because the gridfile uses the g function calculation normally associated with monthly and hourly simulations and the g function assumes greater borehole interactions than the design day calculations



Vertical GHX Loopfield Design

When you import a grid file, GLD always use the g functions for modeling. Therefore, do not be surprised if you get different results using the same loopfield design:





Vertical GHX Loopfield Design

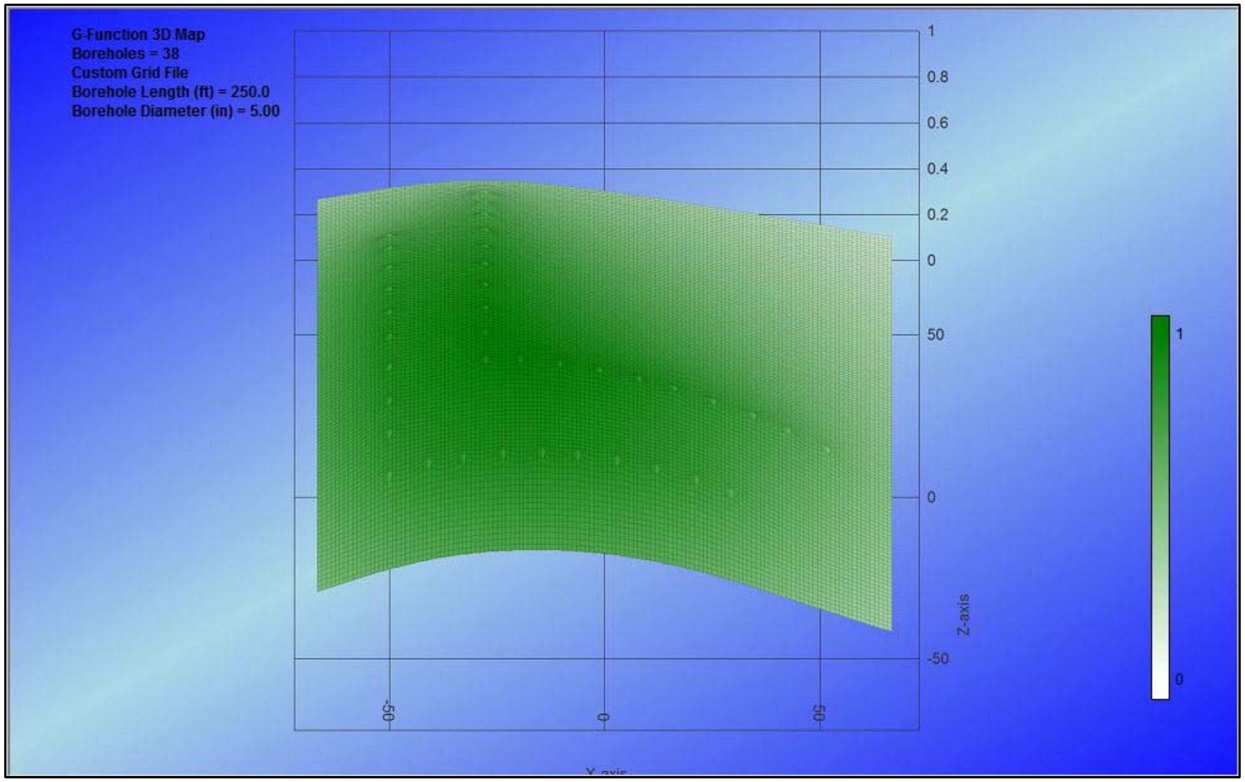
Let's look at an example of the 8 x 10
(uses boston hourly loads profile)

What we notice:

1) As spacing increases, two methods converge
2) G fcn is very sensitive to diffusivity

Vertical GHX Loopfield Design: GMAP

3D map of how bore field layout and thermal diffusivity influence ground temperature changes over time (assuming a constant or non-changing borehole temp over that time).



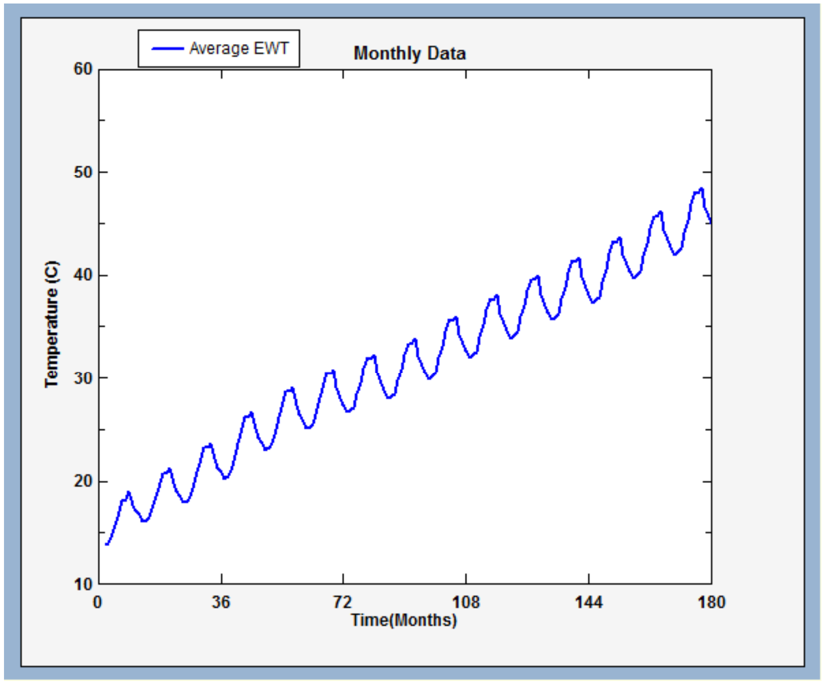
Vertical GHX Loopfield Design

Design Exercise # 2

Exercise Goals:

- Learn design strategies for imbalanced loads
- Look at how Design Day and Monthly results are different
- Learn about Hybrid Designs with the new GLD2014 Hybrid tools

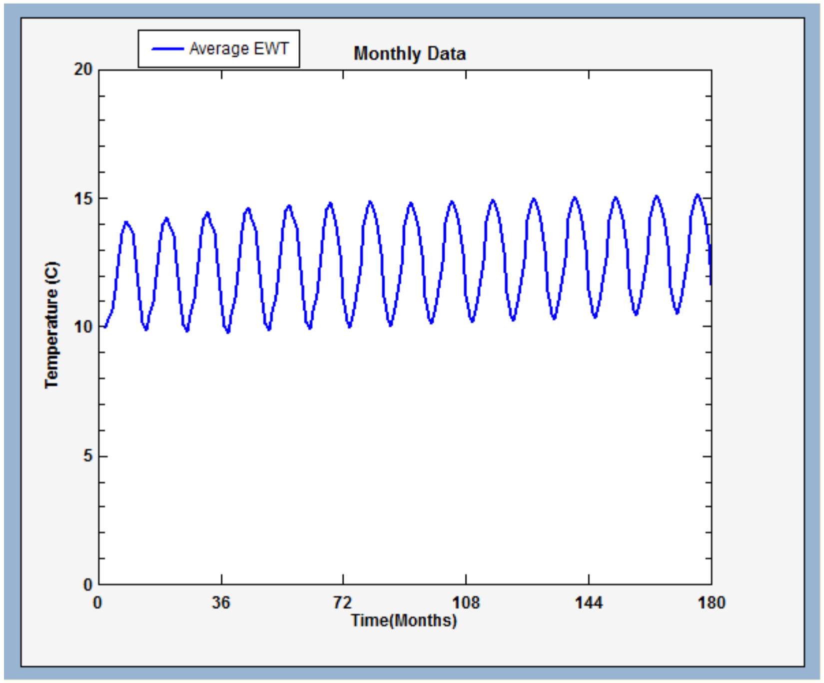
Hybrid Designs are valuable when heating and cooling loads are imbalanced:



This cooling dominant system will overheat and fail

With GLD2014 and hourly heating/cooling loads data, the designer can quickly balance the load and create a sustainable, high performance system.

With GLD2014 we can quickly balance the loads:

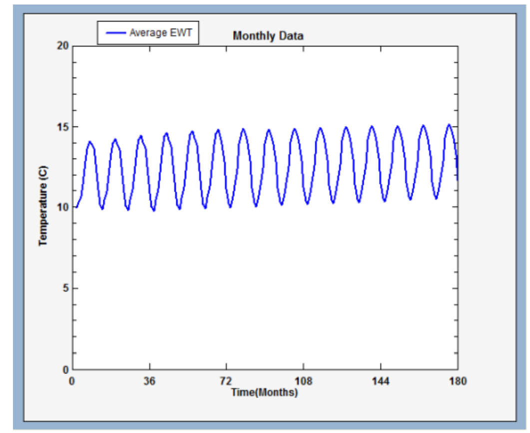


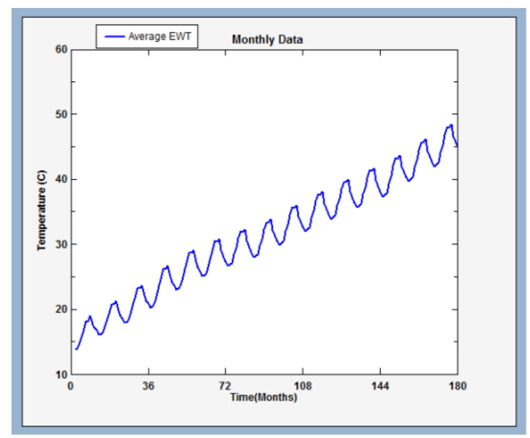
With balanced loads, the system is sustainable and high performance

Remember:

GHX is like a bank account

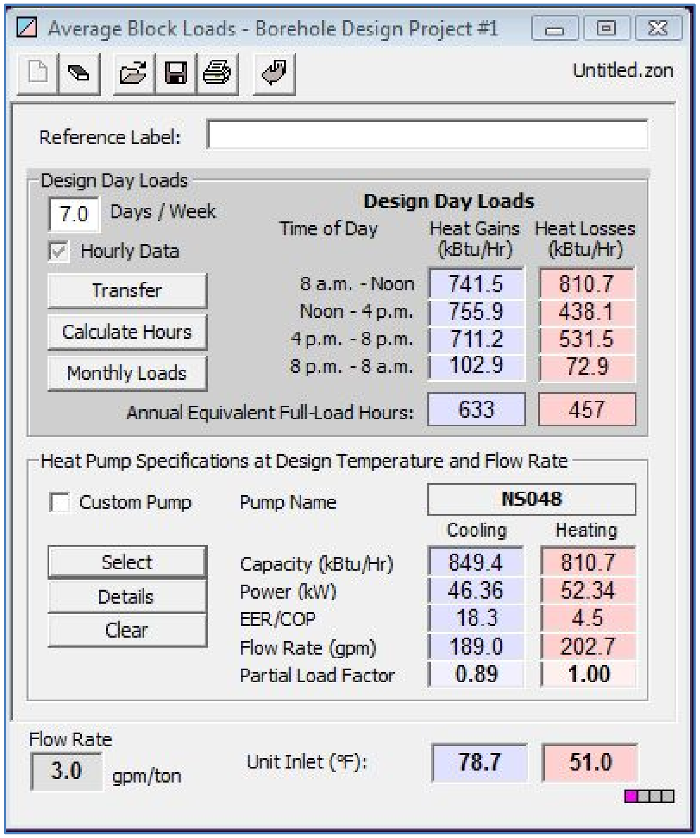
If all you do is take money from a bank account, eventually it will run out of money. If the amount of money deposited is approximately equal to the amount of money withdrawn, the process can go on forever.



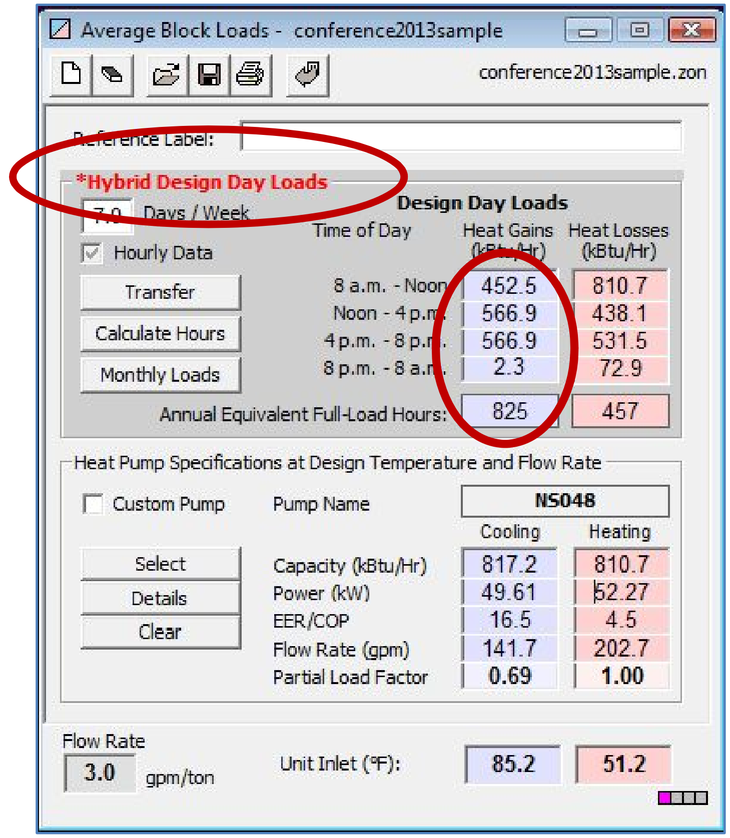


The new hybrid design tool shows you how the loads change as you use the sliders.

2012 Edition



New Edition



The **new** hybrid design tool in GLD provides:

- Precision peak load shaving on 8760 hourly loads profiles
- Intelligent, independent peak and total load shaving on design day and monthly loads profiles
- Fast, direct hybrid design without the need to use external programs, like Excel, for iterative loads modification (as was the case with previous versions of GLD)

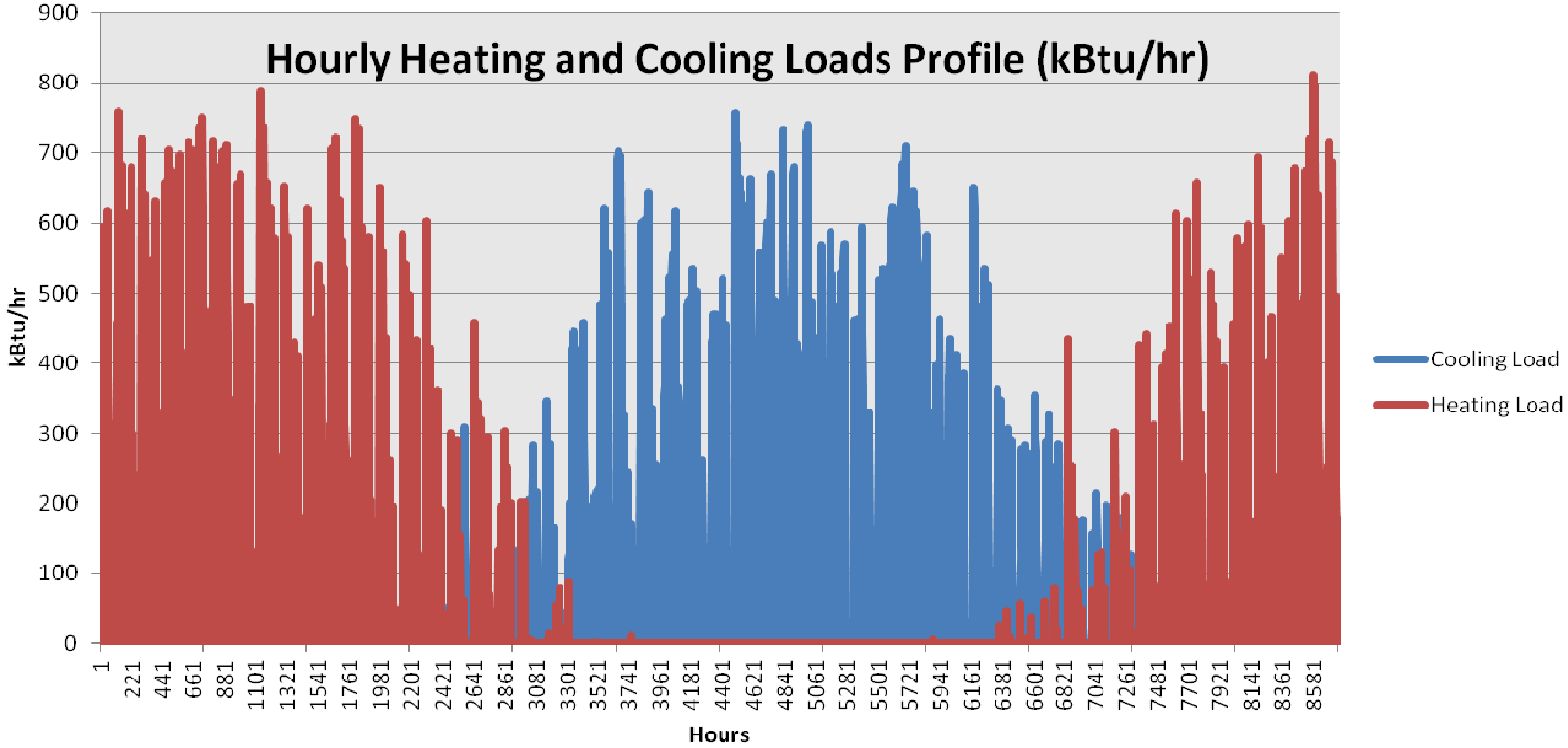
The new hybrid design tool substantially increases hybrid design speed because:

- In real time, it can parse and update hourly and monthly loads profiles.
- The updated loads profiles can then be used for loopfield design and performance simulations. The process is fast, easy and straightforward.

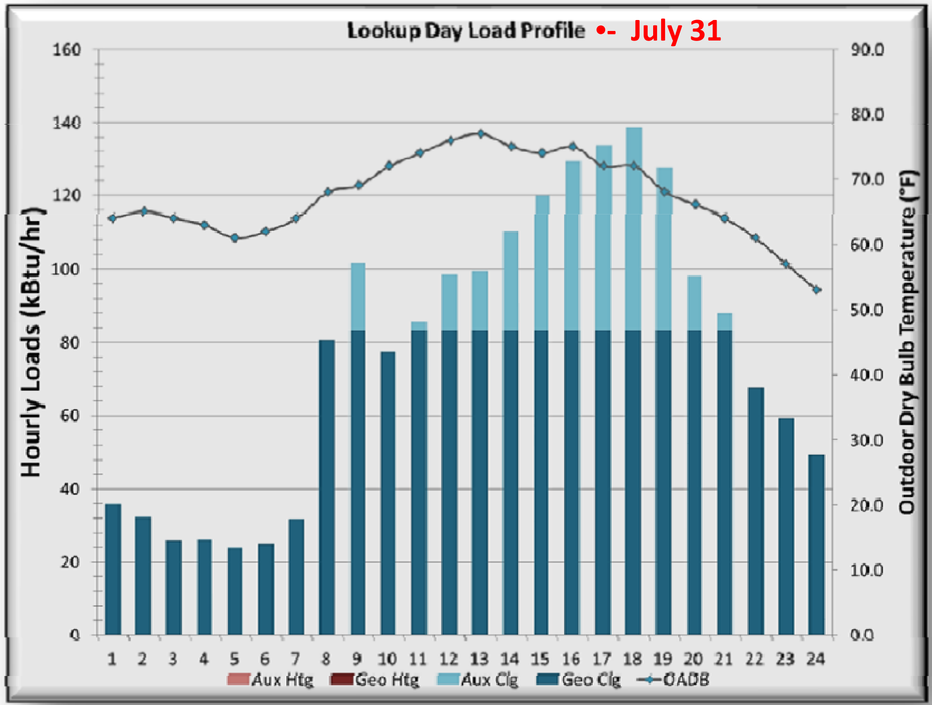
8760 Hourly Heating/Cooling Loads Data are Essential:

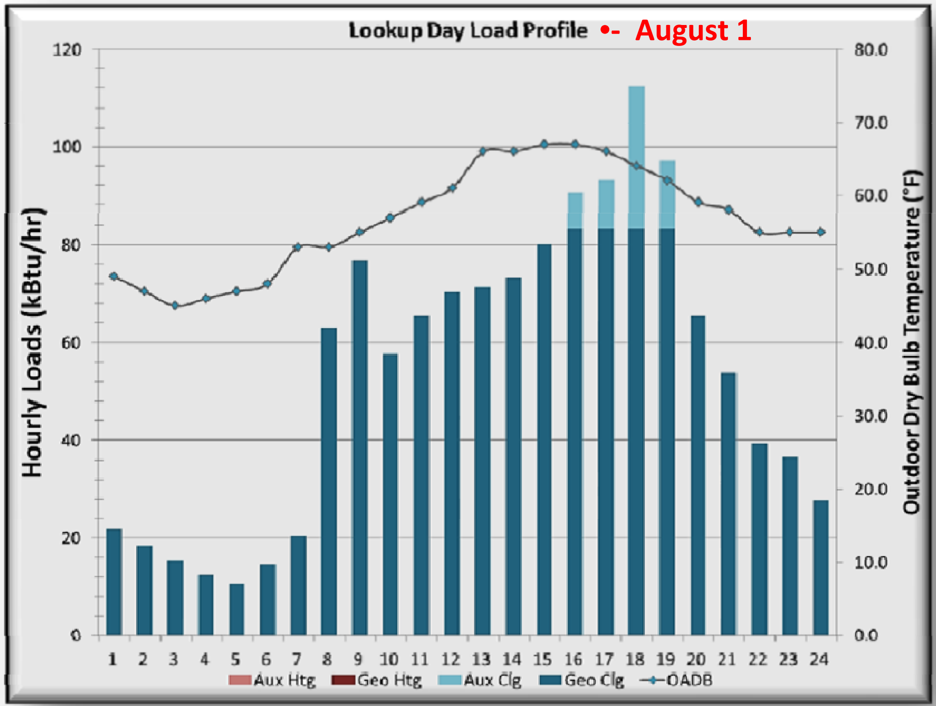
- Each and every building has a unique energy and loads "fingerprint"
- One can predict this fingerprint by properly using one of the 8760 hourly energy simulation tools that are available on the market.
- To take full advantage of the new hybrid tool, designers should be using 8760 hourly heating and cooling loads profiles.

An example 8760 hourly loads profile:



Hourly loads data are invaluable for hybrid design because they enable us to know when the hybrid system is predicted to be active.





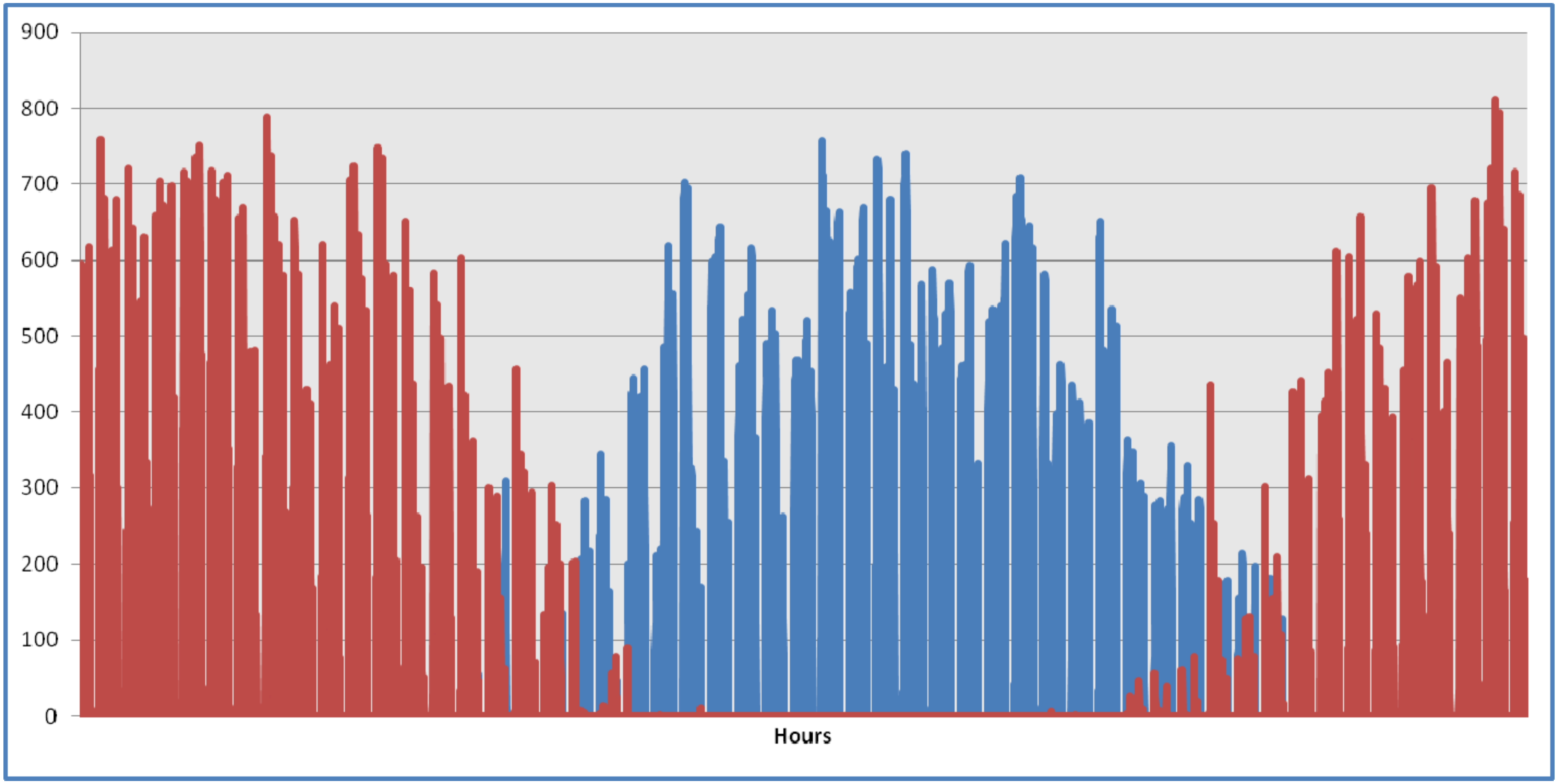
Knowing when the hybrid system is predicted to be on and off on an hour by hour basis enables the designer to:

- ***Accurately*** predict the peak and total energy loads going into and out of the ground
- ***Properly*** size the loopfield for target EWTs
- ***Optimally*** determine the system economics

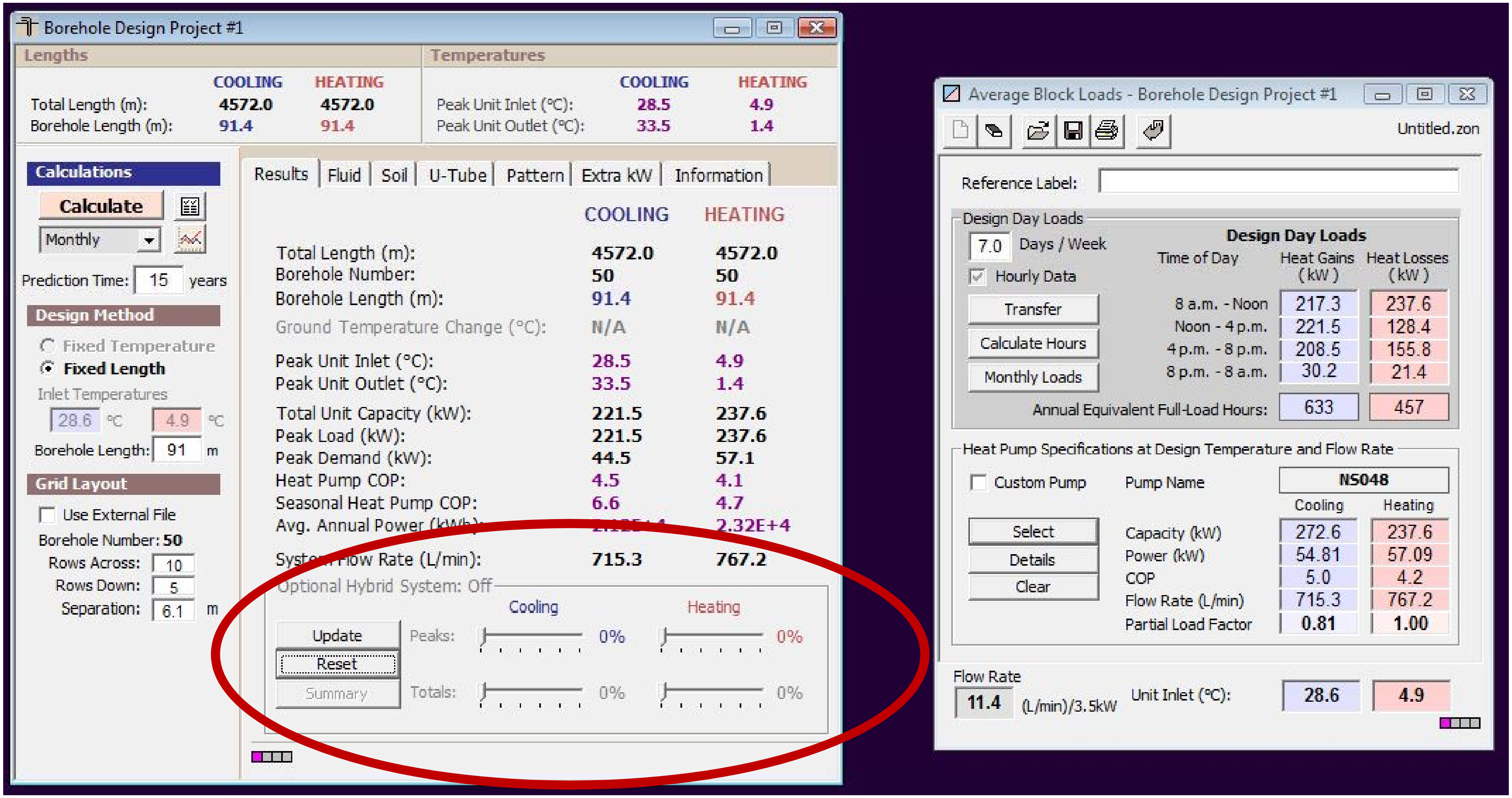
With detailed loads information and the upcoming release of GLD, optimized hybrid sizing has never been more accurate, faster or easier.

•Let’s take a look!

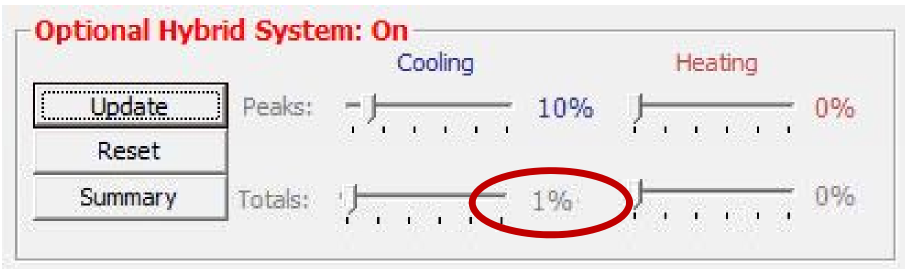
Let's import this hourly loads profile into GLD

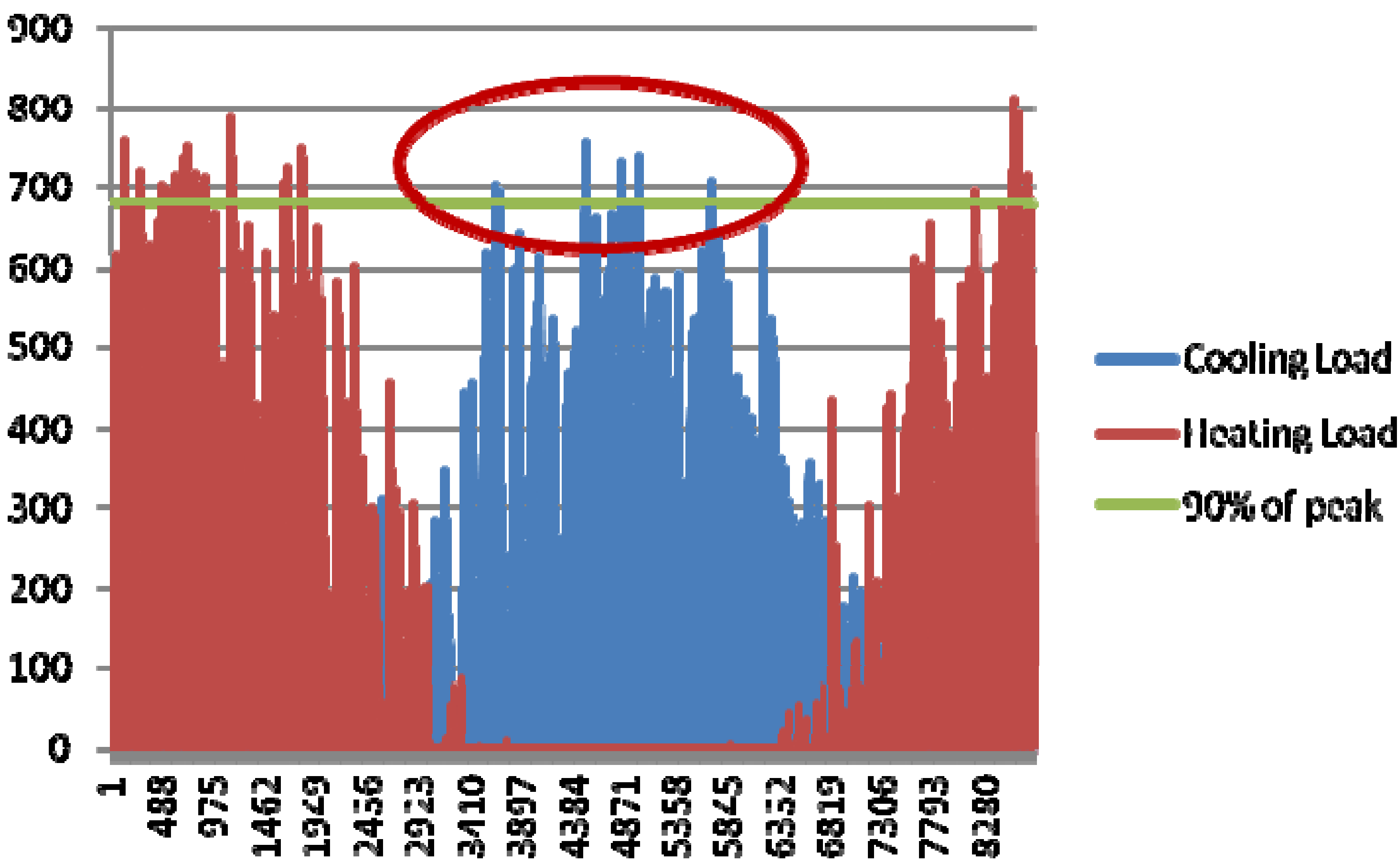


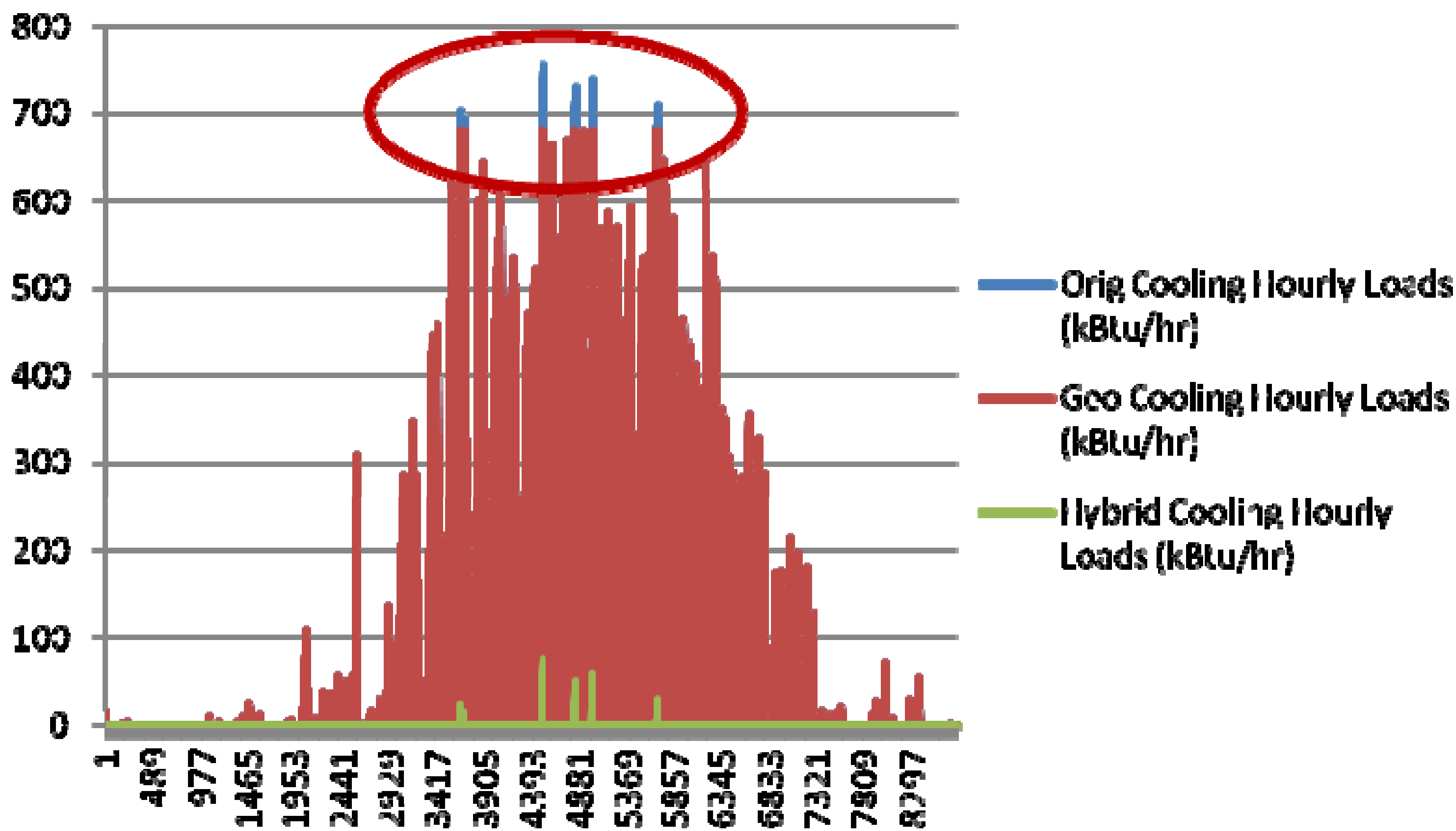
A Design Based on Hourly Loads



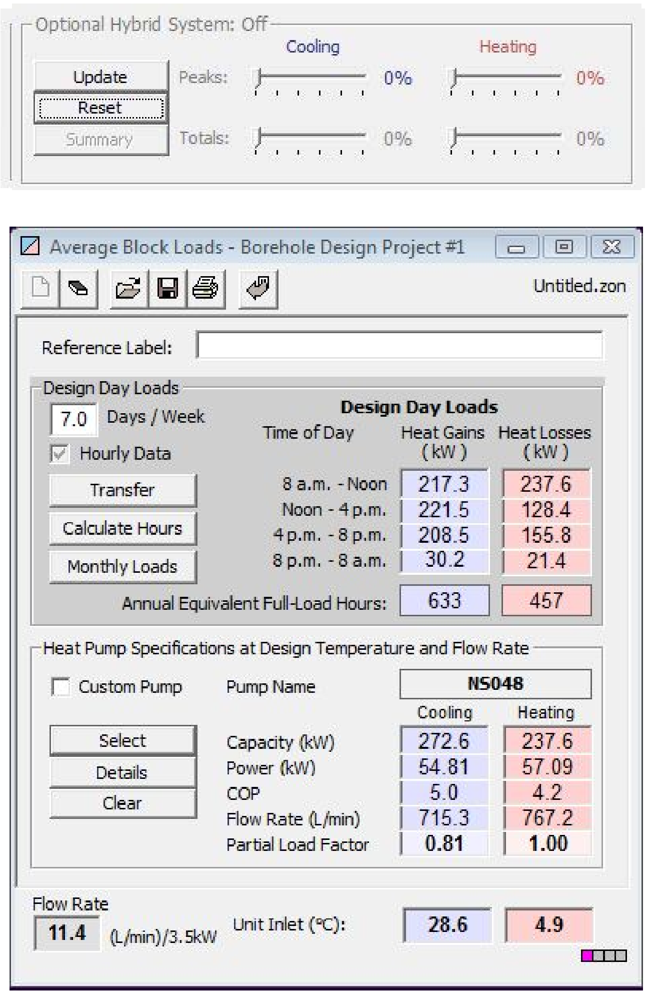
- With an 8760 hourly loads profile, GLD automatically calculates a new hourly loads profile each time the hybrid slider percentage is adjusted.

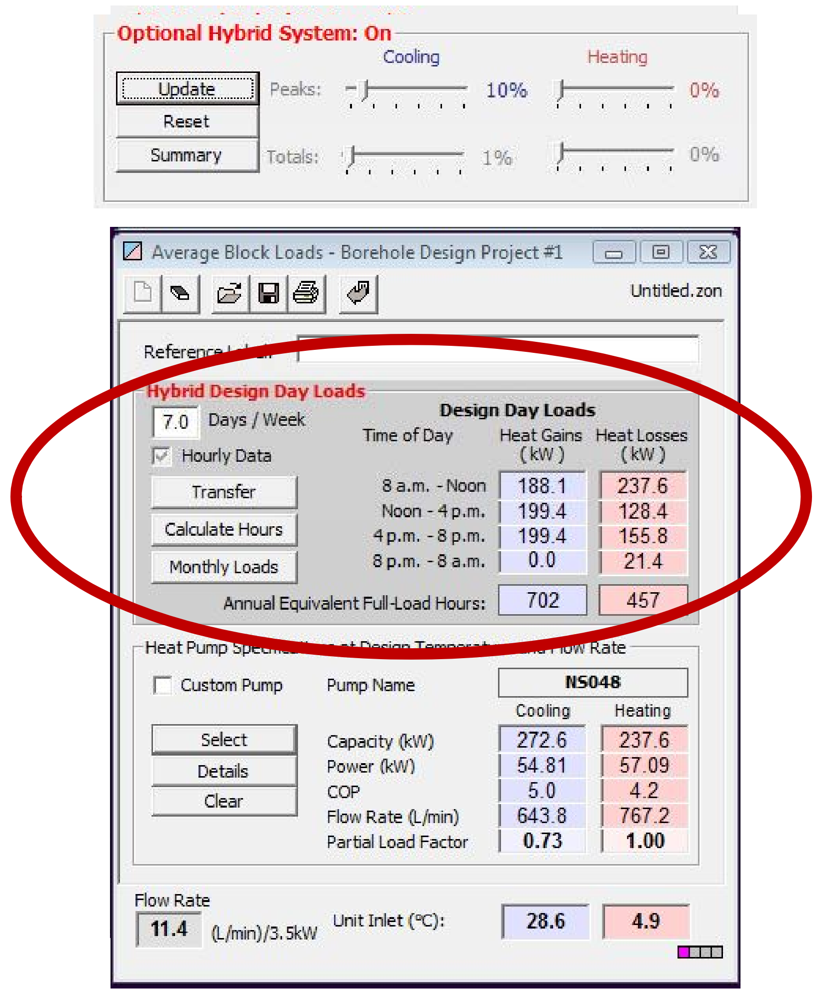



900
800
700
600
500
400
300
200
100
0
1
488
975
1462
1949
2436
2923
3410
3897
4384
4871
5358
5845
6332
6819
7306
7793
8280
Cooling Load
Heating Load
90% of peak

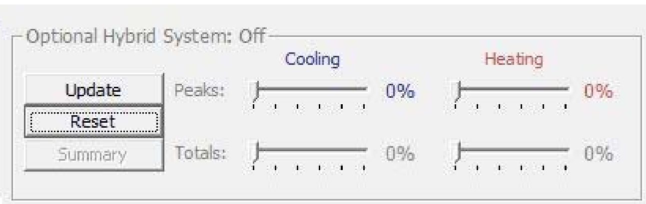

800
700
600
500
400
300
200
100
0
1
489
977
1465
1953
2441
2929
3417
3905
4393
4881
5369
5857
6345
6833
7321
7809
8297
Orig Cooling Hourly Loads (kBtu/hr)
Geo Cooling Hourly Loads (kBtu/hr)
Hybrid Cooling Hourly Loads (kBtu/hr)

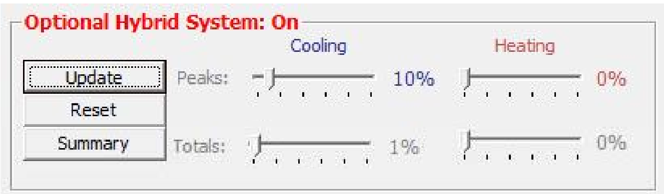
Modified design day loopfield loads are displayed and heat pump performance is updated





Modified monthly peak and total loads are displayed.





Average Block Loads - Borehole Design Project #1 — Untitled.zon

Monthly Load Data

	Cooling Total (kWh)	Cooling Peak (kW)	Heating Total (kWh)	Heating Peak (kW)
January	14	4	28336	222
February	18	3	21505	231
March	276	32	16437	219
April	1095	90	6552	177
May	13623	182	824	74
June	26256	206	6	3
July	37805	222	0	0
August	31092	208	0	0
September	21804	191	62	17
October	7971	104	1360	127
November	120	8	10554	193
December	187	21	23040	238
Total:	140262	3.0 Hours at Peak	108676	3.0 Hours at Peak

Flow Rate 11.4 (L/min)/3.5kW — Unit Inlet (°C): 28.6 / 4.9

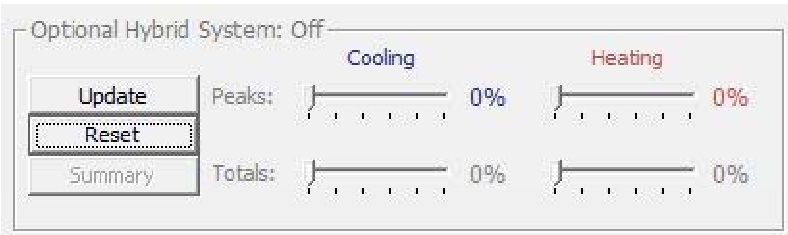
Average Block Loads - Borehole Design Project #1 — Untitled.zon

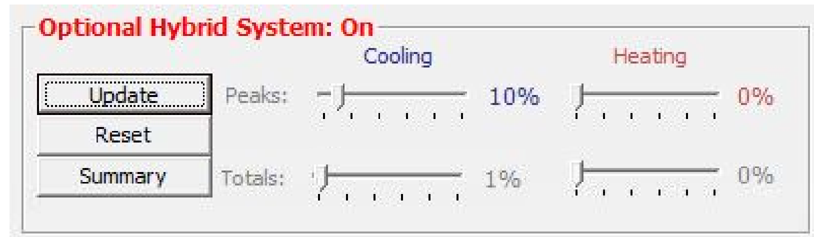
Hybrid Monthly Load Data

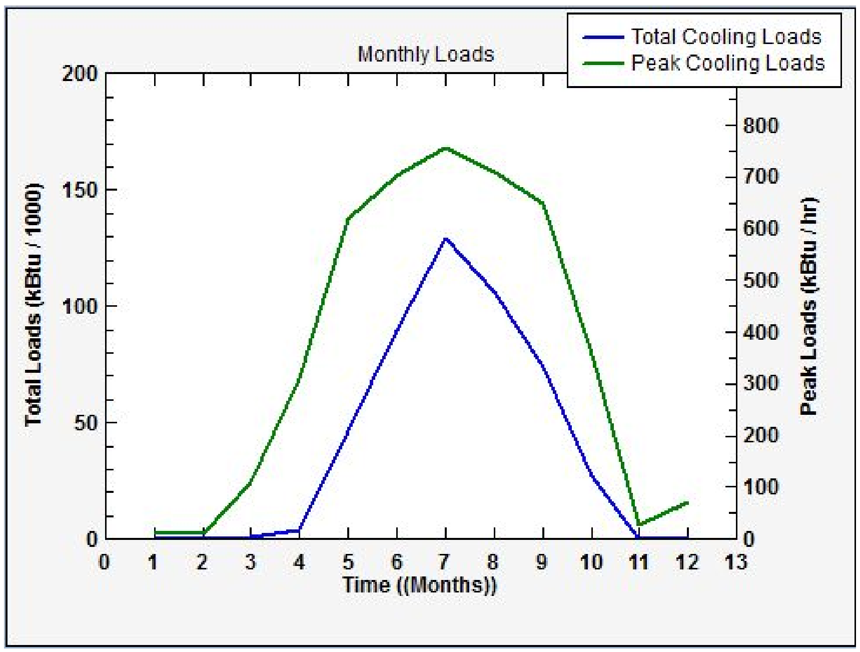
	Cooling Total (kWh)	Cooling Peak (kW)	Heating Total (kWh)	Heating Peak (kW)
January	14	4	28336	222
February	18	3	21505	231
March	276	32	16437	219
April	1095	90	6552	177
May	13623	182	824	74
June	26238	199	6	3
July	37555	199	0	0
August	31083	199	0	0
September	21804	191	62	17
October	7971	104	1360	127
November	120	8	10554	193
December	187	21	23040	238
Total:	139984	3.0 Hours at Peak	108676	3.0 Hours at Peak

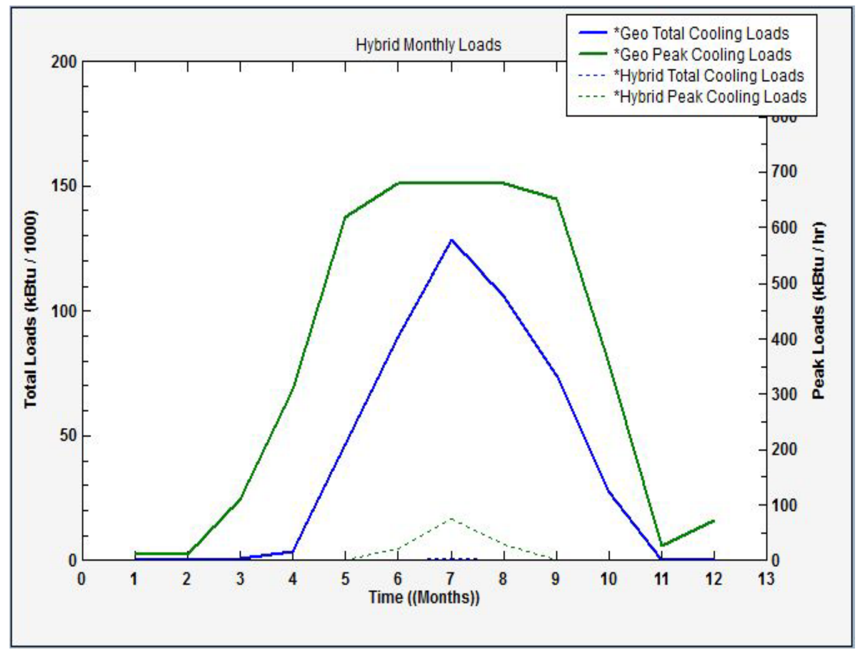
Flow Rate 11.4 (L/min)/3.5kW — Unit Inlet (°C): 28.6 / 4.9

Relationship Between Peak and Total Loads



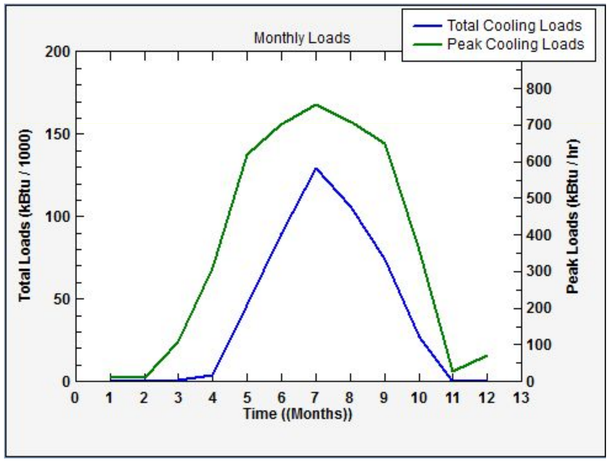




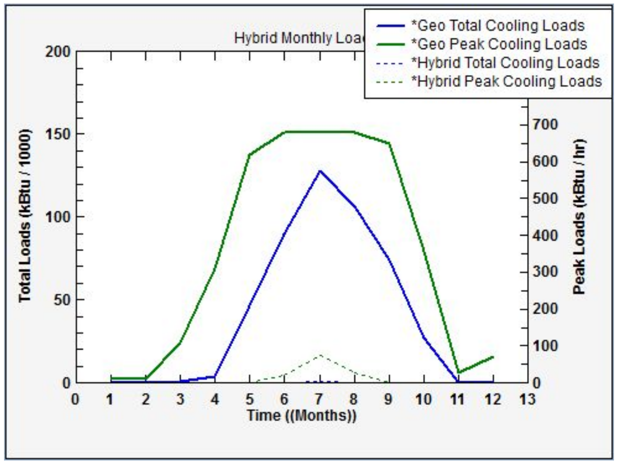


Relationship Between Peak and Total Loads

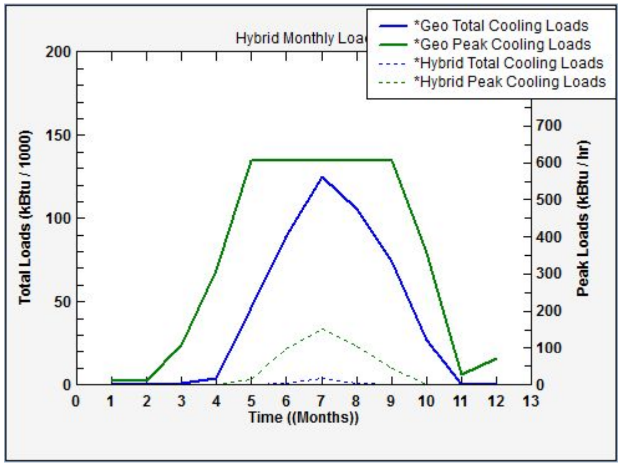
Peaks: 100%/0% Totals: 100%/0%



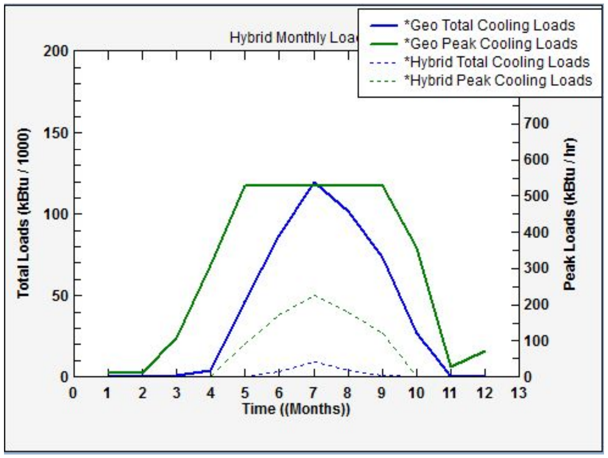
Peaks: 90%/10% Totals: 99.8%/0.2%



Peaks: 80%/20% Totals: 98.7%/1.3%

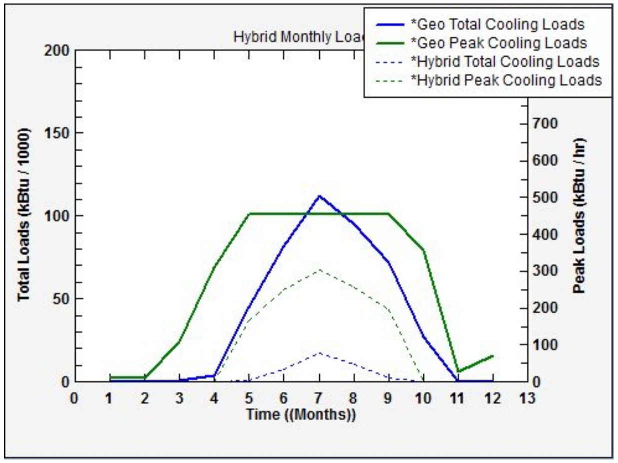


Peaks: 70%/30% Totals: 96.3%/3.7%

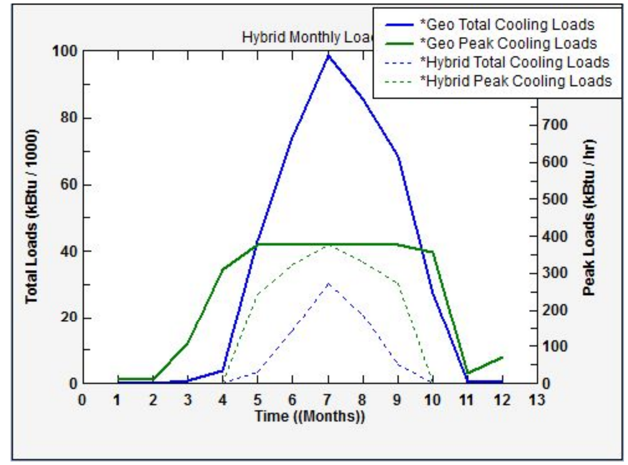


Relationship Between Peak and Total Loads

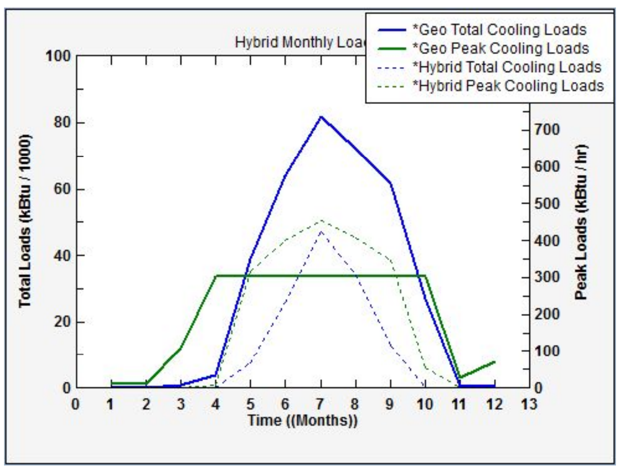
Peaks: 60%/40% Totals: 91.7%/8.3%



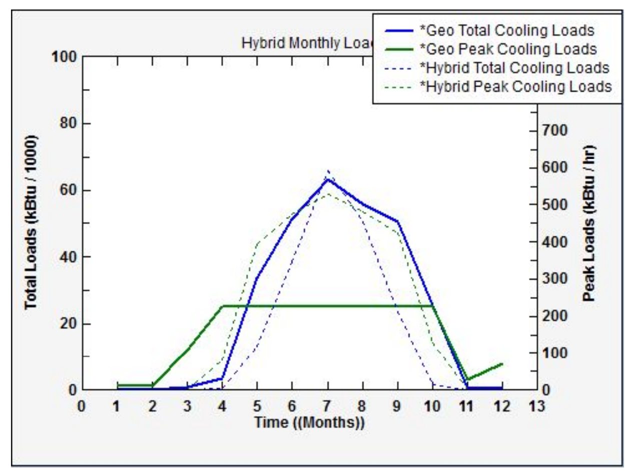
Peaks: 50%/50% Totals: 84.1%/15.9%



Peaks: 40%/60% Totals: 73.3%/26.7%

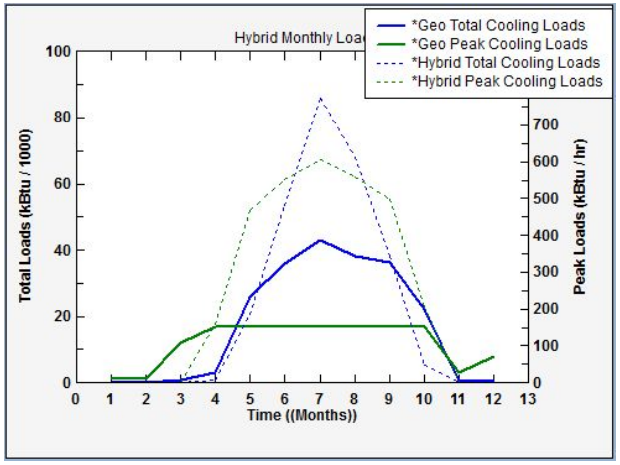


Peaks: 30%/70% Totals: 59.6%/40.4%

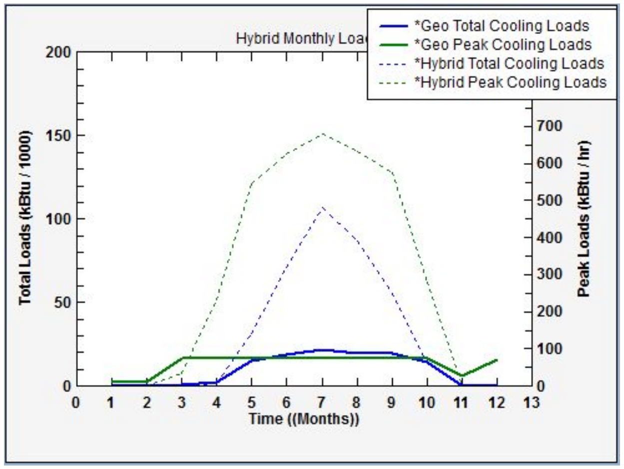


Relationship Between Peak and Total Loads

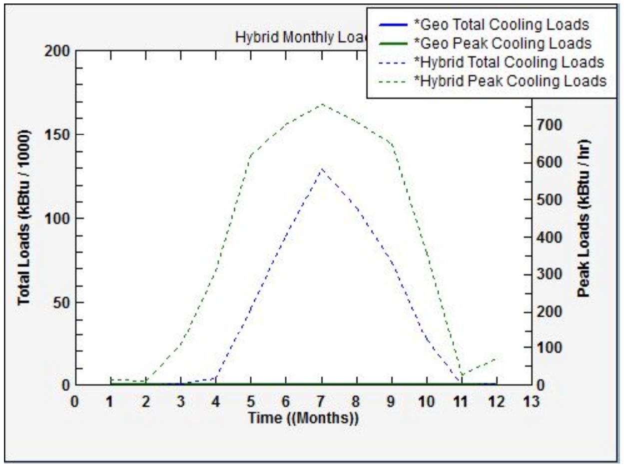
Peaks: 20%/80% Totals: 43.1%/56.9%



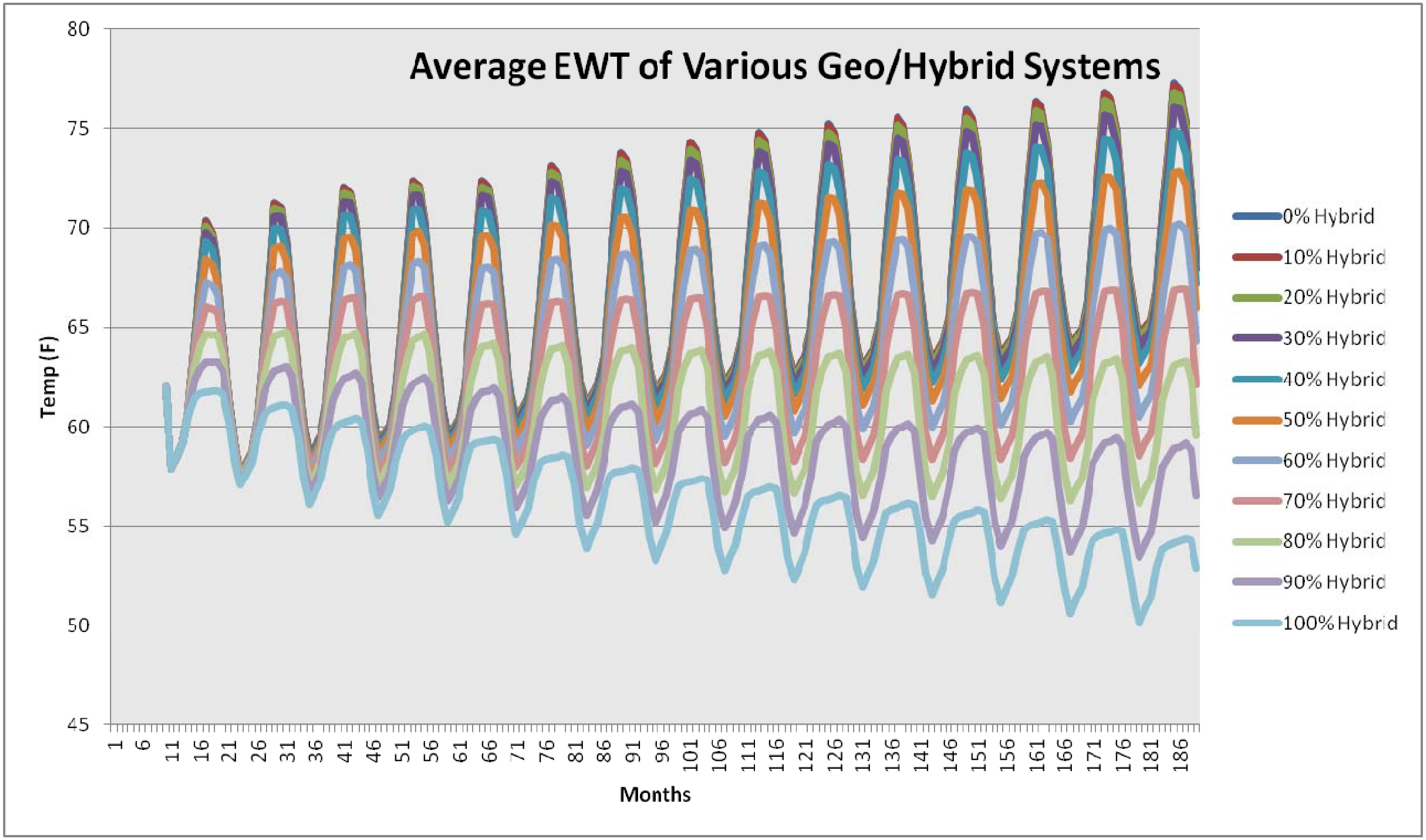
Peaks: 10%/90% Totals: 23.5%/76.5%



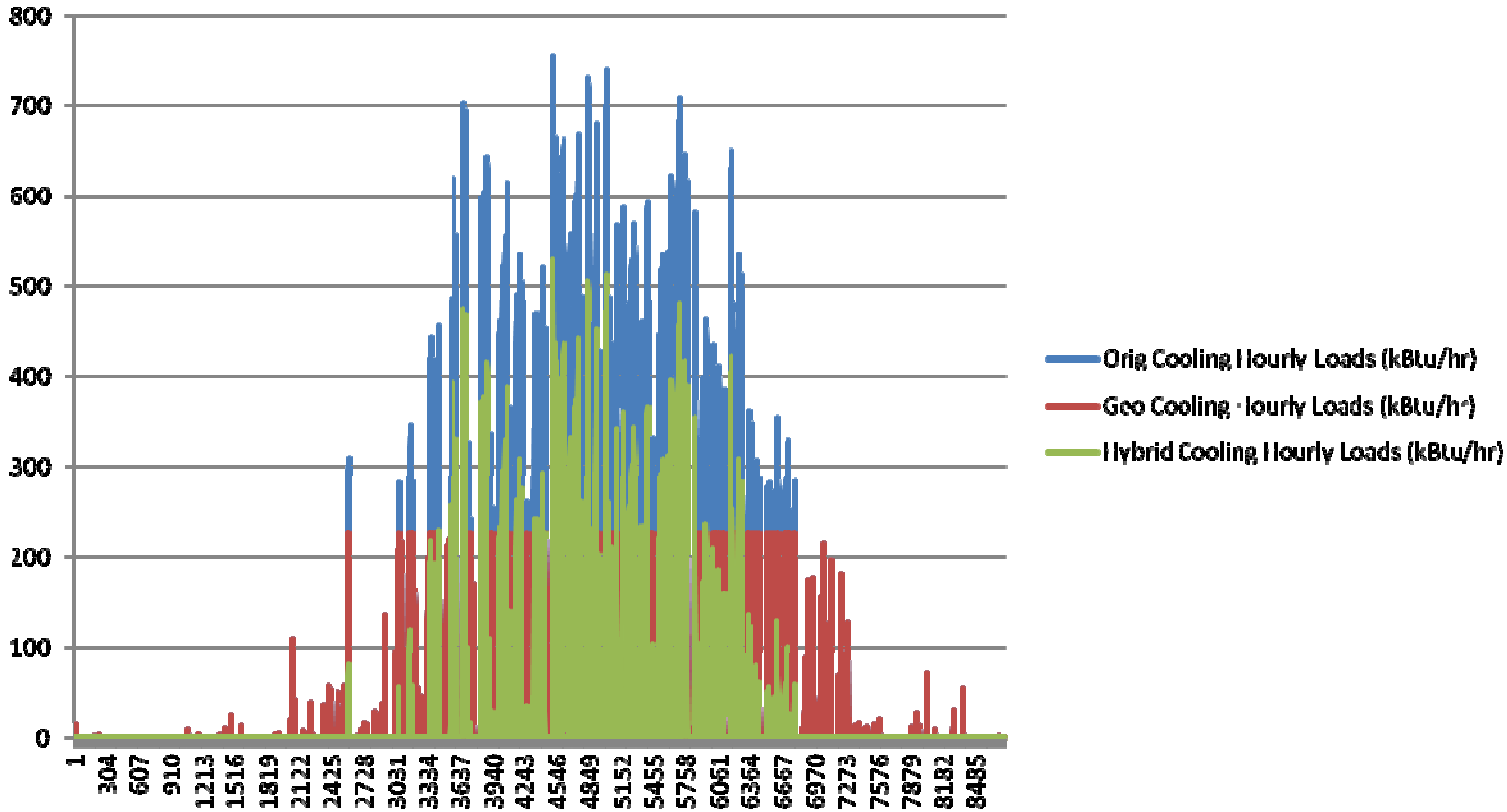
Peaks: 0%/100% Totals: 0%/100%



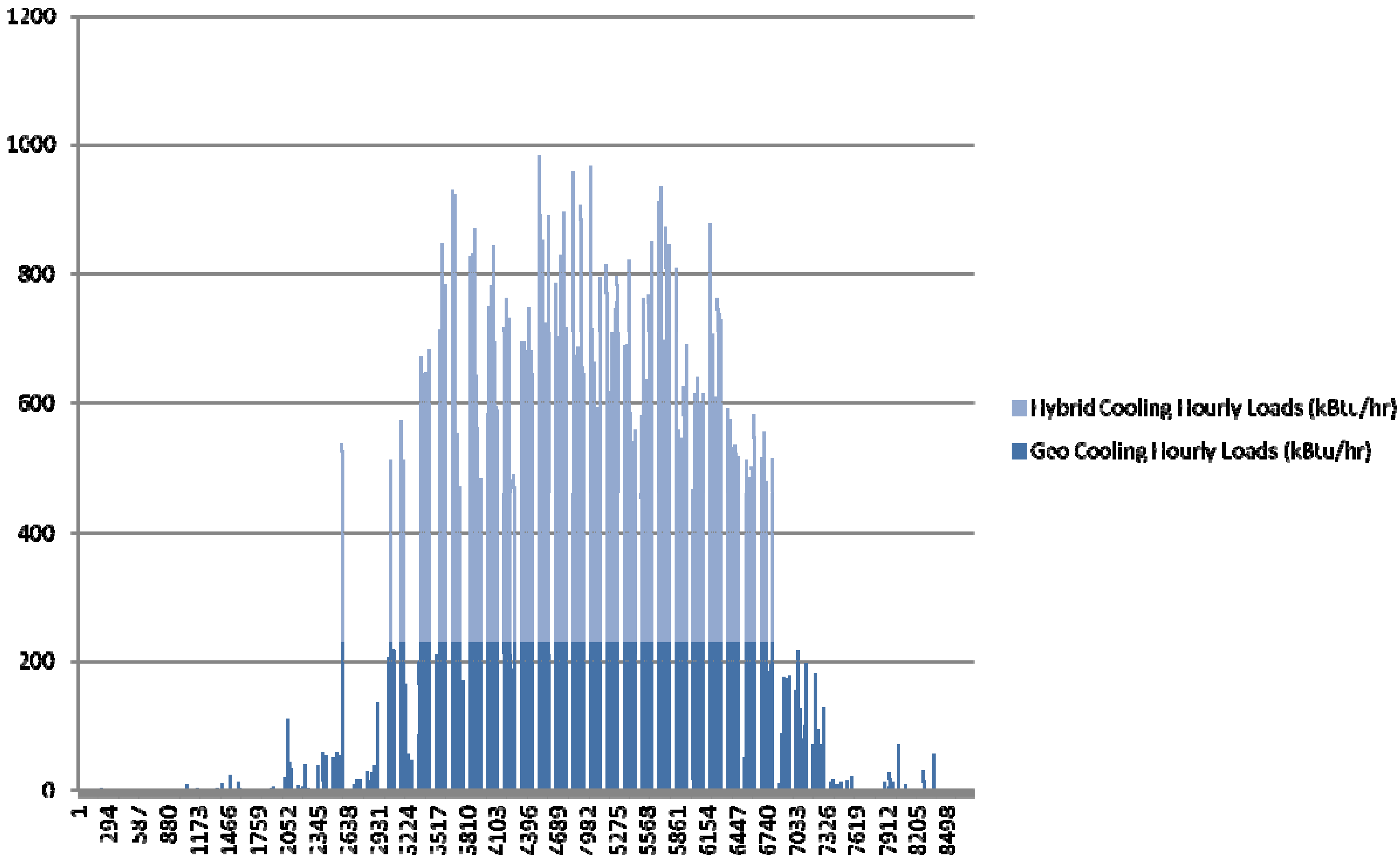
How EWTs change as hybrid slider use changes



Geothermal and hybrid loads at the 70% slider position



Monthly Total and Peak Loads (GLD Screenshot)



Conclusion: Relationship Between Peak and Total Loads is non-linear and impossible to predict without hour-by-hour building loads and GLD.

Peak Geo loads Cut	Total Geo Loads Cut
0%	0.2%
10%	0.2%
20%	1.3%
30%	3.7%
40%	8.3%
50%	15.9%
60%	26.7%
70%	40.4%
80%	56.9%
90%	76.5%
100%	100%

Vertical GHX Loopfield Design

Hybrid Systems:

- With hourly data, GLD automatically determines relationship between geothermal and hybrid loads for each and every hour.
- Can be used to balance systems when building/loopfield design and optimization techniques alone don't work
- Let's look at an example

Vertical GHX Loopfield Design

Sample Design 2: Unbalanced Loads

- Average Block Loads Module
- Hourly Data- **imbalanced** load (Miami hourly)
- Add Hybrid System

Checklist for a Good Design

- ❑ Reasonable Loads
  - high annual hours?
  - high peaks? do a reality check on btu/sq ft
- ❑ Appropriately selected heat pump(s)
  - appropriate "average" pumps for average block
- ❑ Appropriate flow rates/EWTs
  - flow rates in range?
  - EWTs reasonable…not too high/not too low
- ❑ Accurate soil temperatures/TC values
  - ❑ TC test conducted if necessary?
  - ❑ Ground temperature confidence?

What to Look For in a Good Design

- ❑Appropriate Borehole Spacing for land area
  - ❑ spacing too tight?
  - ❑ geometry options?

- ❑Stable soil temperatures over many years (vertical systems)
  - ❑ aiming for ground temp change < 5F?

- ❑Appropriate pipe diameters to minimize PD

Section – Horizontal GHX Loopfield Design

- GLD Overview
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
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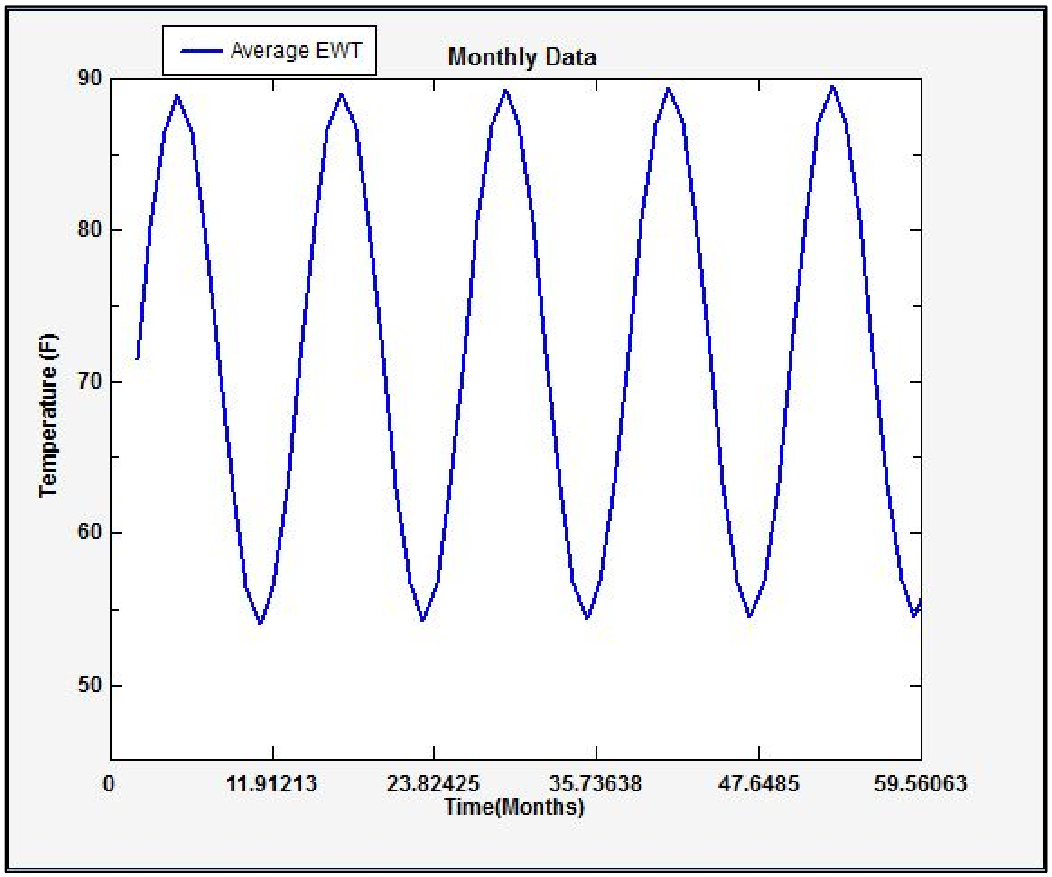
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
- Linking Modules Together
- Vertical GHX Loopfield Design
- **Horizontal GHX Loopfield Design**
- The GSA Module and Lifecycle Costing

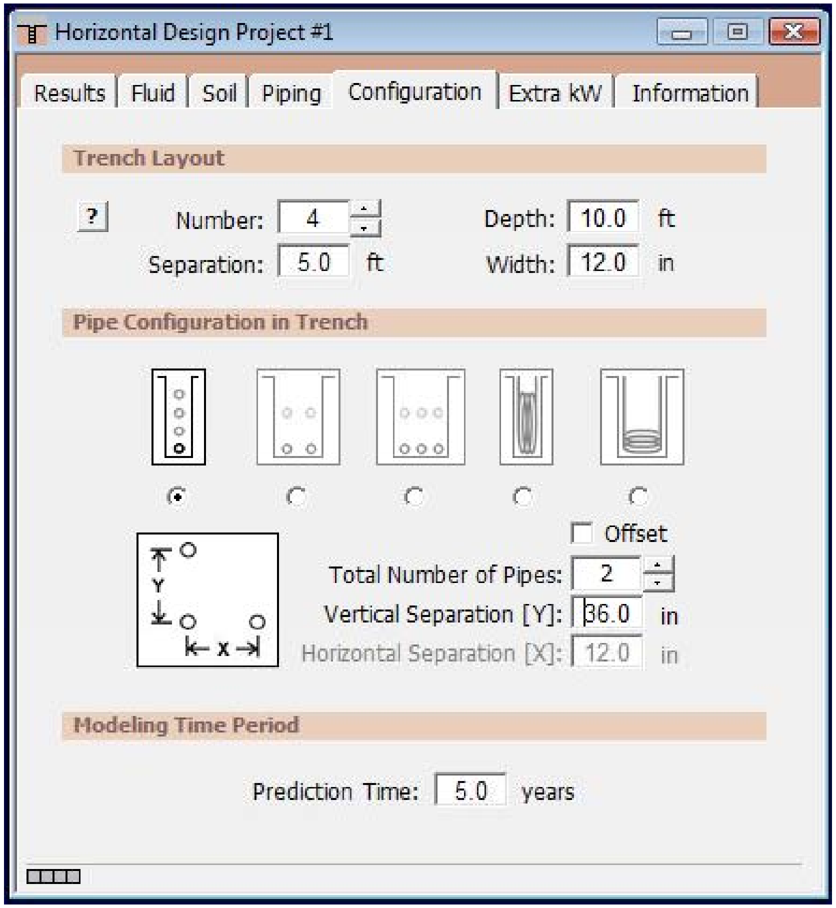
Horizontal GHX Loopfield Design: Overview

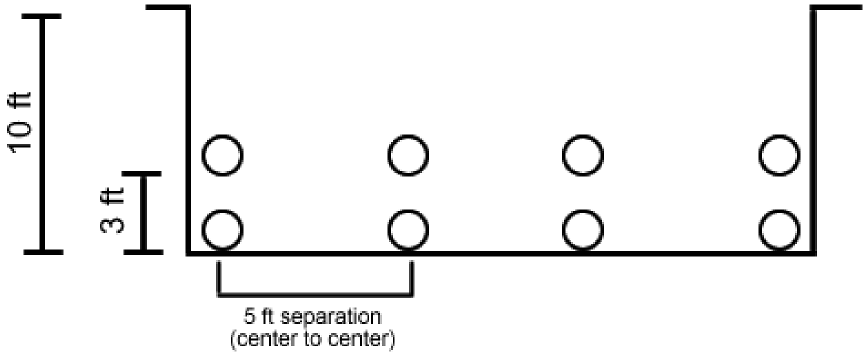
Heat transfer model: variation on Design Day **cylindrical model**



Horizontal GHX Loopfield Design: Overview

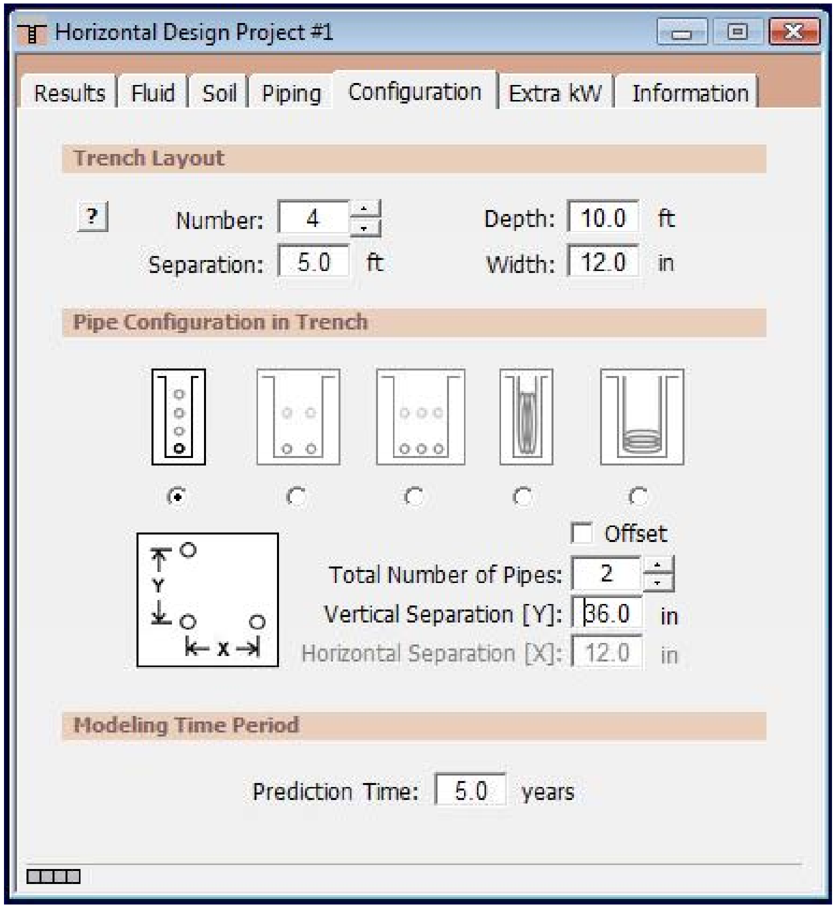
Design pits:

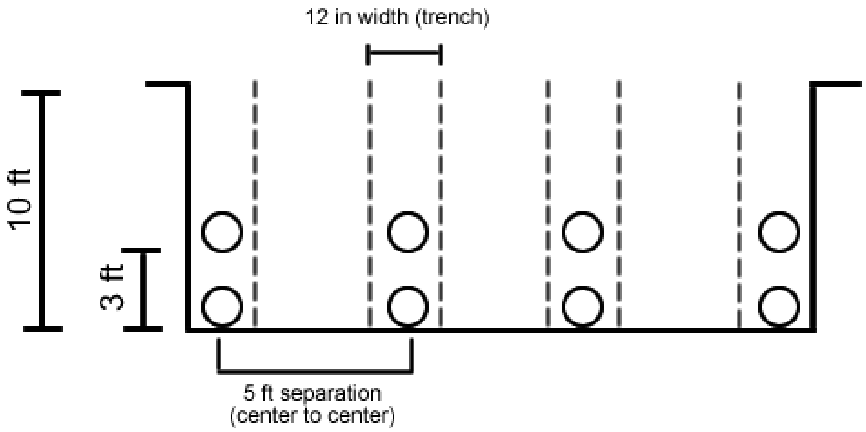




Horizontal GHX Loopfield Design: Overview

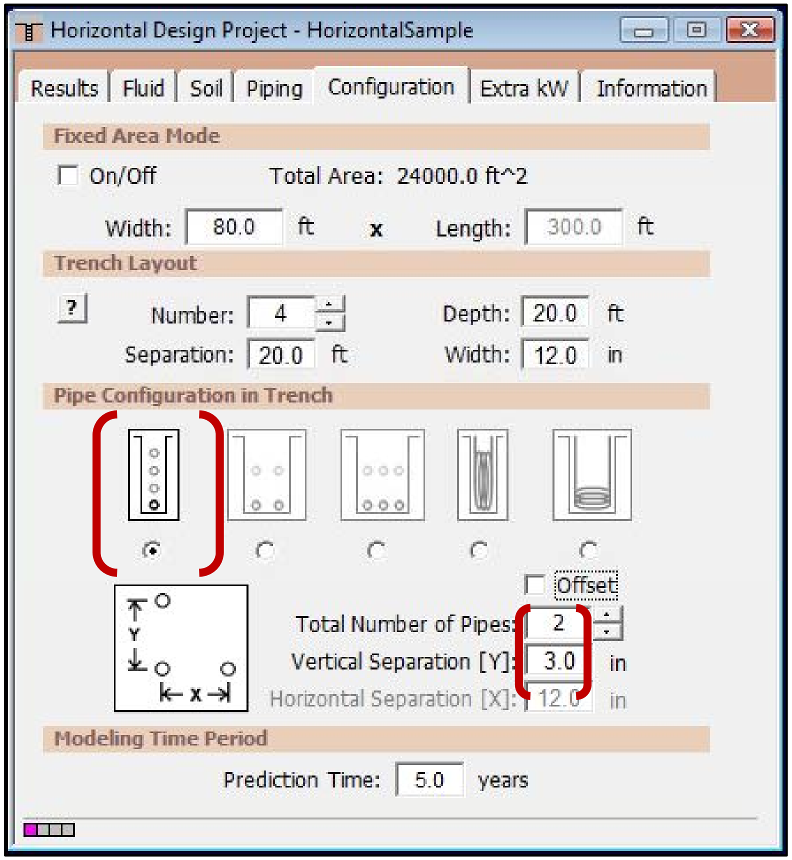
Design trenches:

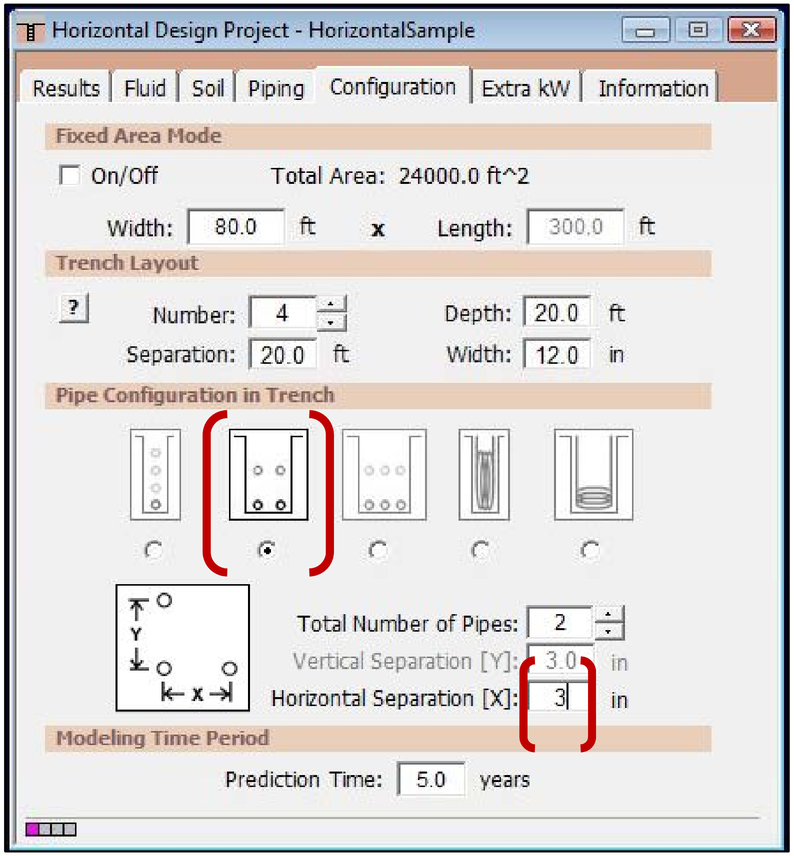




Horizontal GHX Loopfield Design: Overview

Design bores:

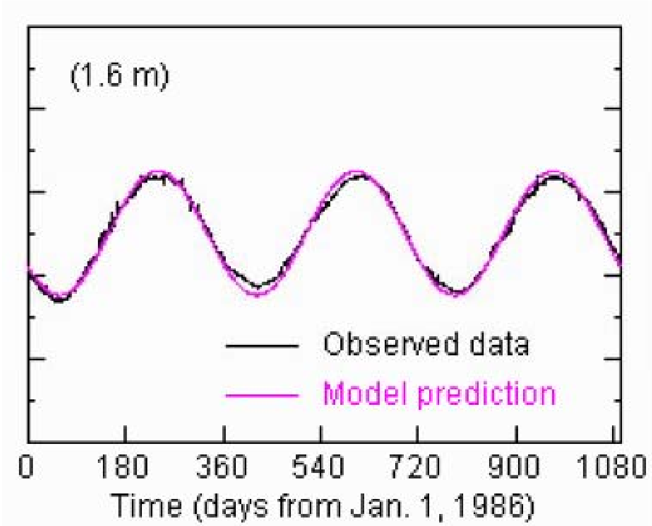




Horizontal GHX Loopfield Design: Overview

Soil temperatures up to about 25 ft deep follow the air temperatures (sinusoid curve) with a delay.

To determine the soil temperatures at the pipe depth GLD needs some info:



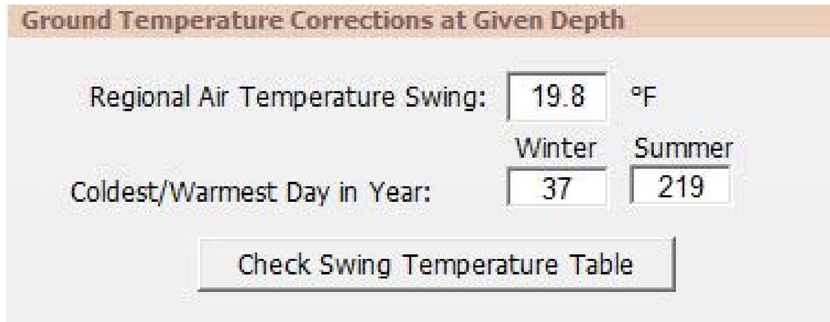
Thx to D.L. Nofziger

- **Temperature Swing**
- **Coldest and Hottest Day of Year (entered as calendar day, 1-365)**

If January 31st is the coldest day of the year, enter "31"

If July 19th is the hottest day of the year, enter "200"

Horizontal GHX Loopfield Design: Overview



One way to estimates swing temperatures:

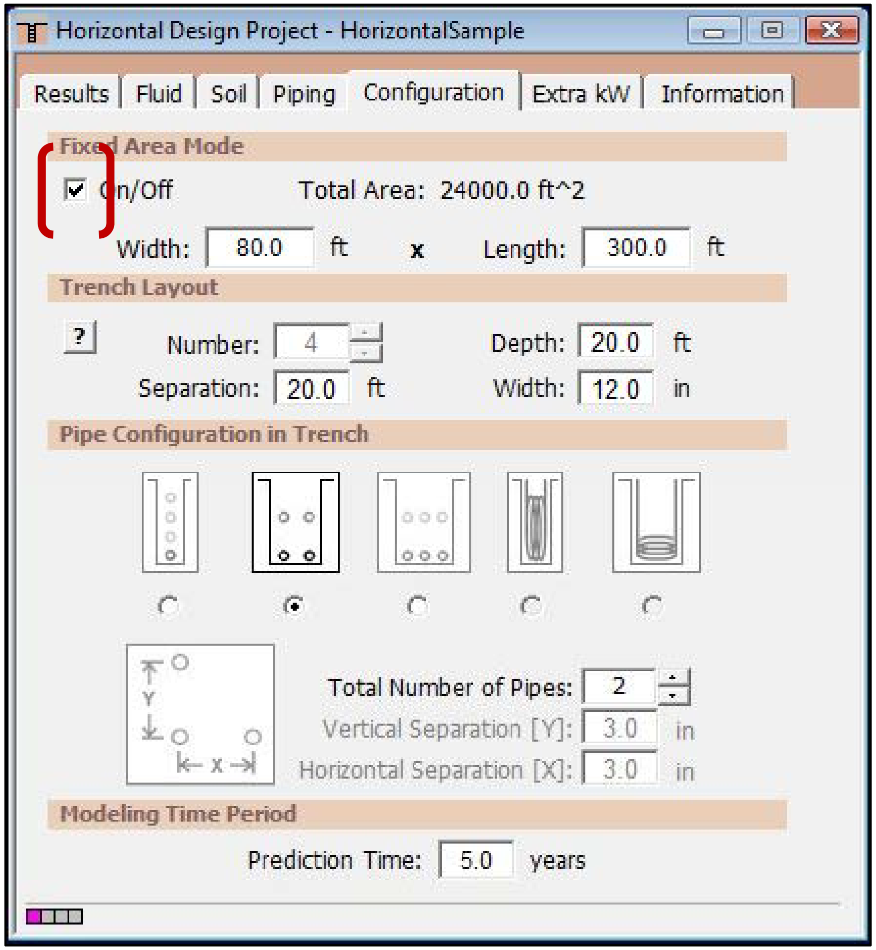
(| Avg annual temp – Avg January temp| + |Avg July temp – Avg annual temp|)/2

Using this method, compare data from www.weatherbase.com with National Rural Electric Cooperative Association, *NRECA Research Project 86-1* and get very similar results.

Horizontal GHX Loopfield Design: Overview

Fixed Area Mode for straight pipe designs (not slinky!):

- Activate Fixed Area mode
- Define width and length
- Define separation between trenches/bores/pipe rows
- Program calculates separation
- Program calculates inlet temps
- Graph inlet temps over time



GHX Loopfield Design Methodology

Optimize Loads → 1) Import Loads

↓

2) Select Heat Pump (s)

↓

3) Design Heat Exchanger ↔ Piping Optimization

↓

4) GSA/CO2 Analysis

Section – The GSA Module

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- **The GSA Module and Lifecycle Costing**

What is Lifecycle Costing?

HARVARD UNIVERSITY OFFICE FOR SUSTAINABILITY
GREEN BUILDING RESOURCE

Life cycle costing is a method of economic analysis for all costs related to building, operating, and maintaining a project over a defined period of time. Assumed escalation rates are used to account for increases in utility costs over time. Future costs are expressed in present day dollars by applying a discount rate. All costs and savings can then be directly compared and fully-informed decisions can be made.

Were Harvard simply a developer whose interest in the buildings it constructs ended with the ribbon cutting, it might be understandable for the university to ignore ongoing operating costs. However, Harvard owns and occupies a large majority of the buildings it constructs, often for the full life of the building – decades into the future. Decisions made to cut costs in the capital budget up-front can easily lead to greatly increased maintenance and utility costs, burdening the university for years and years to come. This would not be an intelligent way for America's most-long lived institution of higher education to operate.

What is Lifecycle Costing?

The basic discount equation is as follows:

$$PV = \frac{F_Y}{(1 + DISC)^Y}$$

Where:

PV is the present value (in Year 0 dollars)
F_Y is the value in the future (in Year Y dollars)
DISC is the discount rate
Y is the number of years in the future

What is Lifecycle Costing?

The formula for calculating the future cost of an item with a known cost today and a known escalation rate is:

$$COST_{YEAR-Y} = COST_{YEAR-0}(1+ESC)^{Y}$$

Where:

$COST_{YEAR-Y}$ is the cost at Y years into the future
$COST_{YEAR-0}$ is today's cost (at Year 0)
ESC is the escalation rate
Y is the number of years into the future

What is Lifecycle Costing?

The basic formula is as follows:

$$LCC = C + PV_{RECURRING} - PV_{RESIDUAL\text{-}VALUE}$$

Where:

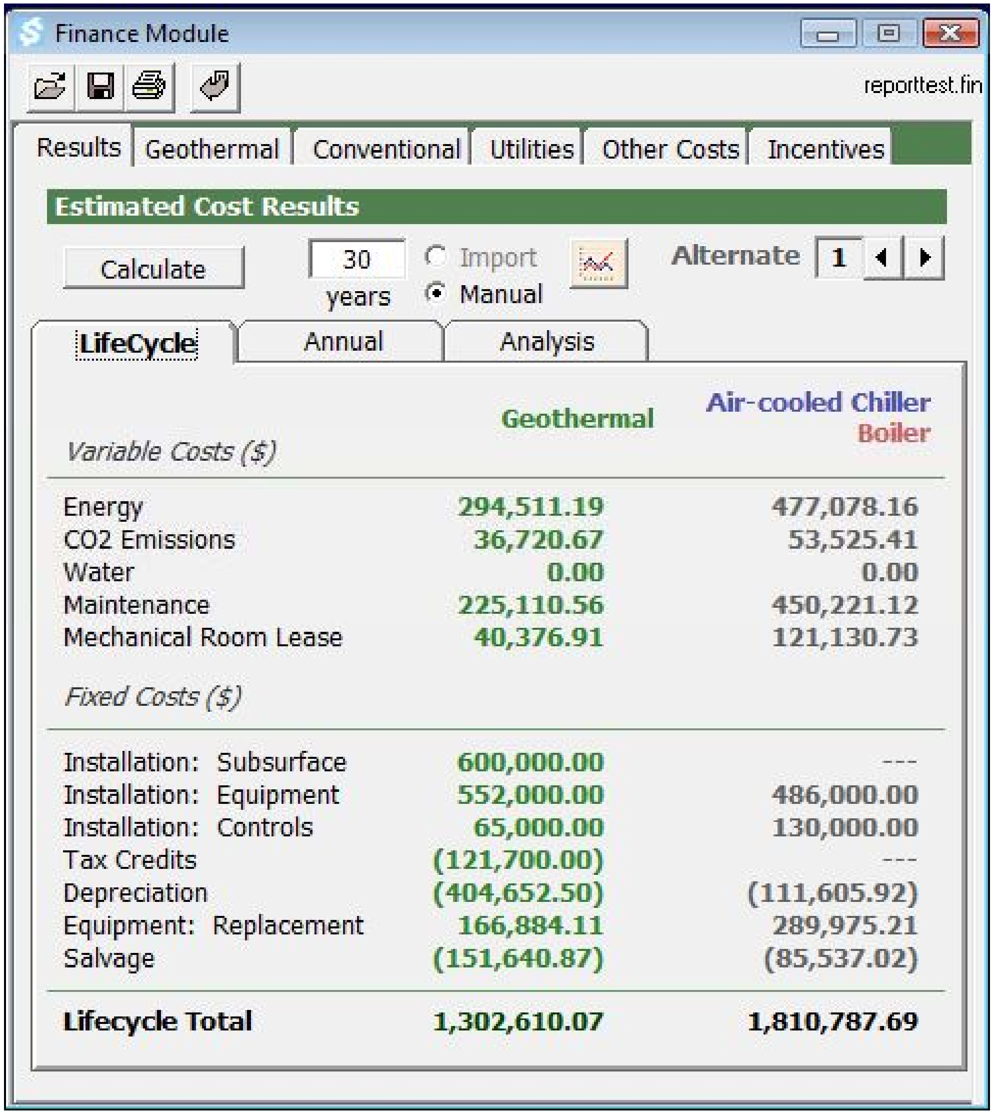
LCC is the life cycle cost

C is the Year 0 construction cost (hard and soft costs)

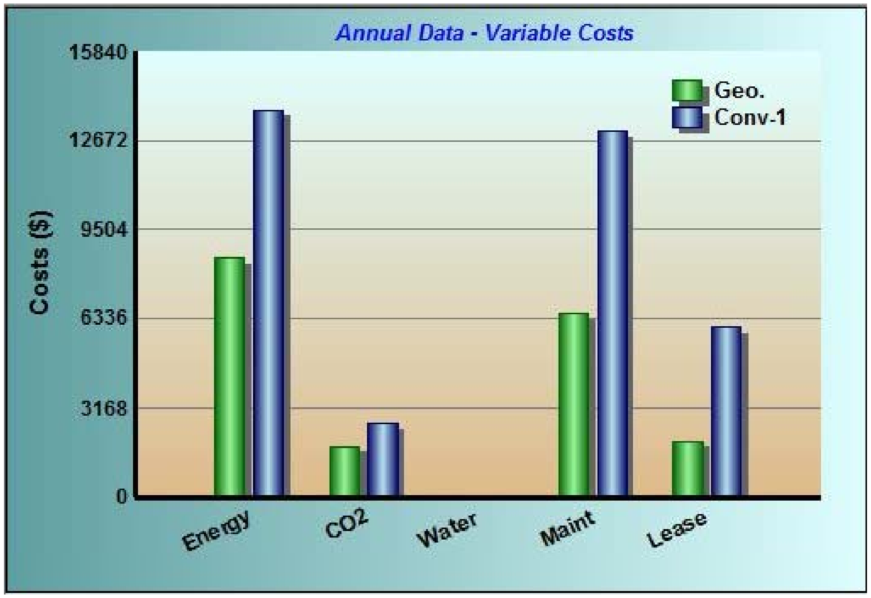
$PV_{RECURRING}$ is the present value of all recurring costs (utilities, maintenance, replacements, service, etc.)

$PV_{RESIDUAL\text{-}VALUE}$ is the present value of the residual value at the end of the study life

What is Lifecycle Costing?



	Geothermal	Air-cooled Chiller Boiler
Variable Costs ($)		
Energy	294,511.19	477,078.16
CO2 Emissions	36,720.67	53,525.41
Water	0.00	0.00
Maintenance	225,110.56	450,221.12
Mechanical Room Lease	40,376.91	121,130.73
Fixed Costs ($)		
Installation: Subsurface	600,000.00	---
Installation: Equipment	552,000.00	486,000.00
Installation: Controls	65,000.00	130,000.00
Tax Credits	(121,700.00)	---
Depreciation	(404,652.50)	(111,605.92)
Equipment: Replacement	166,884.11	289,975.21
Salvage	(151,640.87)	(85,537.02)
Lifecycle Total	**1,302,610.07**	**1,810,787.69**



What is Lifecycle Costing?

In summary, lifecycle costing is a standard investment analysis methodology that counts present and future costs and savings in today's dollar terms (known as net present value, or NPV, analysis.

Future costs and savings are converted into today's dollar terms using the discount rate.

Typically, the commercial real estate sector likes to see NPV analysis that has a investment payback of approximately < =8 years.

To do a full NPV analysis on a geothermal system requires the designer to take into account "hard" and "soft" costs for a geothermal system and one or more conventional systems.

What is the GSA Module?

The Geothermal System Analyzer (GSA) Module enables customized, quick and accurate lifecycle costing specifically for geothermal systems and the unique and valuable benefits that they provide.

What is the GSA Module?

Geothermal System Analyzer Module - Borehole Design Project #1

lifecycleexample.fin

Results | Geothermal | Conventional | Utilities | Other Costs | Incentives

Estimated Cost Results

Calculate | 20.0 years | Import | Manual | Alternate 1

LifeCycle | Annual | Analysis

Variable Costs ($)	Geothermal	Air-cooled Chiller / Boiler
Energy	122,510.04	213,246.38
CO2 Emissions	11,713.57	19,905.09
Water	0.00	0.00
Maintenance	79,274.12	158,548.25
Mechanical Room Lease	7,011.54	10,517.31
Fixed Costs ($)		
Installation: Subsurface	273,960.00	---
Installation: Equipment	584,000.00	576,000.00
Installation: Controls	40,000.00	50,800.00
Tax Credits	(89,796.00)	---
Depreciation	(288,405.31)	(78,881.60)
Equipment: Replacement	0.00	154,523.25
Salvage	0.00	0.00
Lifecycle Total	**740,267.96**	**1,104,658.67**

LifeCycle | Annual | **Analysis**

Financial Metrics	Geothermal	Air-cooled Chiller / Boiler
Annual Total Savings	8,743.22	($)
NPV Total Savings (20 years)	276,247.50	($)
Annual CO2 Reduction	17.75	tons
Total CO2 Reduction (20 years)	355.08	tons
Simple Payback	6.9	years
IRR	6.7	%
Annual RHI	4,210.11	($)
NPV Total RHI	59,038.73	($)

GSA Module Inputs

Hard Costs

- Loads/Efficiencies
- Installation Costs:
  - Subsurface (cost per foot of pipe installed)
  - Equipment (cost per square foot of conditioned space)
  - Controls (cost per square foot of conditioned space)
- Equipment Replacement Costs
- Energy Consumption (kWh) costs

Soft Costs

- CO2 emissions costs
- Opportunity costs related to mechanical room size
- Maintenance costs
- Water consumption costs

Incentives and Taxes

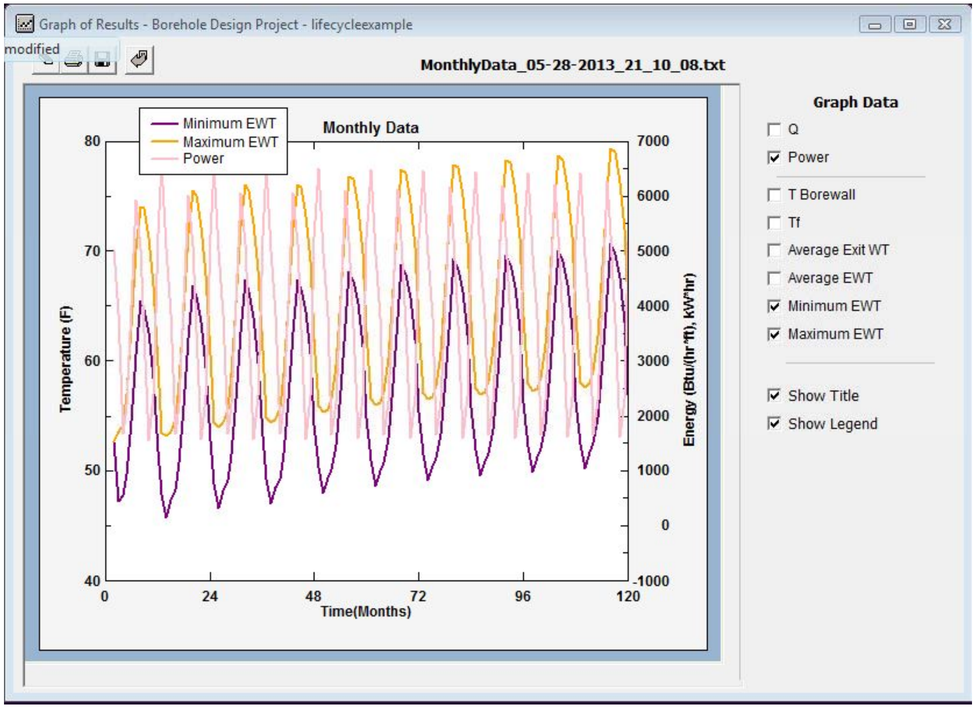
- Tax Credits
- Depreciation
- Salvage

Standard Inputs for Lifecycle Analysis

Hard Costs: Loads and Efficiencies

- Total heating and cooling btus/kWs
- Average equipment performance (COP, EER, etc)

To calculate geothermal average COP/EER values, monthly/hourly loads data, dynamic pump data and advanced loopfield simulations essential



Standard Inputs for Lifecycle Analysis

Hard Costs: Building Construction Costs

- General Costs
  - Cost per square foot for construction
  - Value per square foot for existing buildings

Standard Inputs for Lifecycle Analysis

Hard Costs: Installation Costs

- Subsurface (cost per foot of pipe installed)
- Equipment (cost per square foot of conditioned space)
- Controls (cost per square foot of conditioned space)

Standard Inputs for Lifecycle Analysis

Hard Costs: Installation Costs

System Type	Cost per Square Ft Installed
Geothermal Vertical	$16 to $21
Geothermal Horizontal	$13 to $17
Geothermal Surface Water	$13 to $16
Geothermal Vertical/Hybrid	$14 to $18
VAV- Water Cooled w/boiler	$16 to $19
VAV- Air Cooled w/boiler	$14 to $18
Fan Coil WCC w/ boiler	$12 to $16
Rooftop Gas/Electric	$10 to $16

Standard Inputs for Lifecycle Analysis

Hard Costs: Equipment Replacement Costs

- Factor in time frame, future equipment costs, future labor costs

Equipment Service Life

Equipment Item	Yrs	Equipment Item	Yrs	Equipment Item	Yrs
Split System AC	15	Fan-coil units	20	Cooling towers: Galvanized	20
Water cooled AC	15	VAV Boxes	20	Cooling towers: Wood	20
Heat Pumps	15	Duct work	30	Cooling towers: Ceramic	34
Water Source Heat Pump	19	Fans: Roof-mounted	20	Pumps: Base mounted	20
Packaged Roof-top Units	15	Coils: DX: water/steam	20	Pumps: Pipe mounted	10
Boiler: Steel water-tube	27	Shell & Tube Heat Exch.	24	Sump and well Pumps	10
Boiler: Steel fire-tube	25	Recip compressors	20	Condensate Pump	15
Boiler: Cast Iron	33	Chiller: Reciprocating	20	Motor Starters	17
Boiler: Electric	15	Chiller Centrifugal	23	Pneumatic Controls	20
Furnaces	18	Chiller Absorption	23	Electric Controls	16
Unit Heater: Gas	13	Radiant heater Steam: HW	25	Electronic Controls	15

—Source: ASHRAE Handbook

Geothermal heat pumps average: 22 years

Standard Inputs for Lifecycle Analysis

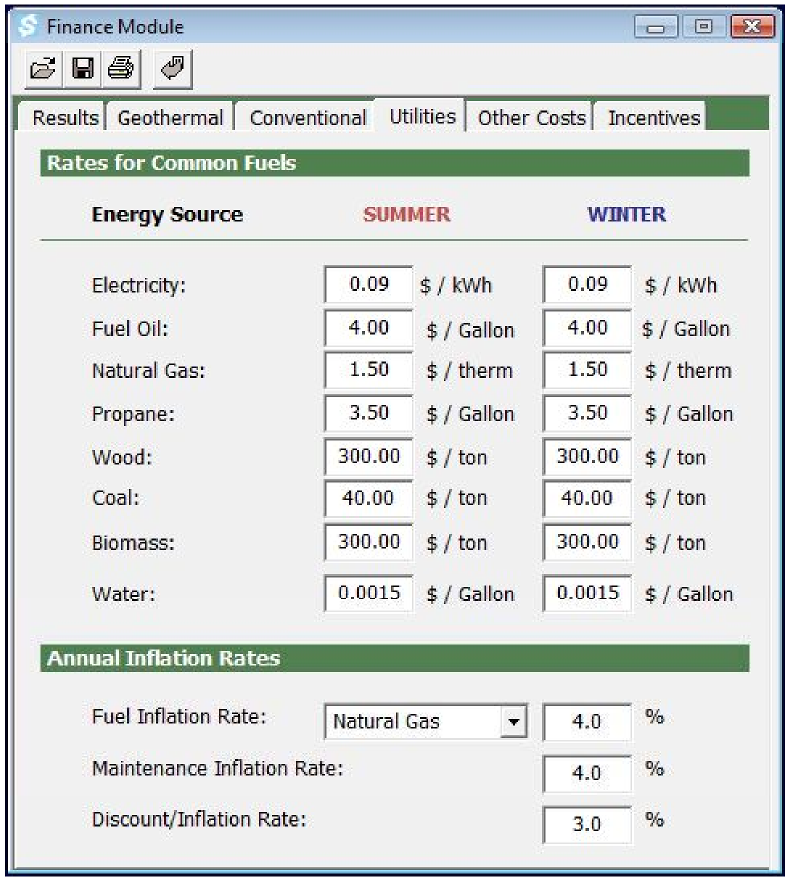
Hard Costs: Controls Costs

- Range from $0.1 to $1.50 per square foot of the conditioned space.
- Simple, well designed geo systems can have low controls costs.

Standard Inputs for Lifecycle Analysis

Hard Costs: Energy Consumption Costs

- Factor in fuel types, current prices, fuel inflation rates



Standard Inputs for Lifecycle Analysis

Hard Costs: Maintenance Costs

System Type	Cost per Square Ft per year
Geothermal Vertical	$0.09 to $0.11
VAV- Air Cooled Chiller w/ gas boiler	$0.10 to $0.14
VAV- Water Cooled Chiller w/boiler	$0.18 to $0.20
Cooling tower systems	$0.50 or more

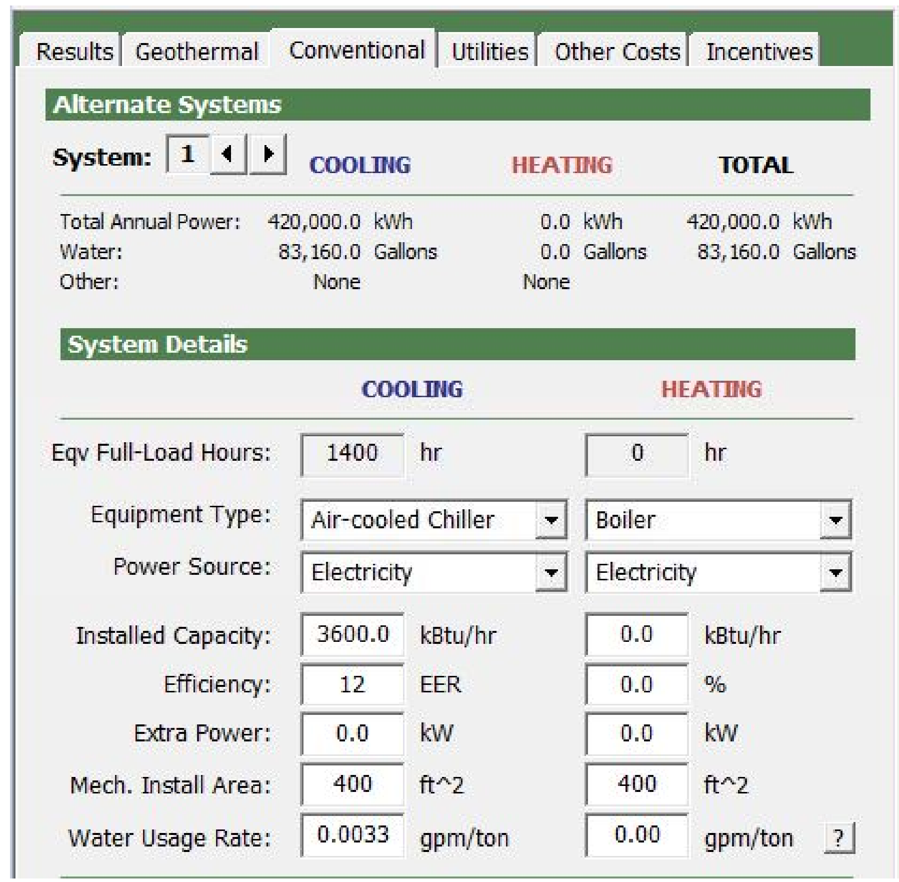
Maintenance costs typically increase over time. This is accounted for with a maintenance cost inflation rate.

Standard Inputs for Lifecycle Analysis

Hard Costs: Water Consumption Costs

If comparing a closed geothermal system with say a cooling tower:

- A 300 ton system will use 600g/hr
- Water can cost $2.50/hour
- In the future in drought prone regions?



Standard Inputs for Lifecycle Analysis

Soft Costs: Mechanical Room Size

Mechanical rooms are expensive to build ($/sq ft). For new construction, geothermal systems may require a smaller footprint and save money.

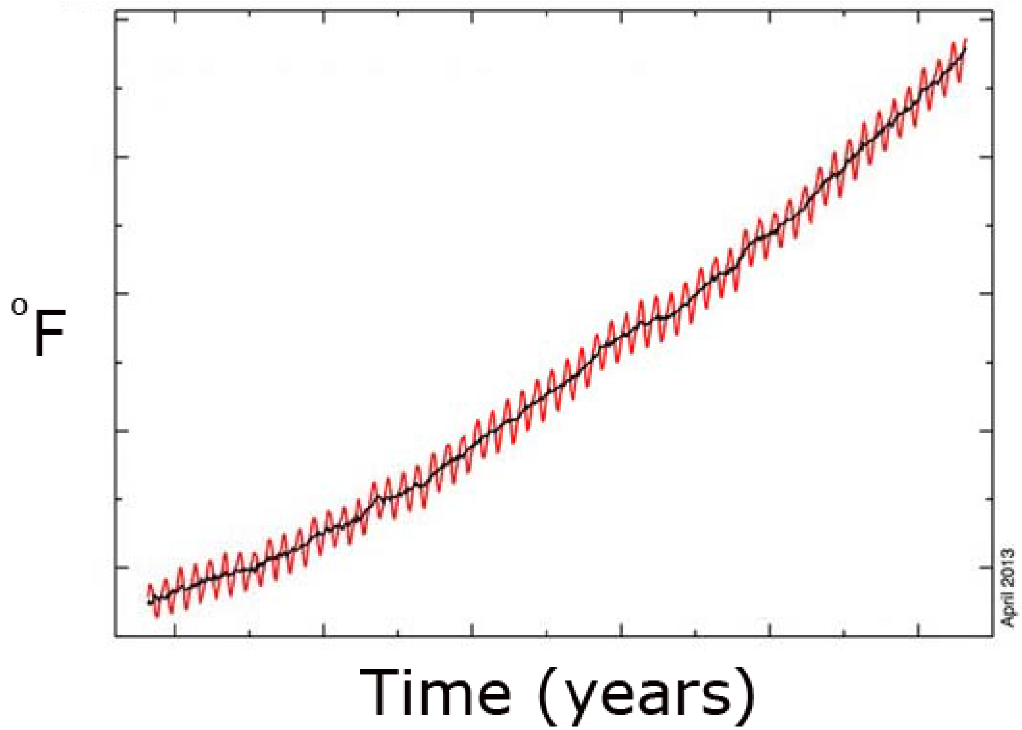
With a geothermal retrofit, existing mechanical rooms may be converted to other valuable uses.

Standard Inputs for Lifecycle Analysis

POP QUIZ!

1)Is this graph represent the long term fluid temps of a cooling or heating dominant geothermal system?

2)Is this a stable design? Does it warrant some sort of an intervention?

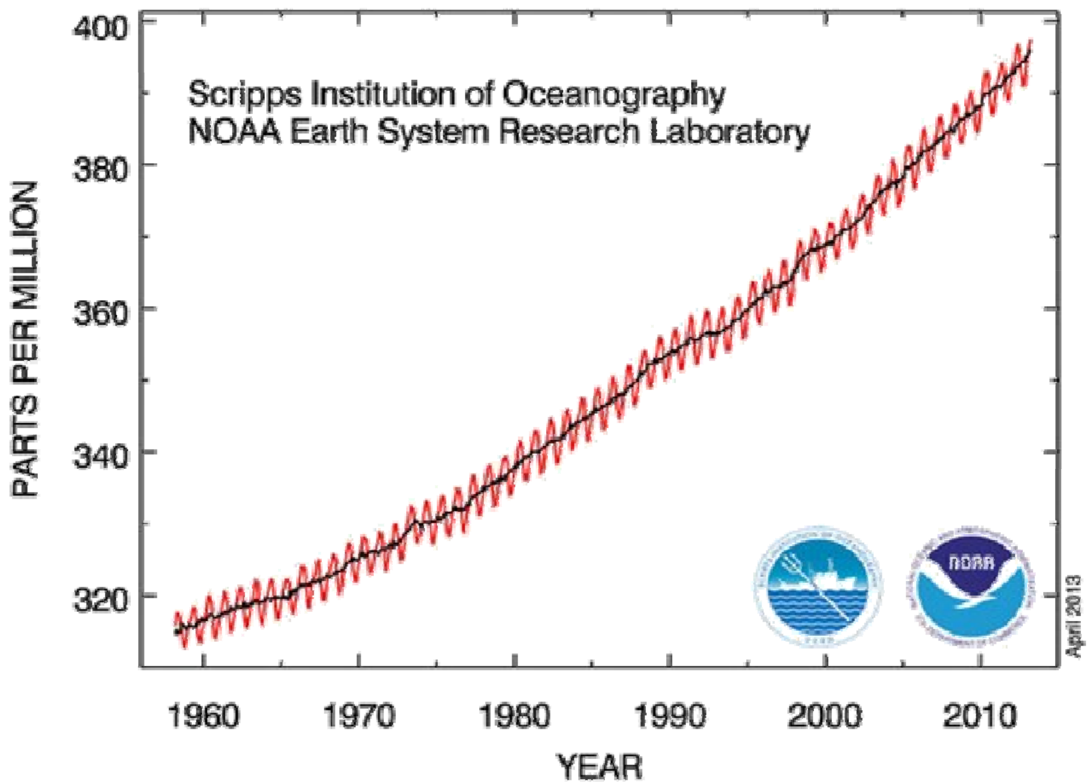


Standard Inputs for Lifecycle Analysis

Soft Costs: C02 Emissions Costs

Tax or cap on emissions inevitable during lifetime of new geothermal installations.

Estimates range from $20/ton up to $600+/ton.



The Geothermal System Analyzer Module

Soft Costs: CO_2

Emissions Costs

CO2 Emission Rate:	0.8	lbs / kWh
CO2 Emissions Cost:	100.00	$ / ton ?
Effective Initiation Delay:	0	yr

Region/State	CO_2 Emission Factors			CH_4	N_2O
	lbs/kWh	short tons/MWh	metric tons/MWh	lbs/MWh	lbs/MWh
New England	0.98	0.491	0.446	0.0207	0.0146
Connecticut	0.94	0.471	0.427	0.0174	0.0120
Maine	0.85	0.426	0.386	0.0565	0.0270
Massachusetts	1.28	0.639	0.579	0.0174	0.0159
New Hampshire	0.68	0.341	0.310	0.0172	0.0141
Rhode Island	1.05	0.526	0.477	0.0068	0.0047
Vermont	0.03	0.014	0.013	0.0096	0.0039
Mid Atlantic	1.04	0.520	0.471	0.0093	0.0145
New Jersey	0.71	0.353	0.320	0.0077	0.0079
New York	0.86	0.429	0.389	0.0081	0.0089
Pennsylvania	1.26	0.632	0.574	0.0107	0.0203
East-North Central	1.63	0.815	0.740	0.0123	0.0257
Illinois	1.16	0.582	0.528	0.0082	0.0180
Indiana	2.08	1.038	0.942	0.0143	0.0323
Michigan	1.58	0.790	0.717	0.0146	0.0250
Ohio	1.80	0.900	0.817	0.0130	0.0288
Wisconsin	1.64	0.821	0.745	0.0138	0.0260

Standard Inputs for Lifecycle Analysis

Incentives and Taxes

Tax Credits: Fixed, %, per sq ft.

Depreciation: MACRS vs Straight Line

Salvage: include?

RHI: renewable heat incentive

Standard Inputs for Lifecycle Analysis

The Discount Rate

The discount rate is a rate/% that enables us to convert future costs and savings into today's dollar terms. Selecting a discount rate is a non-trivial exercise.

One approach is to use the average inflation rate in the USA over the past century: 3.35%

Another more technical approach is to use the Weighted Average Cost of Capital (WACC) for a particular company or institution (Harvard University at present time uses 5.5%).

The higher the discount rate, the less you value (the more you discount) future costs and savings.

The Geothermal System Analyzer Module

Optimize Loads → 1) Import Loads

↓

2) Select Heat Pump (s)

↓

3) **Design Heat Exchanger** ↔ Piping Optimization

↓↑

4) **Finance/CO2 Analysis**

Thank You!

Q & A

Thank you for using GLD Software and for learning how to use it correctly!
Please try to use some of what you have learned prior to the next session

- For more information about GLD Software, visit our website at:

www.groundloopdesign.com

- Additional training is available for advanced GSHP systems. Visit the Geothermal Training Institute website at:

Geothermal Training Institute www.geotrainers.com

Section – Surface Water GHX Design

- GLD Overview
- System Design Inputs and their Impact
- Average Block vs. Zone Manager Loads Module
- Bringing Loads into GLD
- Adding/Editing Heat Pumps
- Selecting Heat Pumps
- Linking Modules Together
- Vertical GHX Loopfield Design
- Horizontal GHX Loopfield Design
- The GSA Module and Lifecycle Costing
- **Surface Water GHX Design**

GHX Loopfield Design Methodology

Optimize Loads → 1) Import Loads

↓

2) Select Heat Pump (s)

↓

3) Design Heat Exchanger ↔ Piping Optimization

↓

4) GSA/CO2 Analysis

Pond GHX Loopfield Design

Assume:

- Loads calculated (no annual loads necessary)
- Heat pump manufacturer/family known
- Body of water can handle heating/cooling loads

Pond GHX Loopfield Design

Sample Design 1

- Single Heat Transfer Model

Note: it is **critical** turbulent flow be maintained in the heat exchangers. Design process revolves around this requirement.

Pond GHX Loopfield Design

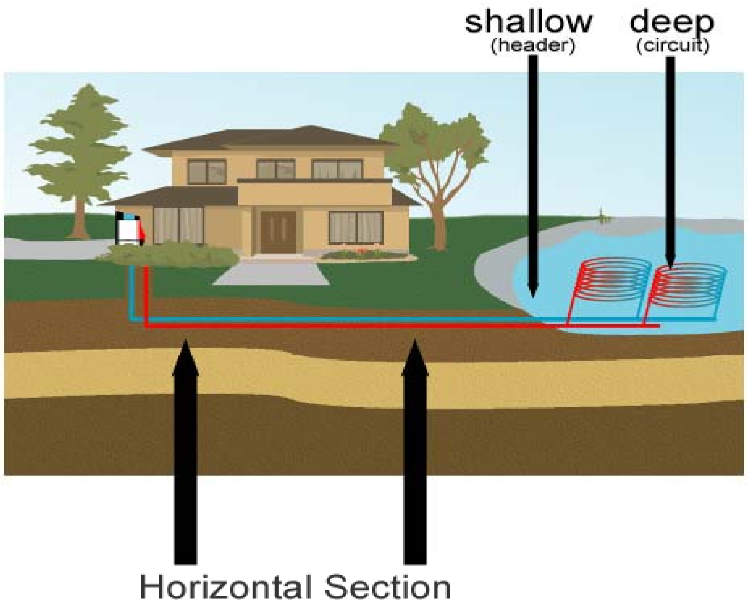
- Pond depth- want 10 ft measured at lowest seasonal level
- Rule of thumb- 20 tons/acre max for cooling
- Rule of thumb – 10 tons/acre max for heating
- Better- do a detailed lake analysis including weather, geology, rainfall, temperatures, relative humidity, wind speed, cloud cover at day and night, water clarity, solar radiation, surface inflows and outflows, groundwater inflows and outflows, thermal conductivity of lake bed, etc.

Pond GHX Loopfield Design

- Pond Temps: Get info from geological surveys of lake and streams if you can't collect data yourself
- Winter: coldest water/ice near surface. Water at bottom is 39F, the temperature of maximum H20 density
- In warm climates where lakes don't freeze, winter temps are usually in the 40-50F range unless they are spring fed
- In summer, shallow water approaches the average air temp
- In summer, stratified deeper lakes tend to have cold water (40-60F) through the summer (sunlight doesn't go deep/denser water doesn't go up)
- In stagnant lakes, you ideally want 20 ft spacing between coils

Pond GHX Loopfield Design

- Building Loads
- Capacity of body of water
- Pond Temperatures
- Soil Properties
- Pipe Size
- Pressure Drop Calculations
  - Turbulent flow essential
- Note: No Annual/Duration loads with ponds!



Pond Module Method

- Step 1: Enter Loads/Pond Temps
- Step 2: Choose pipe style and size for primary HX
- Step 3: Check the minimum allowable flow rate for turbulent flow and enter it
- Step 4: Choose a layout
- Step 5: Enter head loss for pipe and header
- Step 6: Calculate
- Step 7: Modify the parallel loops to balance turbulent flow and reduce pump power.