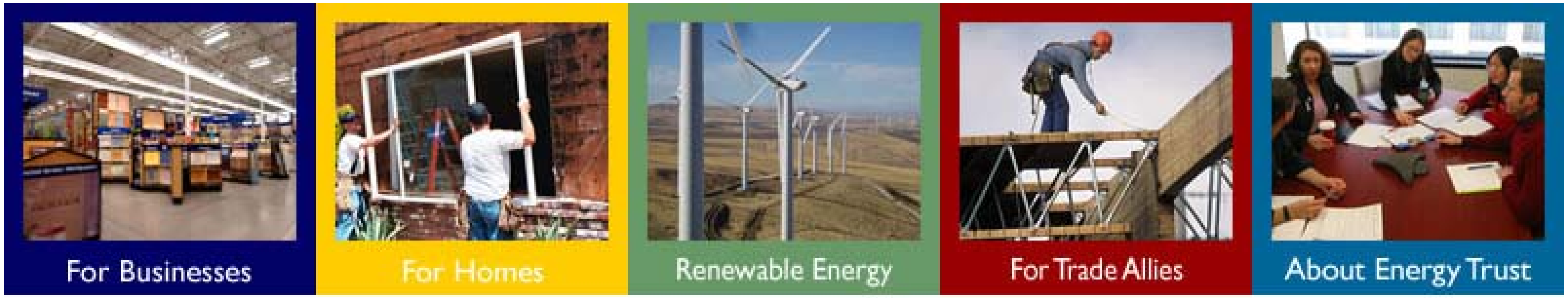


Energy Trust of Oregon, Inc.
BSUG – April 16, 2008

EnergyTrust
of Oregon, Inc.

Building Simulation Users' Group

Reminder

- Collegial Organization - Volunteer
- Attend, Recruit, Participate

Building Simulation Users' Group

Sponsors

- The Energy Trust - Funding
- NW Natural – Space & AV
- ODOE – Technical Input
- BPA – Outreach
- NEEA - Outreach
- ASHRAE - PDHs for P.E.s

EnergyTrust of Oregon, Inc.

Building Simulation Users' Group

eQuest Intermediate Training

Present Configuration

- **Four sessions – April 2, 9, 16 & 23**
- **5:30 – 9:00 p.m.**
- **Hosted by the Energy Trust**
- **First session appeared to go very well**
- **Will have some holes in curriculum**

EnergyTrust of Oregon, Inc.

Networking

- The meeting room will be open at least by 11:30 a.m. for casual networking
- Members will also be allowed to help setup tables, etc.

Today's Discussion

Modeling of Ground Source Heat Pumps in eQuest

Xiaobing Liu, PhD.
ClimateMaster, Inc.

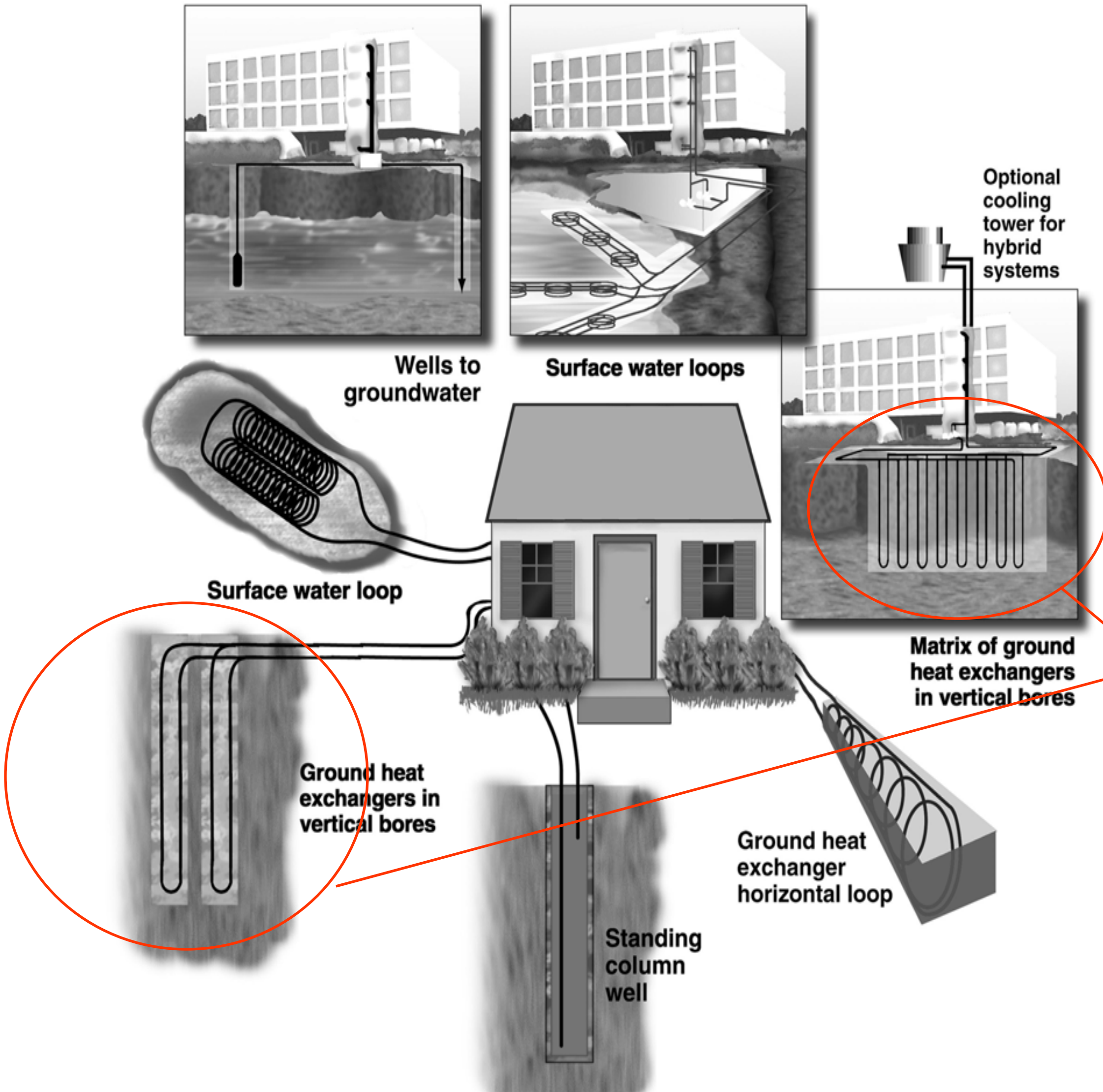
Geothermal Heat Pump System Simulation with Enhanced eQUEST

Xiaobing Liu, Ph. D.
ClimateMaster
xliu@climatemaster.com

Agenda

- Introduction of geothermal heat pump (GHP) systems
- Overview of enhanced GHP simulation algorithms/capabilities of eQUEST
- Simulation-based design and energy analysis of GHP systems using eQUEST
- Current limitations and future enhancements
- Q & A

Geothermal Heat Pump Systems



GHP systems with various ground heat exchangers

Vertical close loop ground loop heat exchangers are most commonly used in the US

(http://www.eren.doe.gov/femp)

Geothermal Heat Pump Systems

“the most energy-efficient, environmentally clean, and cost-effective space-conditioning system”

“produce the lowest carbon dioxide emissions, including all source effects, of all available space-conditioning technologies”

(EPA, 1993)

Equivalent to

Geothermal Heat Pump Systems

- Hurdles in initial cost
- Hurdles in design
  - Cumulative heating and cooling loads required for sizing ground heat exchanger (GHX) is much more complicated to calculate than the peak loads
  - Performance of various type of GHX is affected by many factors and their design heavily relies on computerized calculation
  - Lack of GHX design required geology information
  - Unfamiliar with GHX related construction technologies
- Hurdles in the construction field

GSHP Simulation Algorithms/Capabilities

- Advanced model for vertical close loop ground loop heat exchangers (VGLHE)
- Dedicated wizard interface for specifying VGLHE with on-line help, database, and/or design tips for each input entry
- Access to water-to-air heat pump libraries
- Capability for simulating advanced water-to-air heat pump with staged capacity and airflow

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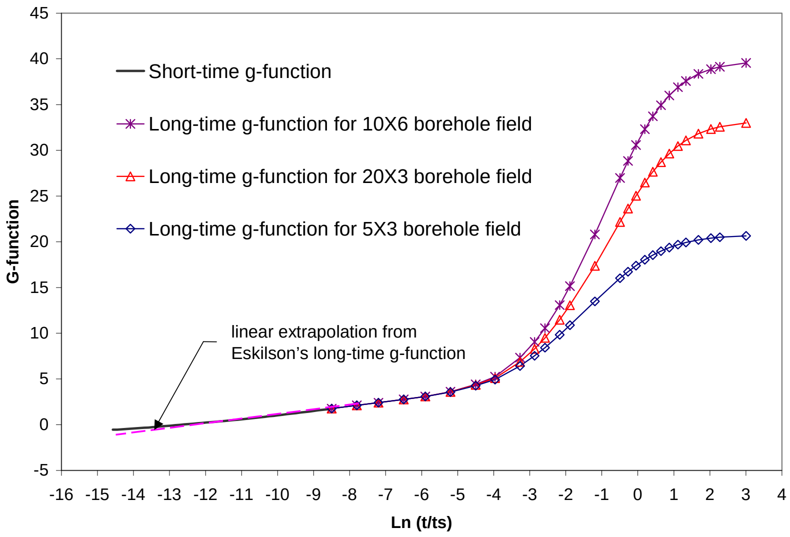
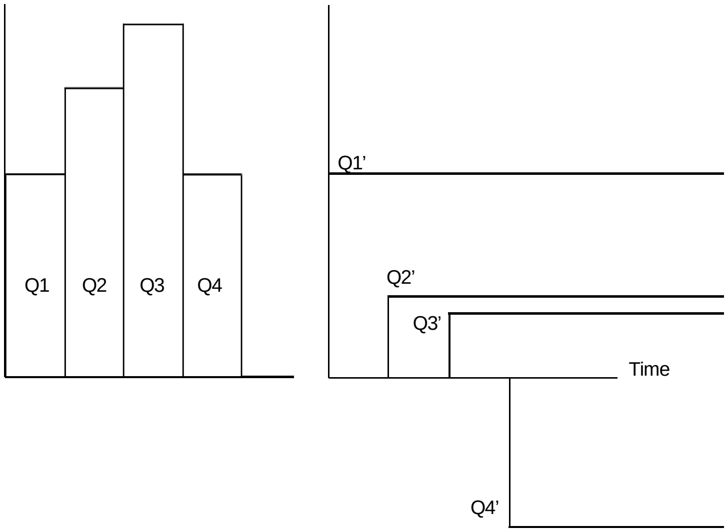
Modeling VGLHE

- Advanced model for VGLHE
  - ✓ Based on widely-accepted g-function algorithm developed by Eskilson et al at Sweden (1987)
  - ✓ Extended short-term g-functions for hourly simulation of VGLHE
  - ✓ Unlimited borehole field configurations *
  - ✓ Sophisticated borehole thermal resistance calculation that accounts for the effects of borehole geometry, grouting material, and anti-freeze solution (Hellstrom 1991)

Example of g-functions

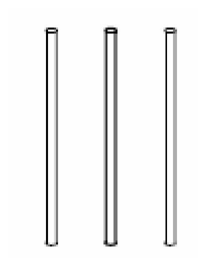




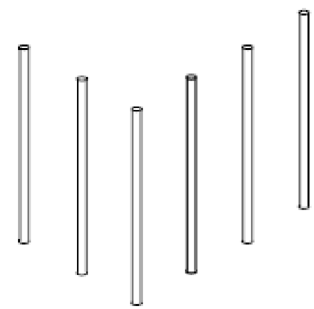
Example of normalized borehole wall temperatures (g-functions) in response to given constant heat rejection flux

Superposition of piece-wise linear step heat inputs in time. The step heat inputs Q2', Q3' and Q4' are super-imposed in time on to the basic heat pulse Q1'.

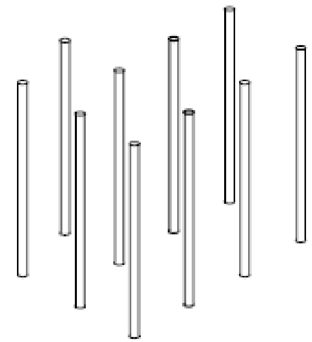
Example of Borehole Field Configurations



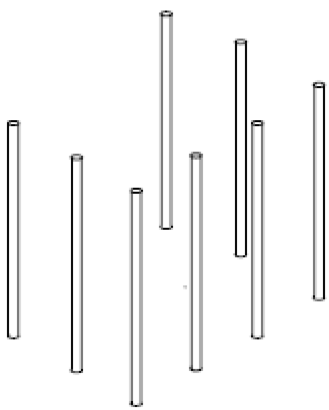
Straight line



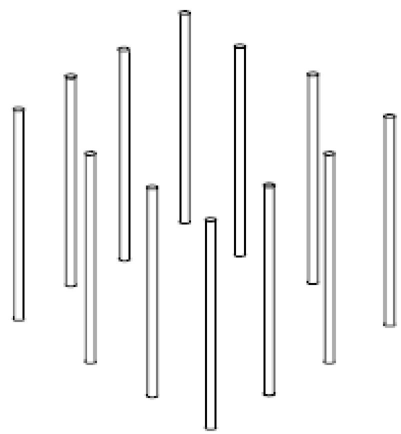
One L- shaped line



Two parallel L- shaped lines



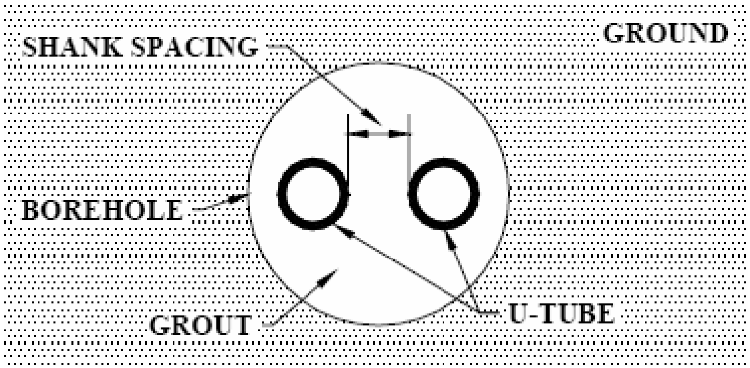
U-shaped lines



Open rectangle

Rectangle

Borehole Thermal Resistance



- Convective heat transfer resistance of the fluid in the U-tube
- Tube wall thermal resistance
- Conductive thermal resistance of grout

GSHP Simulation Algorithms/Capabilities

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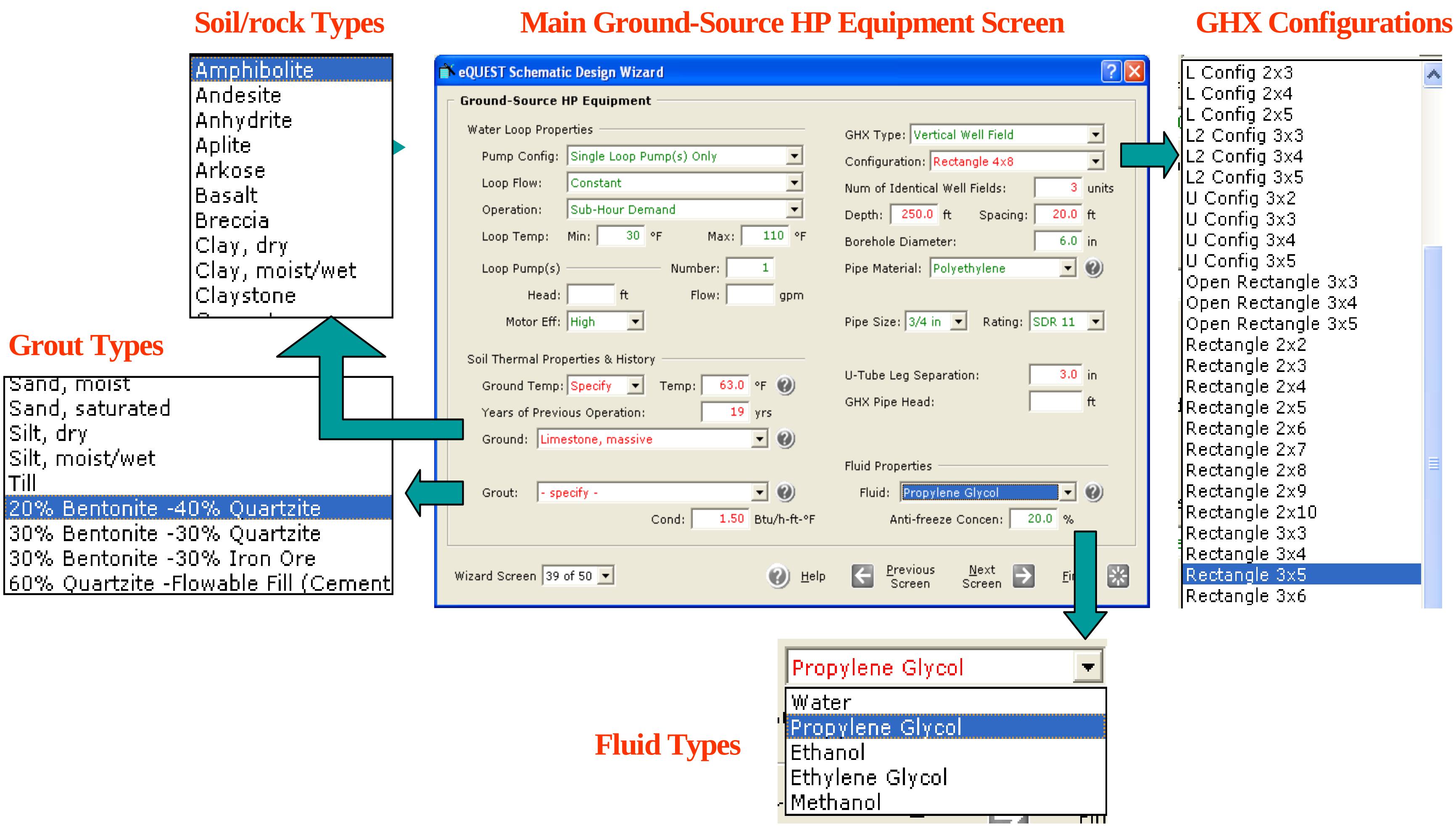
Dedicated Wizard Interface

- Dedicated wizard interface for specifying VGLHE with on-line help, database, and/or design tips for each input entry
  - ✓ Water loop properties
  - ✓ Soil thermal properties & History
  - ✓ Ground heat exchanger properties
  - ✓ Fluid properties

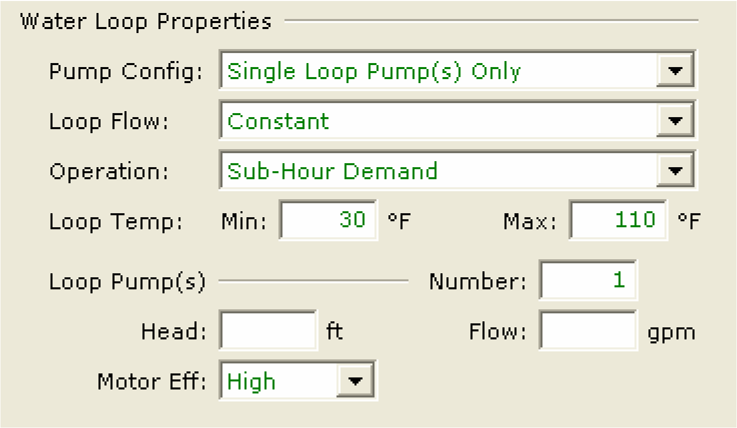
Dedicated Wizard Interface

Dedicated wizard interface for specifying VGLHE



Dedicated Wizard Interface

Water Loop Properties



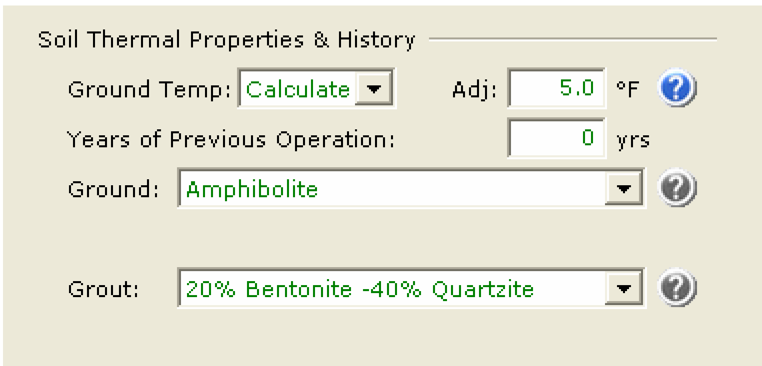
- Pump configuration
  - ✓ Single Loop Pump(s) only
- Loop flow
  - ✓ Constant
  - ✓ Variable
- Operation
  - ✓ Standby
  - ✓ Demand
  - ✓ Sub-hour Demand
- Loop temperature range
- Loop Pump(s)

Tips:

1. To properly simulate variable flow, isolation valve option of heat pump should be "Yes".
2. Loop temperature range will affect both the sizes of GHX and heat pump(s).

Dedicated Wizard Interface

Soil Thermal Properties & History



Tips:

1. For projects with large borehole field, in-situ test of ground thermal properties is highly recommended.
2. Specify "Years of previous operation" to assess the effect of heat/cool built-up on the performance of GHX.

- Ground temperature
  - ✓ Calculated via weather data
  - ✓ User specified
- Years of previous operation
- Ground thermal properties
  - ✓ Picked from built-in database
  - ✓ User specified
- Grout thermal properties
  - ✓ Picked from built-in database
  - ✓ User specified

Dedicated Wizard Interface

Soil Thermal Properties & History

Ground Temp: Calculate Adj: 5.0 °F

Years of Previous Operation: 0 yrs

Ground: Amphibolite

Grout: 20% Bentonite -40% Quartzite

eq_wiz

GSHP Ground Temperature - Undisturbed Ground Temperature

Mean Undisturbed Ground Temperature.

The **Mean Undisturbed (far-field) Ground Temperature** ($\bar{T}_{ground}$) input is available only if the user has chooses "Specify" for the Ground Temperature Specification Type and is used for simulating vertical wells. It is the mean undisturbed ground temperature along the depth of a ground loop heat exchanger. By default, it is estimated as shown in the following using the mean annual air temperature ($\bar{T}_{air}$), geothermal heat flux (Q_{ground}), ground thermal conductivity (K_{ground}) and the depth of the ground loop heat exchanger (L_{GLHX}).

$$\bar{T}_{ground} = \bar{T}_{air} + \frac{Q_{ground} \cdot L_{GLHX}}{2 \cdot K_{ground}}$$

Back Forward Print Options

Ground Thermal Properties Table

Description	Thermal_Conductivity (Recommended) Btu/hr-ft-F	Thermal_Conductivity (Minimum) Btu/hr-ft-F	Thermal_Conductivity (Maximum) Btu/hr-ft-F	Diffusivity (Recommended) Ft^2/day	Diffusivity (Minimum) Ft^2/day	Diffusivity (Maximum) Ft^2/day
Amphibolite	1.7	1.1	2.7	1.0		
Andesite	1.3	0.8	2.8	0.9	1.1	1.7
Anhydrite	2.4	0.9	4.5	1.9		
Aplite	1.8	1.5	2.3	1.2		
Arkose	1.7	1.5	2.2	1.3		
Basalt	1.0	0.8	1.4	0.7	0.5	0.9
Breccia	1.8	1.3	2.4	1.2		
Clay, dry	0.2	0.2	0.5	0.2	0.2	0.5
Clay, moist - wet	0.9	0.5	1.3	0.8	0.5	0.8
Claystone	1.3	0.8	1.7	0.9	0.5	1.2
Coal	0.2	0.2	0.4	0.2		
Concrete	0.9	0.5	1.2	0.8		
Conglomerate	1.8	0.8	2.1	1.2		
Diorite	1.5	1.1	1.9	0.8	0.7	1.0
Dolomite	1.9	0.9	3.8	1.2	0.8	2.3
Dunite	2.4	2.3	2.7	1.3		
Eclogite	1.7	1.3	2.4	0.9		
Gabbro	1.1	0.9	1.8	0.7	0.7	1.2
Gneiss	1.7	1.0	3.3	1.3	0.9	2.3
Granite	2.0	1.1	3.0	1.3	0.9	1.8

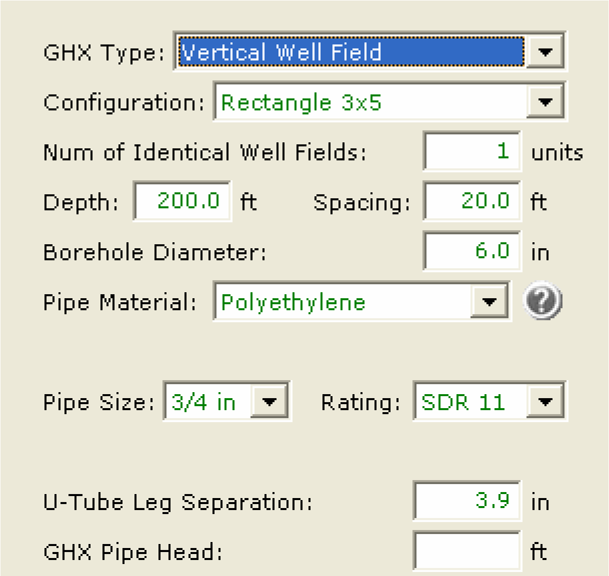
Back Forward Print Options

Grout Thermal Properties Table

Description	Thermal Conductivity Btu/hr-ft-F
Grouts without Additives	
Bentonite 10%, frozen	0.8
Bentonite 10%, in water	0.4
Bentonite 20%, in water	0.3
Bentonite 40%, frozen	0.5
Bentonite 40%, in water	0.3
Bentonite, dry	0.1
Clay, dry	0.2
Clay, moist - wet	0.9
Concrete	0.9
Gravel, dry	0.2
Gravel, saturated	1.0
Sand, dry	0.2
Sand, dry, compacted	0.7

Dedicated Wizard Interface

Ground heat exchanger (GHX) properties



- GHX Type
  - ✓ Vertical well field
- Configuration
  - ✓ 42 built-in borehole config
  - ✓ Maximum 32 boreholes
- Num of identical well fields
- Borehole depth
- Borehole spacing
- Borehole Diameter
- Pipe material, size, pressure rating
- U-tube leg separation
- GHX Pipe head

Tips:

1. For access to other borehole field configurations, contact ClimateMaster.
2. Default GHX pipe head is 30 ft. Change when necessary.

Dedicated Wizard Interface

Fluid Properties

Tips:

1. Select weight concentration of anti-freeze compound based on: design min. loop temperature less max. temperature difference between supply and return.

Freezing point [F]

Anti-freeze Compound	Anti-freeze concentration (% of weight)				
	0	10	20	30	40
Ethylene Glycol	32	26.2	17.9	6.7	-8.1
Propylene Glycol	32	26.1	19.2	9.2	-6
Methanol	32	20	0	-15	-40
Ethanol	32	25	12	-4	-21

- Fluid type
  - ✓ Water
  - ✓ Anti-freeze solution
    - Propylene Glycol
    - Ethylene Glycol
    - Methanol
    - Ethanol
- Anti-freeze weight concentration

  (if aqueous anti-freeze solution is selected)

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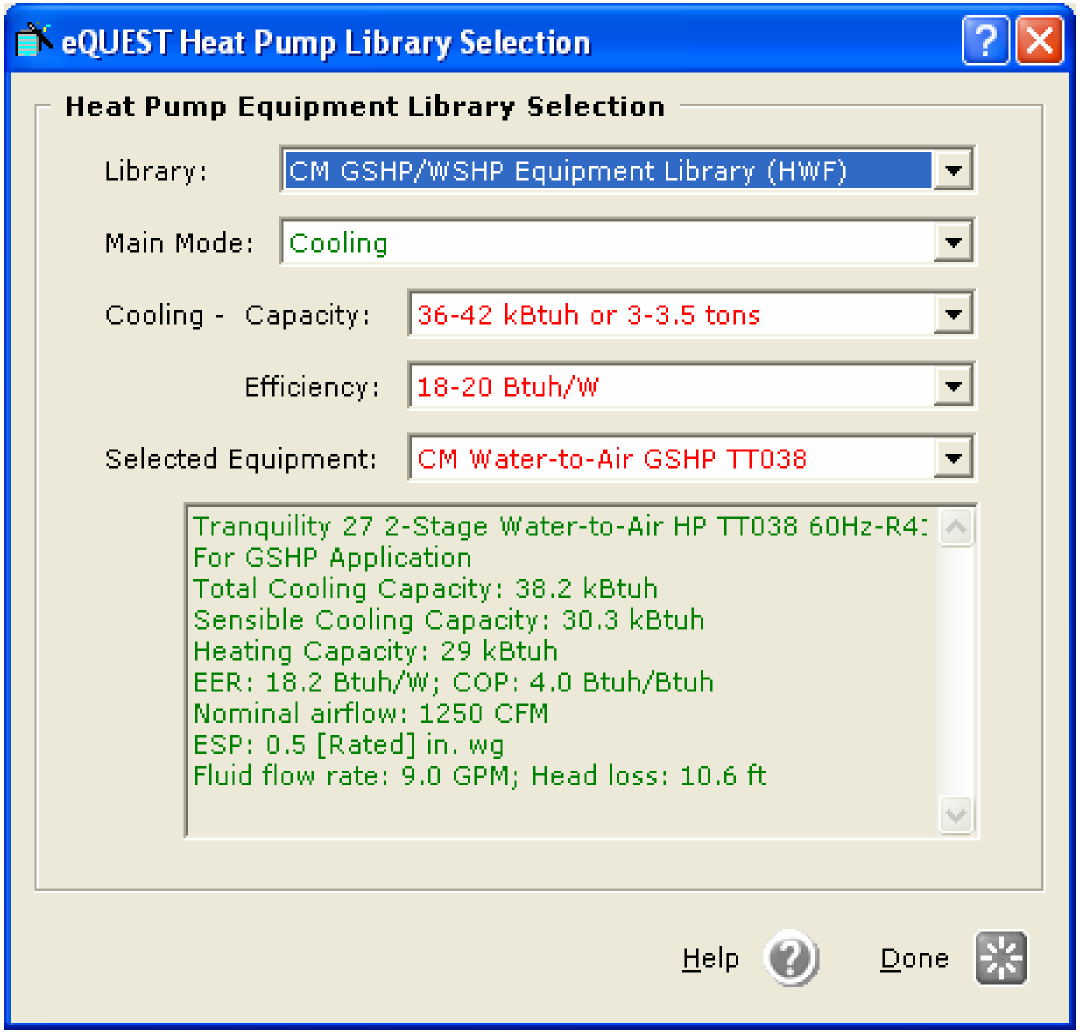
Water-to-Air Heat Pump Library

The access to heat pump library is only available after proper installation of the add-on feature from ClimateMaster

Water-to-Air Heat Pump Library

- Four-steps heat pump selection procedure
- Information include heating and cooling capacities, EER, COP, airflow, water flow, pressure drop, ESP, and etc at ARI/ASHRAE/ISO rating conditions
- Performance curves at off-rating conditions



Water-to-Air Heat Pump Library

Performance curves required by DOE-2.2 for W-A heat pump simulation

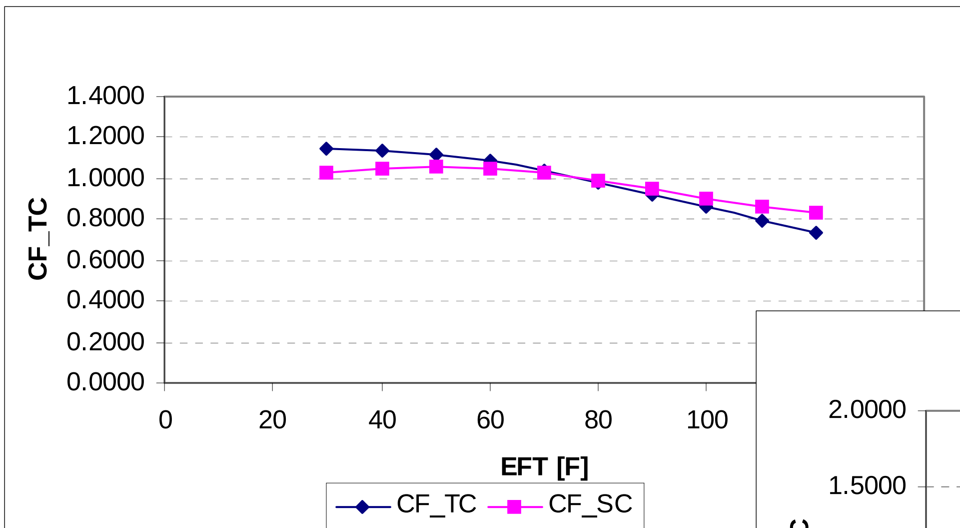
Curve Name	Description	Note
TC = f(EWB, EFT)	Correction factor for Total Cooling (TC) capacity as a function of the Entering Wet Bulb temperature (EWB) and the Entering Fluid Temperature (EFT).	For cooling
SC = f(EWB, EFT)	Correction factor for Sensible Cooling (SC) capacity as a function of the Entering Wet Bulb temperature (EWB) and the Entering Fluid Temperature (EFT).	For cooling
EIR_C = f(EWB, EFT)	Correction factor for Electric Input Ratio (EIR) as a function of the Entering Wet Bulb temperature (EWB) and the Entering Fluid Temperature (EFT).	For cooling
BPF = f(EWB, EFT)	Correction factor for Bypass Factor (BPF) as a function of the Entering Wet Bulb temperature (EWB) and the Entering Fluid Temperature (EFT).	For cooling
HC = f(EDB, EFT)	Correction factor for Heating Capacity (HC) as a function of the Entering Dry Bulb temperature (EDB) and the Entering Fluid Temperature (EFT).	For heating
EIR_H = f(EDB, EFT)	Correction factor for Electric Input Ratio (EIR) as a function of the Entering Dry Bulb temperature (EDB) and the Entering Fluid Temperature (EFT).	For heating
EIR_C = f(PLR)	Correction factor for Electric Input Ratio (EIR) as a function of Part Load Ratio (PLR).	For cooling
EIR_H = f(PLR)	Correction factor for Electric Input Ratio (EIR) as a function of Part Load Ratio (PLR).	For heating

Non-PLR

PLR

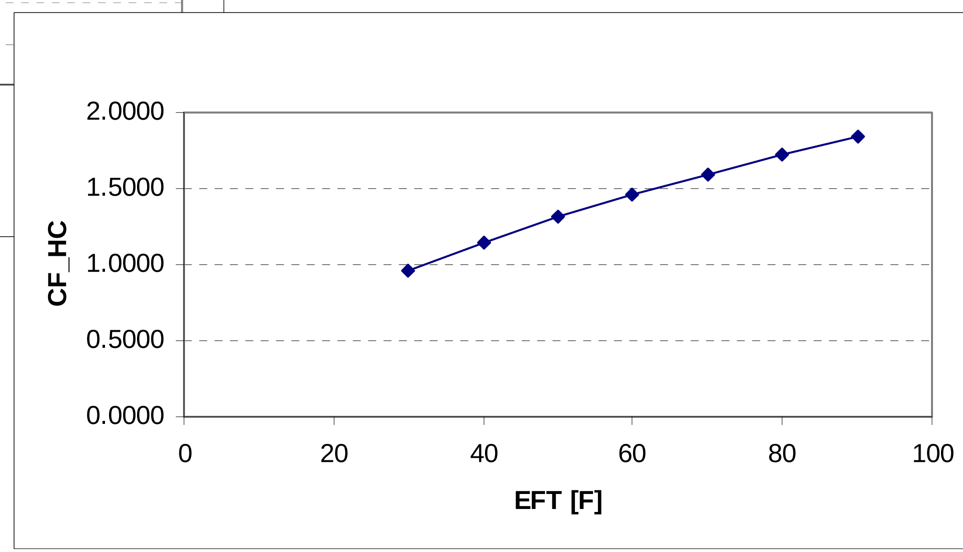
Water-to-Air Heat Pump Library

Example of performance curves



Non-dimensional total and sensible cooling capacity as a function of entering fluid temperature

Non-dimensional heating capacity as a function of entering fluid temperature



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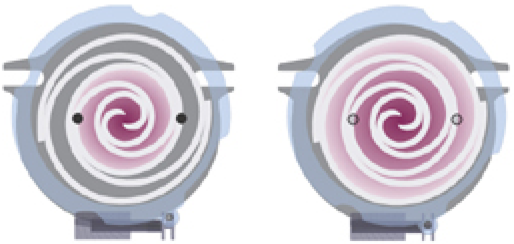
Staged Capacity and Airflow

Two-stage scroll compressor



67% Capacity

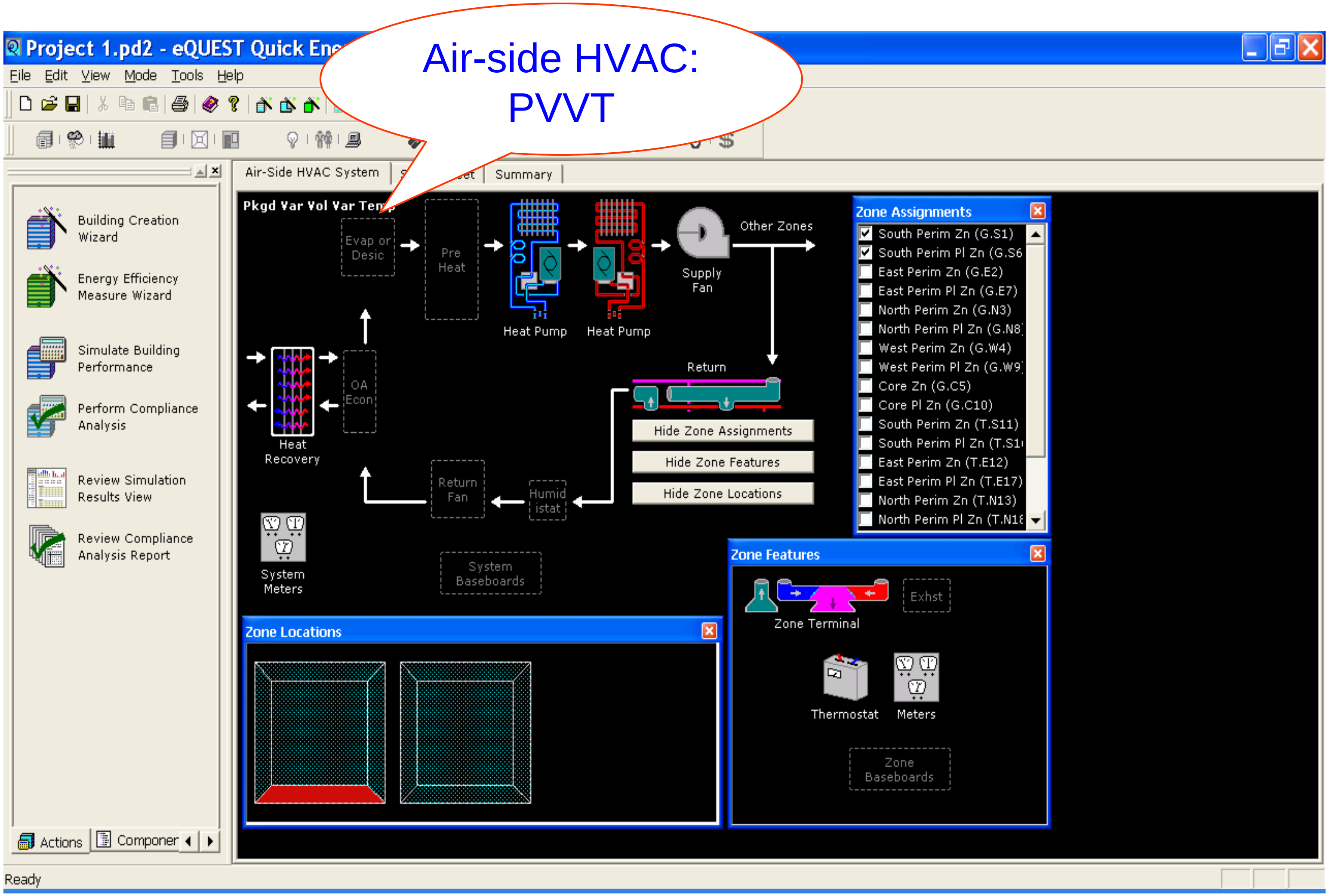
100% Capacity

ECM variable speed fan motor

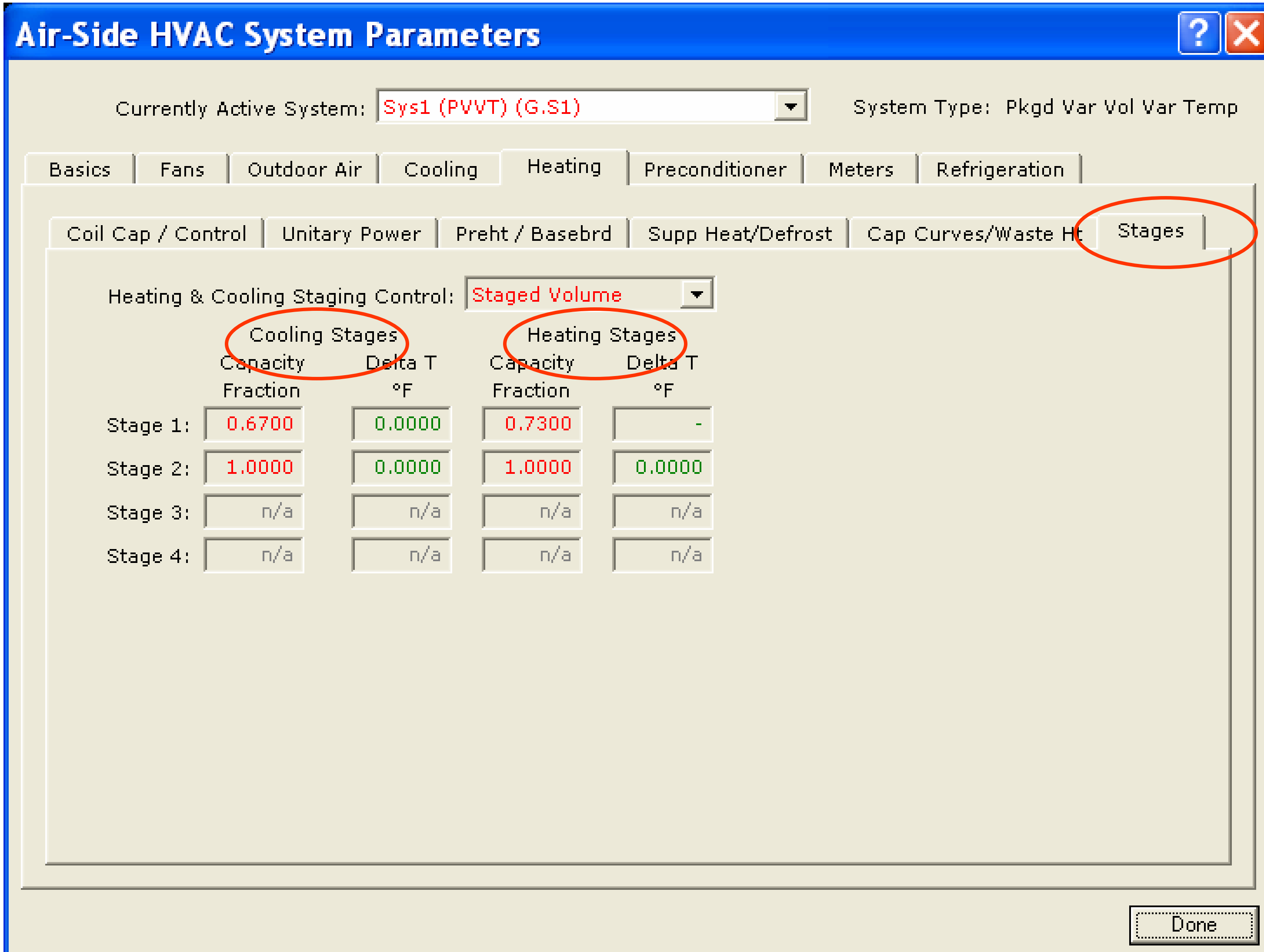
Advantage of heat pump with staged capacity and airflow

- High efficiency cooling and heating at part load conditions
  - ✓ Oversized heat exchangers
  - ✓ Reduced airflow
- Improved humidity control due to longer run time
- More precise temperature control

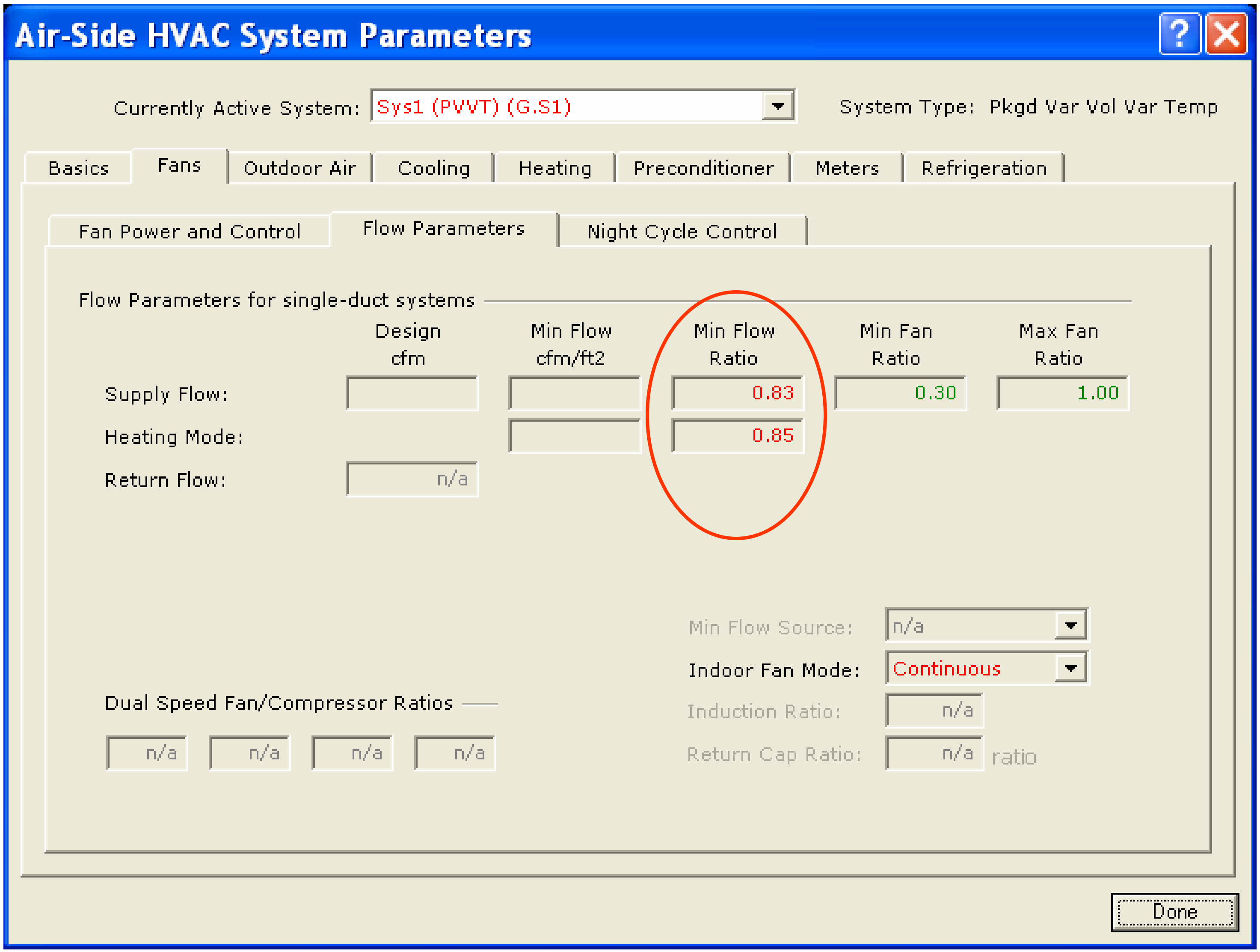
Staged Capacity and Airflow



Staged Capacity and Airflow

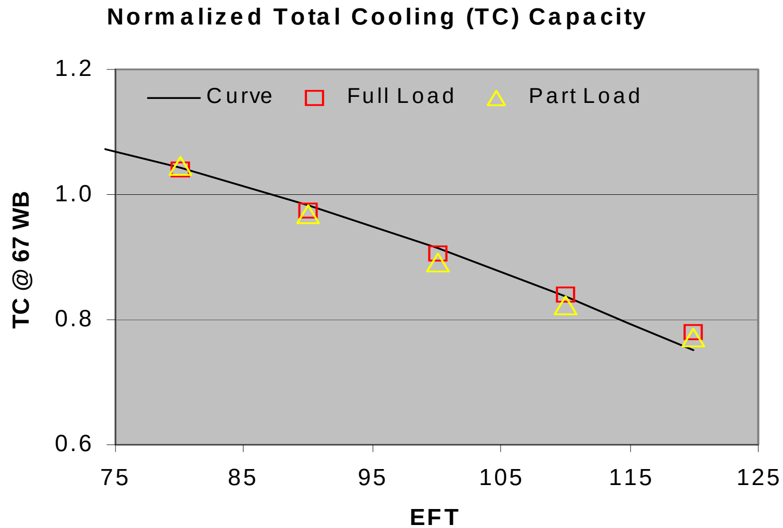


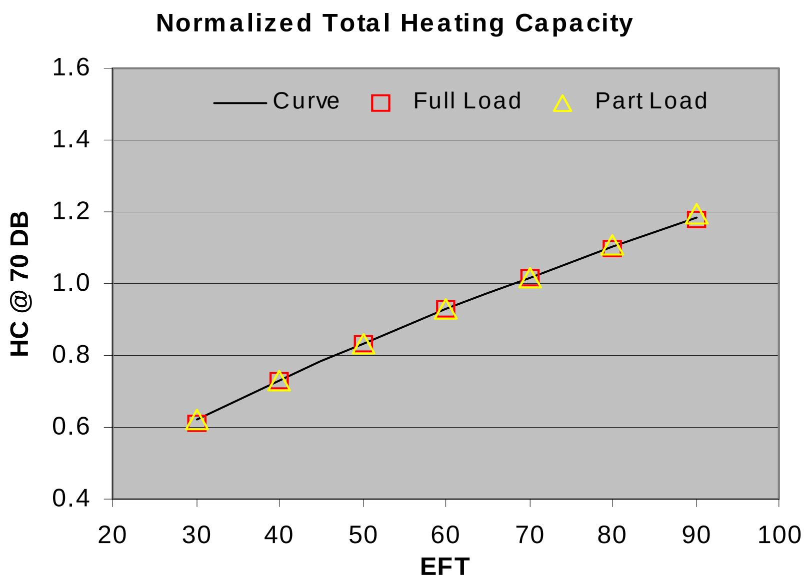
Staged Capacity and Airflow



Example of Two-stage Performance Curves

TC and HC as a function of EFT

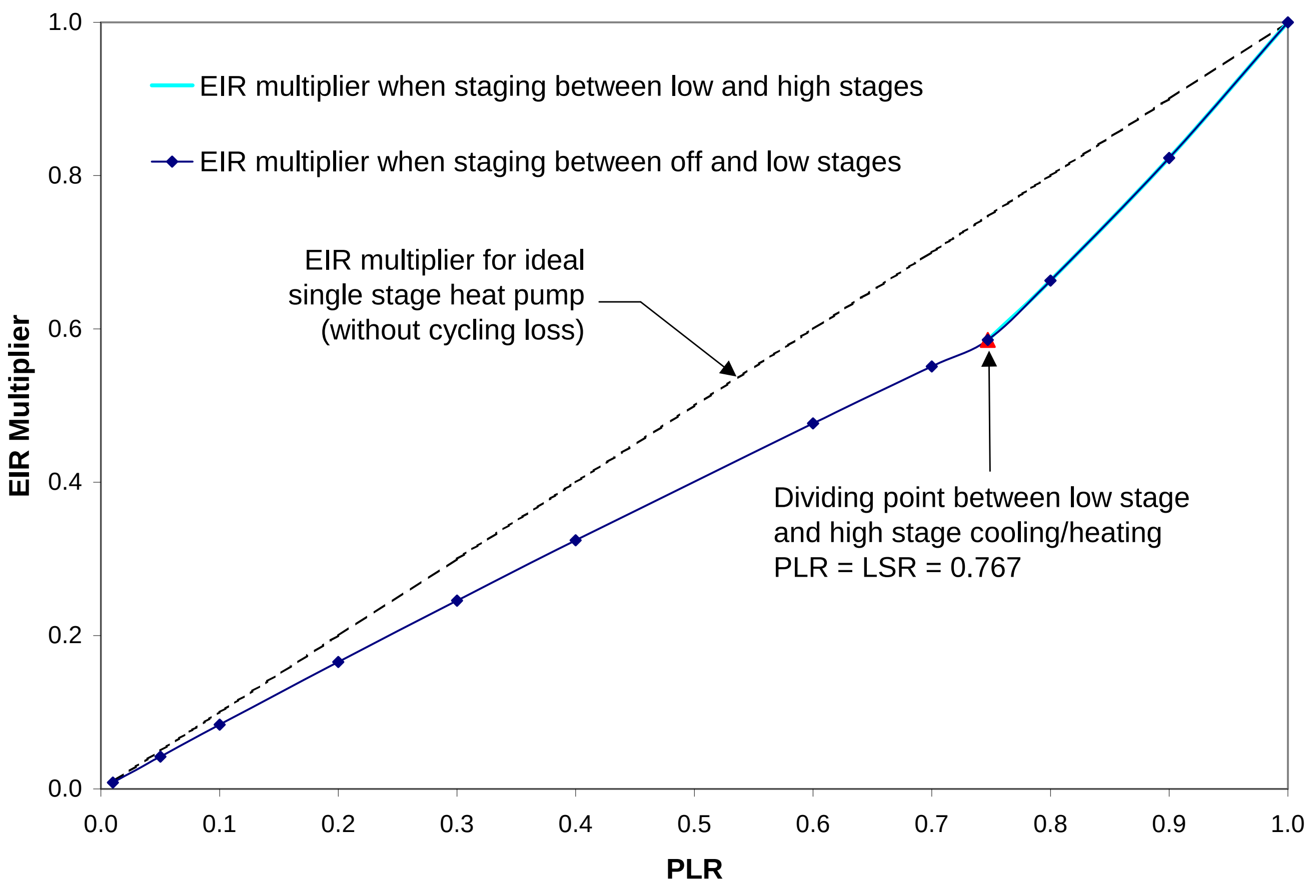




Due to the similarity, the average of the non-PLR curves at two stages is used to represent the characteristics of the heat pump and DOE-2 does not distinguish whether the compressor runs at low or high stage.

Example of Two-stage Performance Curves

EIR as a function of PLR



Verification and Validation

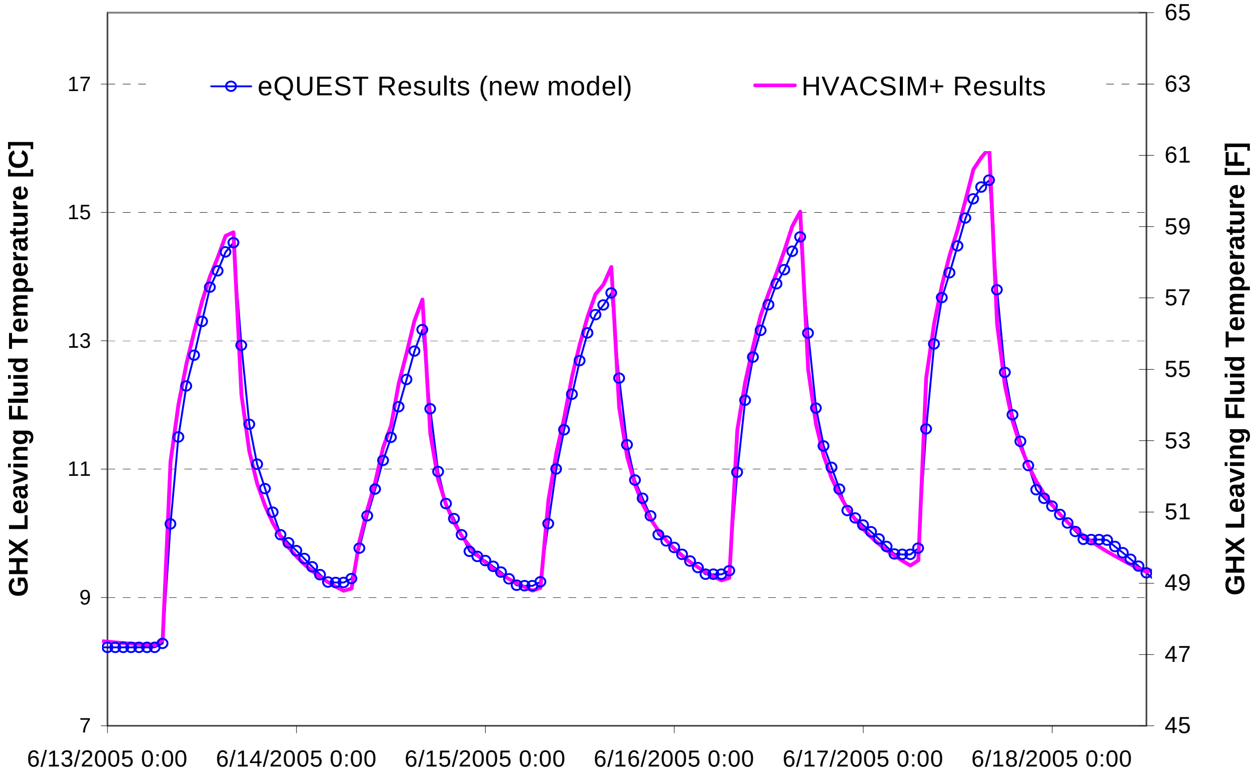
- Verification of newly implemented g-function based VGLHE model
- Sensitivity study through parametric runs
- Validate predicted whole building and GHP system energy consumption with monitored meter level data
- Validate predicted whole building and GHP system performance (including energy consumption, loop/room temperature, and etc) with detailed component level data *

* *Ongoing process using monitored data from a fully instrumented Zero Energy Home.*

Verification and Validation

VGLHE Model Verification

Enhanced eQUEST *vs.* HVACSIM+ (experimentally validated model)

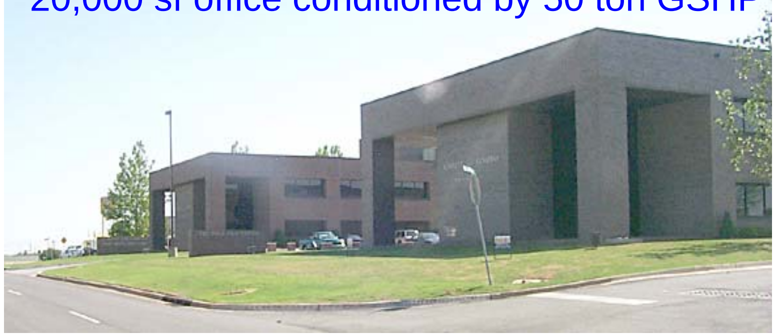


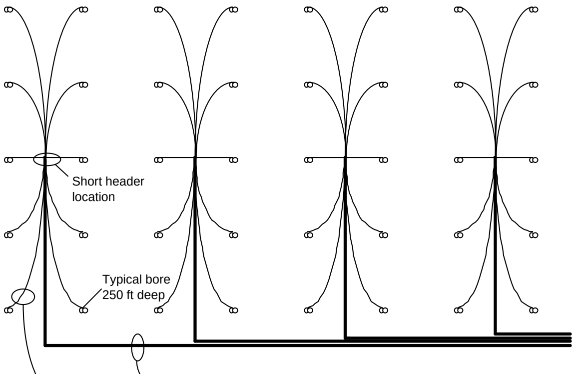
Verification and Validation

Validation with Meter Level Data (1)

Garrett Geothermal Buildings

20,000 sf office conditioned by 50 ton GSHP



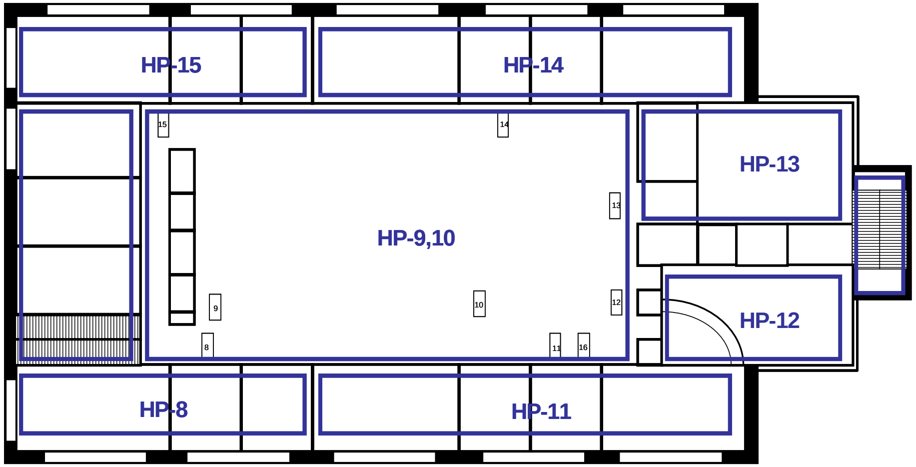


VGLHE

40 boreholes
5 by 8 grid
250’ deep
20’ spacing
4.5” bore diameter
¾” PE U-tube
Standard grout

Zoning

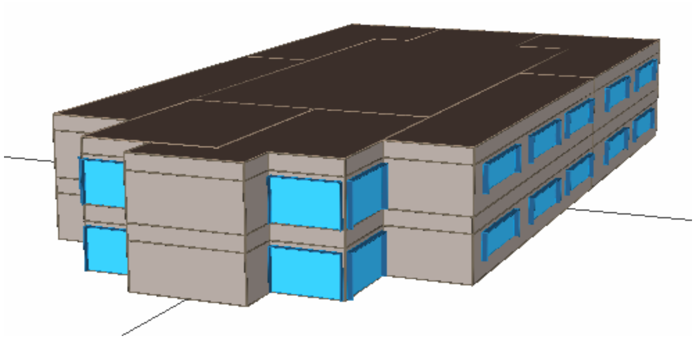
Two floors
7 perimeter zones each floor
1 core zone each floor
Each zone conditioned with individual water-air heat pump



Verification and Validation

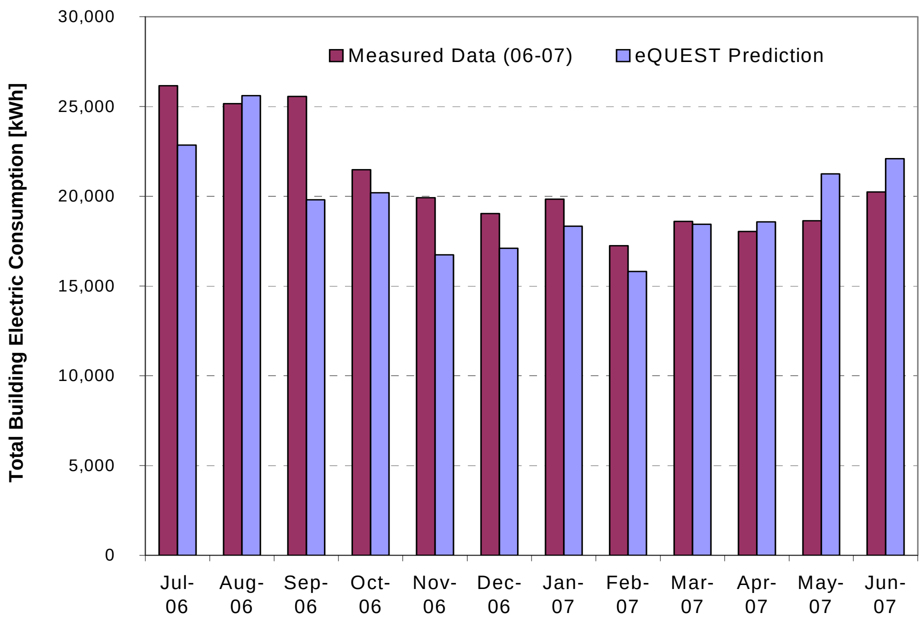
Validation with Meter Level Data (2)

Garrett Geothermal Building



Thermal Model 3-D view in eQUEST

Monthly Electric Use (kWh)



Annual Total Electric Use (kWh)

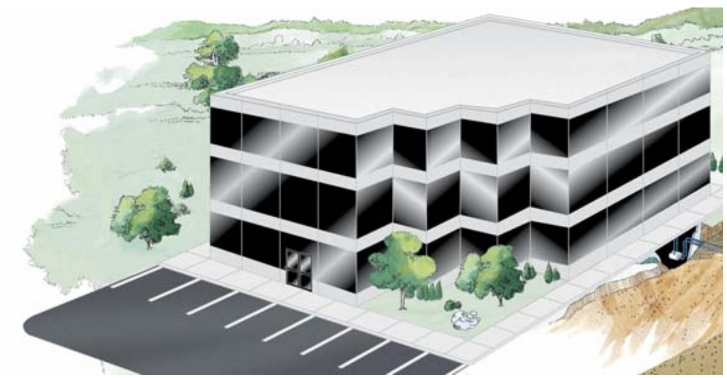
Metered	Predicted	Error
249,920	236,790	5%

Integrated Simulation-Based Design

- No hassles any more in transferring data among individual programs

Estimate building loads using various tools/software

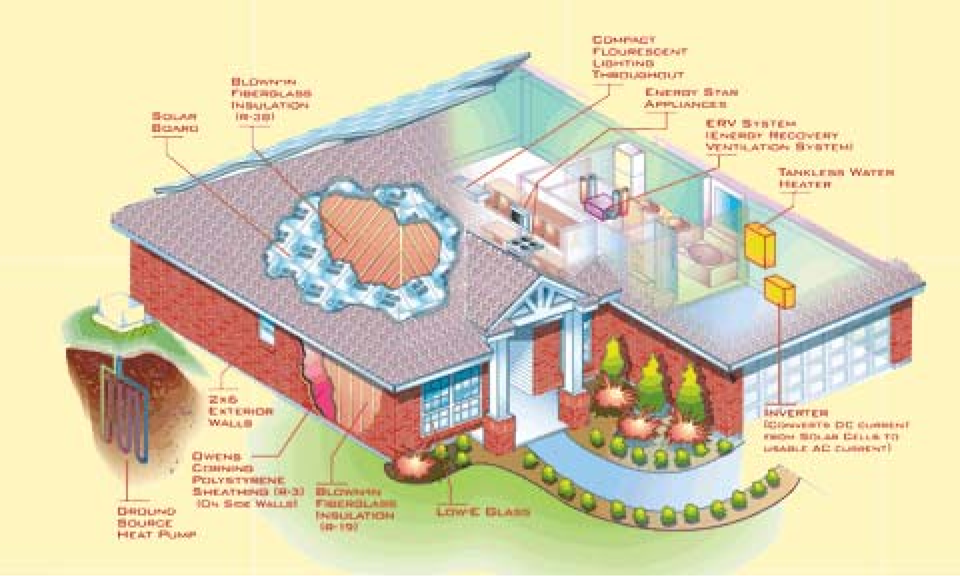
Size ground heat exchanger using OTHER tools/software



- Assess GHP system design by examining the system performance in virtual reality

Integrated Simulation-Based Design

- Document energy savings for LEED certification, energy efficiency incentives, and etc.
- Optimize design of high performance building toward the goal of Zero Energy



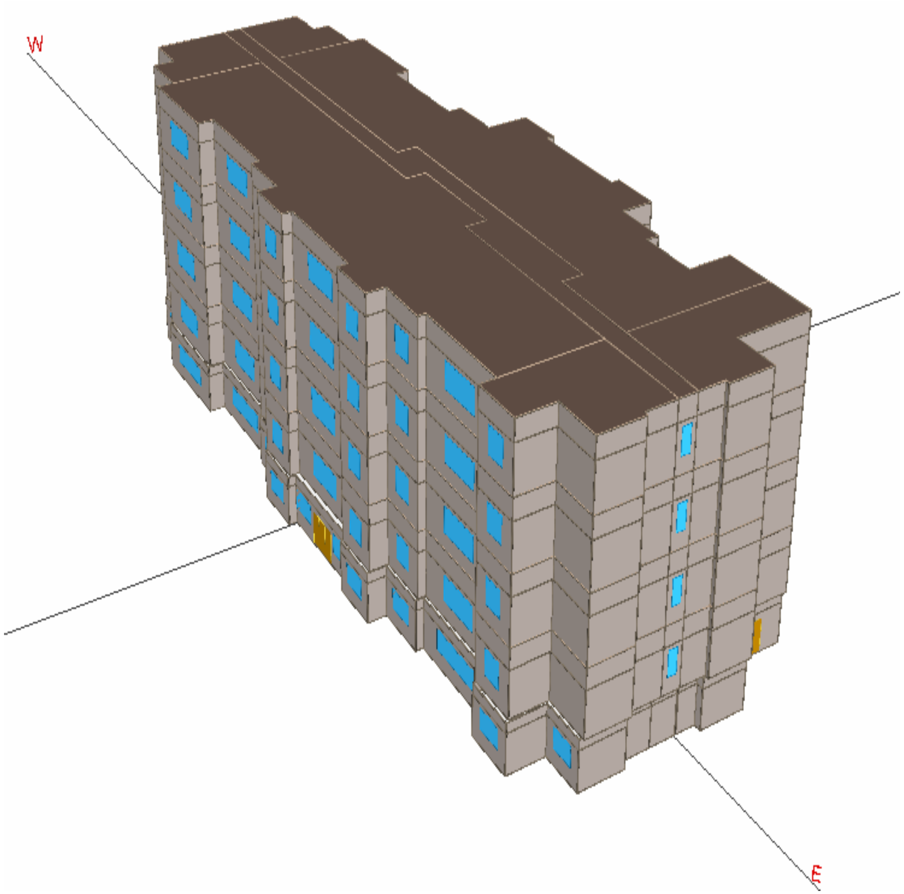
The above illustration is from http://www.ideal-homes.com/

Zero Energy Home

- GSHP
- ERV
- PV panel
- Better insulation
- Double low-e windows
- Compact Fluorescent Lights
- Energy efficient appliances

Applications

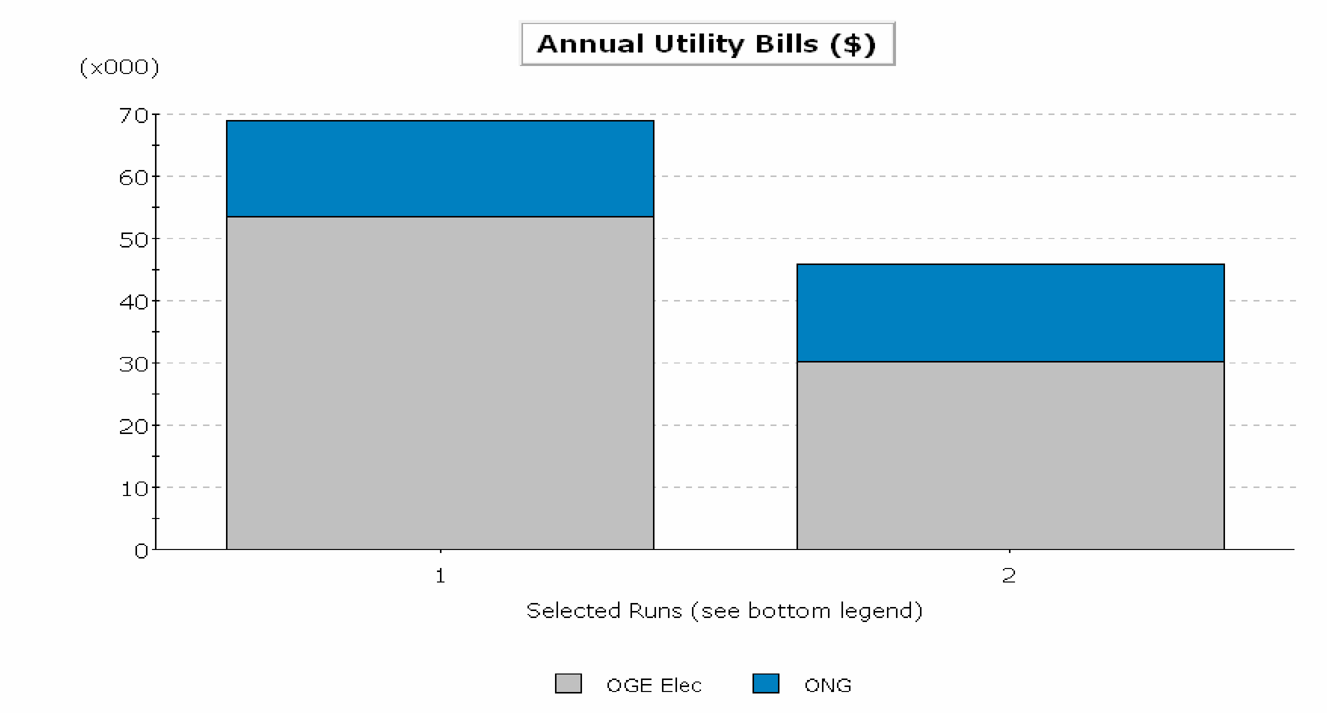
Example of HVAC Systems Comparison (1)



- Building Type: Hotel
- Area: 66,000 sf
- Candidate HVAC systems
  - ✓ PTAC with electric heater
  - ✓ GHP with VGLHE
- Equipment efficiency
  - ✓ PTAC: EER 8.8
  - ✓ GSHP: EER 18.5; COP 4.0
- Utility rates: OG&E PL-1 SL-5

Applications

Example of HVAC Systems Comparison (2)

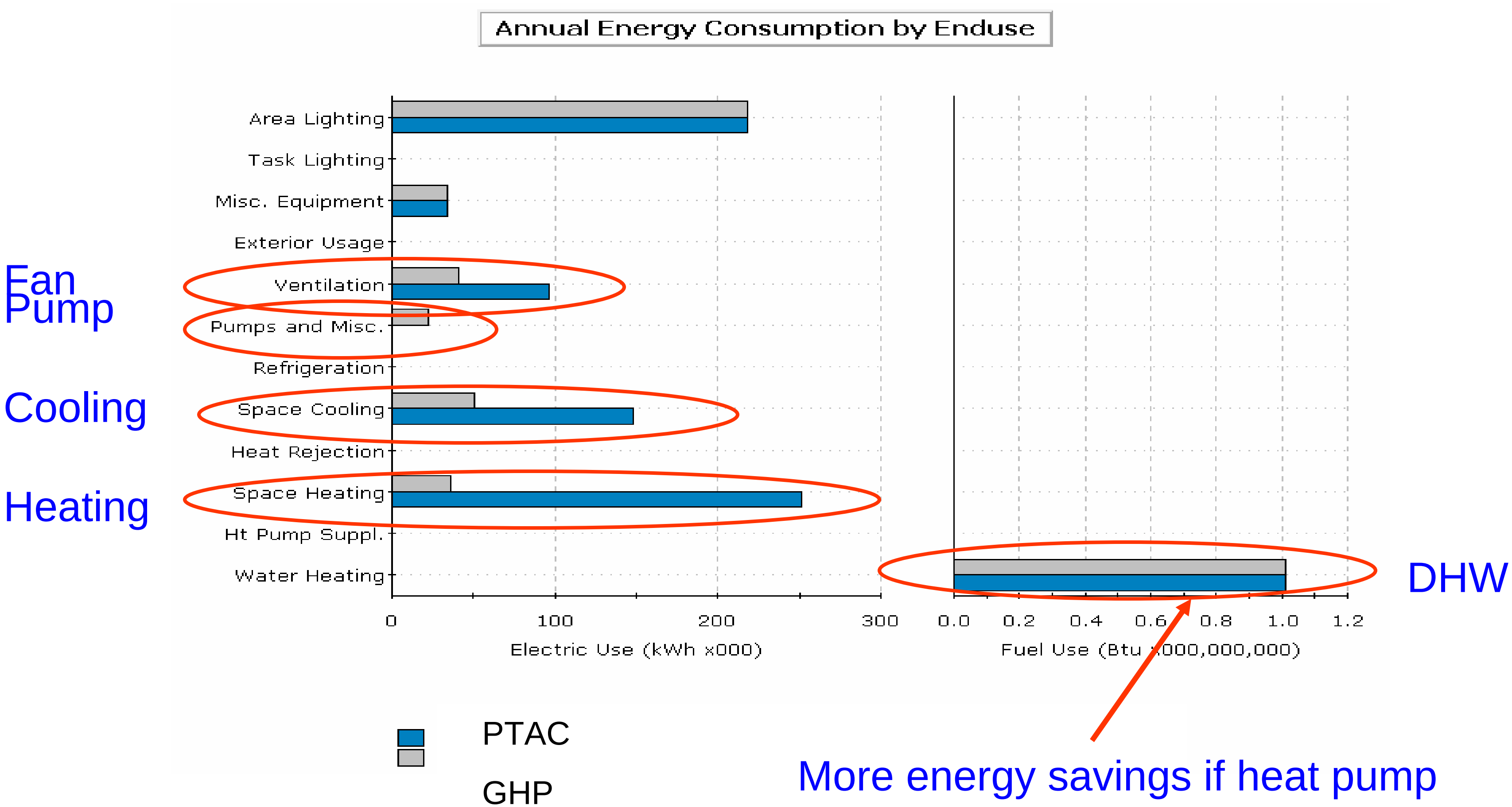


1: PTAC ($ 69,012)

2: GHP ($ 45,834)

Applications

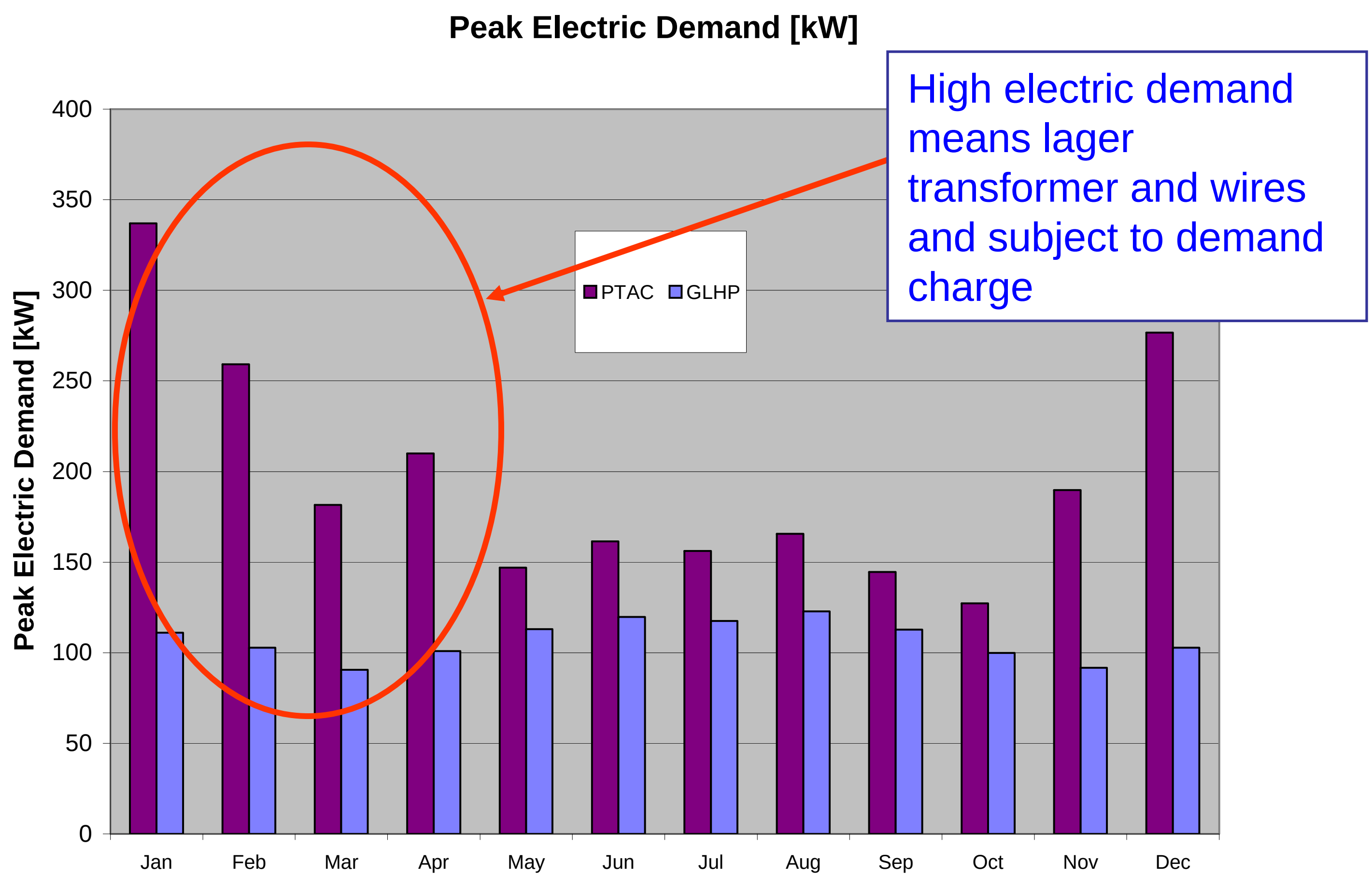
Example of HVAC Systems Comparison (3)



More energy savings if heat pump condensing heat is used for DHW

Applications

Example of HVAC Systems Comparison (4)



This graph is made with Excel using the hourly results predicted by eQUEST

Applications

Sizing GHX with eQUEST

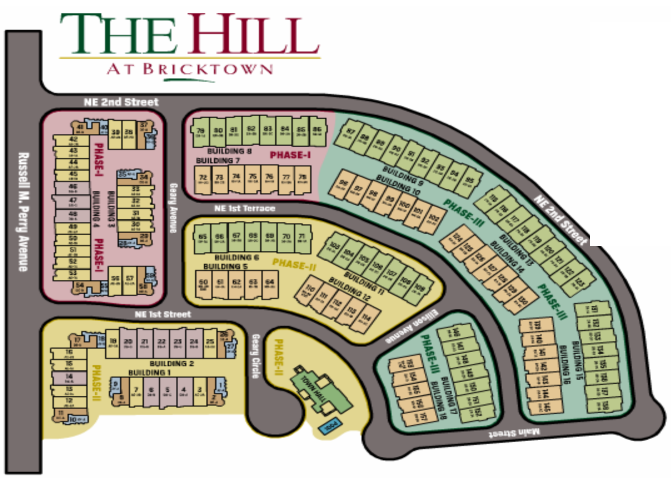
- GHX can not be automatically sized by eQUEST
- The default GHX parameters of eQUEST may be only valid for small commercial buildings
- “Rule of Thumb” of GHX design (i.e. 200 ft bore per ton) may be used as a starting point of the simulation-based design of the GHX
- Iterative process

“Rule of Thumb” →Initial run→Examine hourly report of GHX leaving fluid temperature (LFT)→ Adjust GHX parameters→ Run simulation

Repeat until LFT within the specified loop temperature range

Applications

Example of GHP System Design (1)



157 town homes grouped in 18 buildings

Varying in height from 2 to 4 stories

Ranging in size from 1600 sf to 3517 sf

Over twenty-six floor plans

Challenges in design

- Boreholes are limited in garage only
- Attached homes but with individual loop for each home
- Very short time for design

Solution

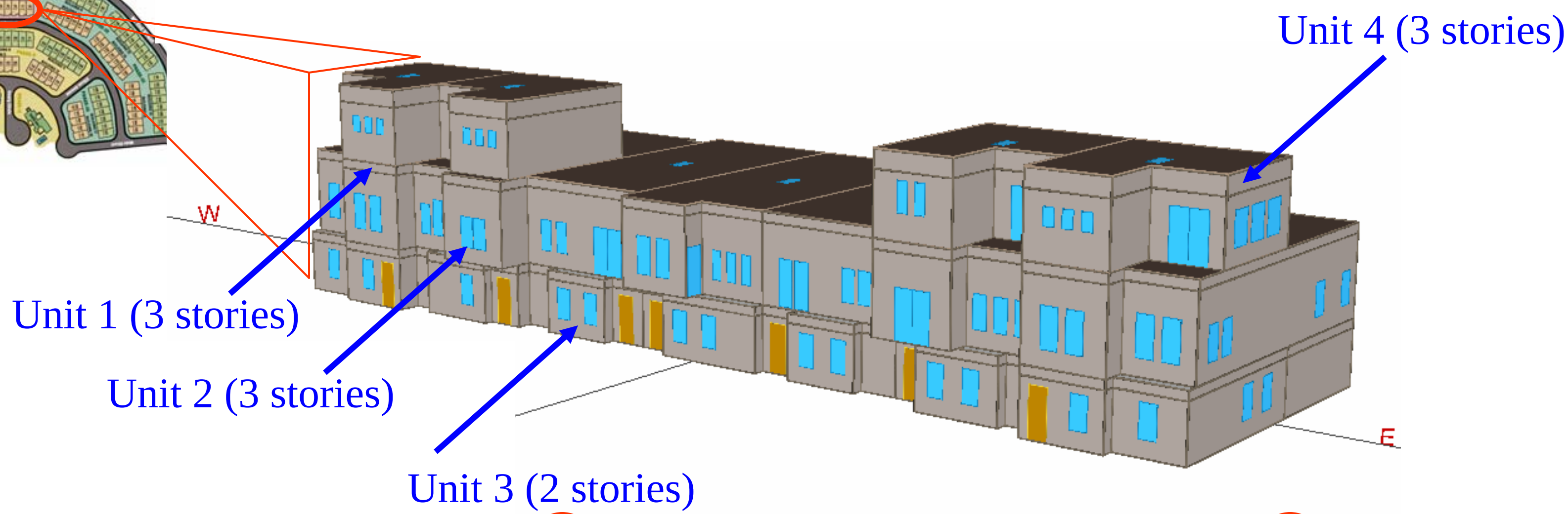
- Integrated simulation with customized g-function for VGLHE modeling

Result

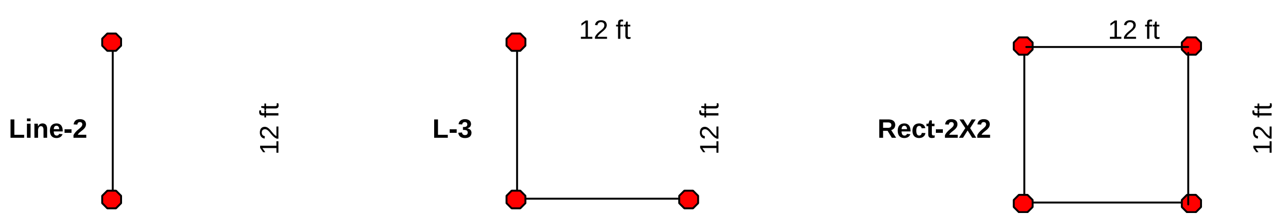
- VGLHE size varies from 200 – 280 ft/ton depending on location, orientation, window/wall ratio of each town home

Applications

Example of GHP System Design (2)



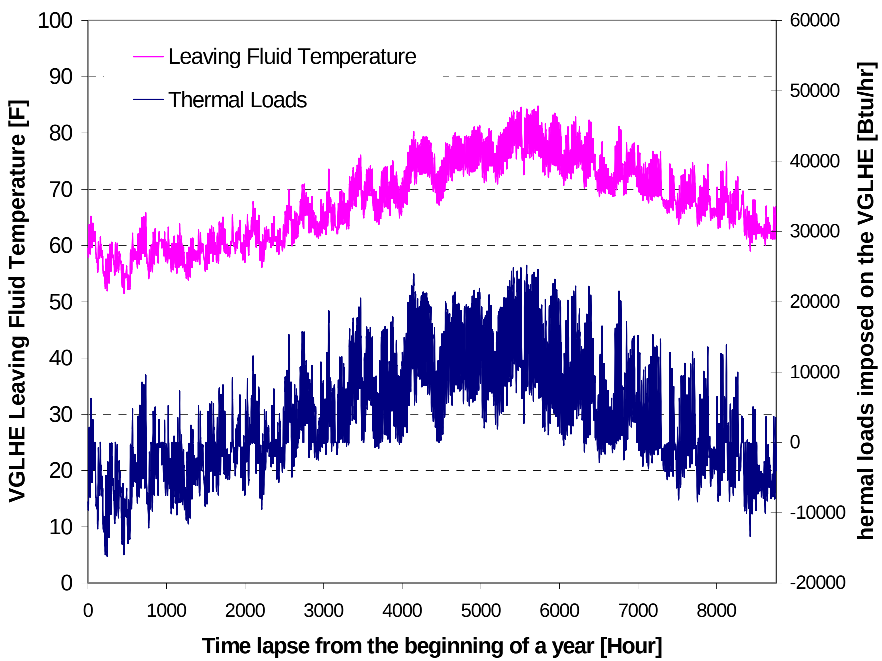
Dwelling Unit		**Heat Pump**		**VGLHE**						
Index	Area ft2	Clg Tons	SF/Ton	Config	Num. of bore	Bore depth	Total bore length	bore length / ton	Min LFT	Max LFT
1	2,698	5.5	**491**	Rect-2X2	4	360	1440	**262**	51.9	96.5
2	2,630	4.5	**584**	L-3	3	300	900	**200**	50.5	96.0
3	2,045	3.0	**682**	Line-2	2	320	640	**213**	51.5	96.5
4	2,698	5.0	**540**	Rect-2X2	4	320	1280	**256**	51.1	95.7



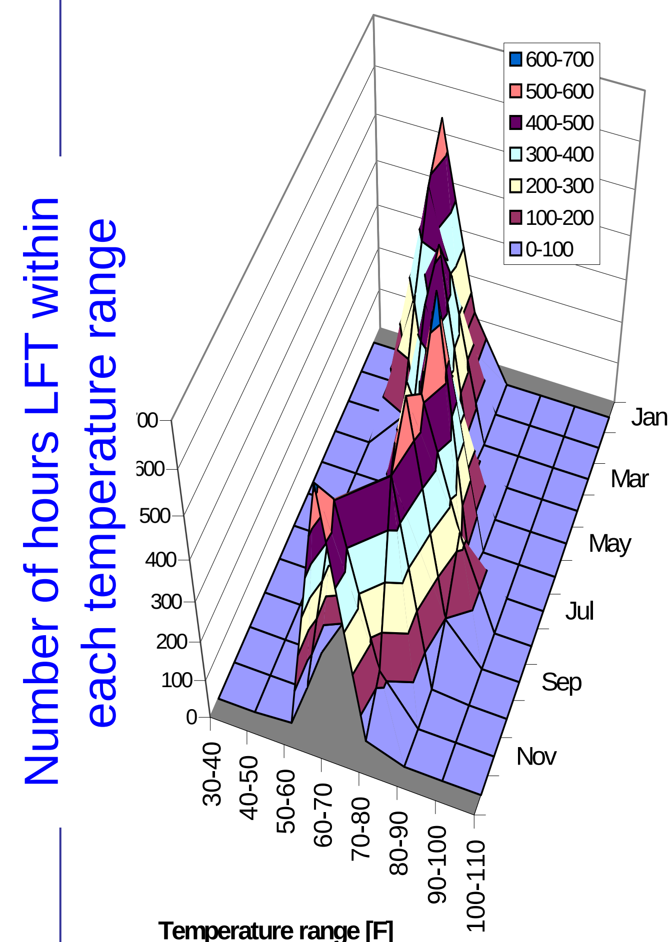
Applications

Example of GHP System Design (3)

The graphs are made with Excel using the hourly results predicted by eQUEST

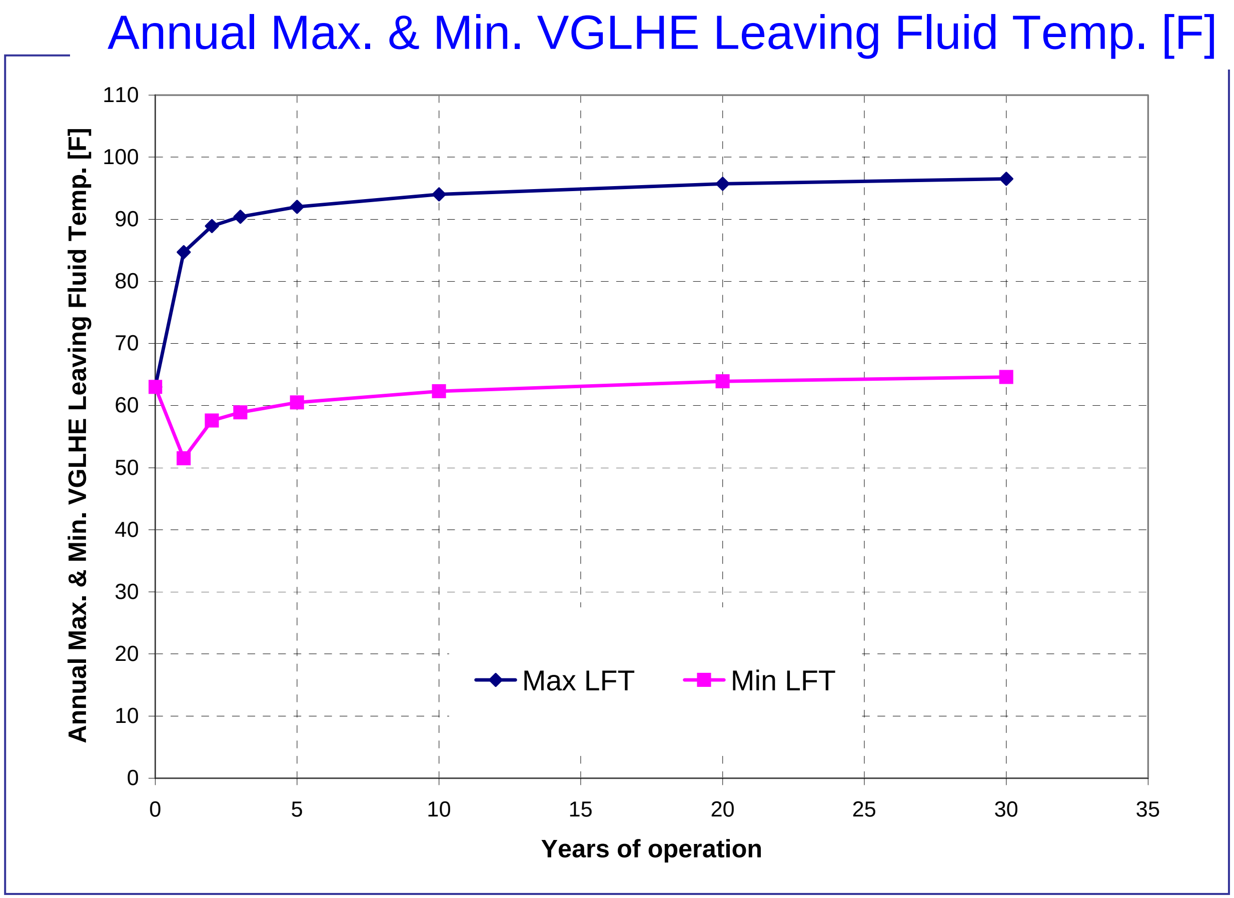


Thermal Loads of VGLHE and Leaving Fluid Temperature



Applications

Example of GHP System Design (4)



This graph is made with Excel using the hourly results predicted by eQUEST

Summary

- To overcome hurdles in GHP system design, eQUEST has been enhanced to facilitate the integrated simulation-based design process
- Extensive efforts have been conducted to validate the enhanced eQUEST and more intensive validation is ongoing
- The enhanced eQUEST is making revolutionary change in GHP system design

Limitations and Future Enhancements

- Prediction of GHP system long-term performance
- Hybrid GHP systems: combination of a variety of heat sink and/or source
- Geothermal water-water heat pump with integrated domestic hot water heater
- Other types of GHX, including horizontal loop, pond/lake, standing column well, and other emerging technologies

Geothermal Heat Pump System

A smart solution for energy efficiency

Thank You!

Questions?