U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Federal Energy Management Program

Ground Source Heat Pumps:

An Introduction to the Technology

John A. Shonder

Oak Ridge National Laboratory

What this Workshop Will Cover

- Theory of Operation
- System Options
- Installation of GHPs
- Important Factors in Design
- Thermal Conductivity Testing
- Case Studies
- Advantages and Disadvantages -- Summary

Theory of Operation

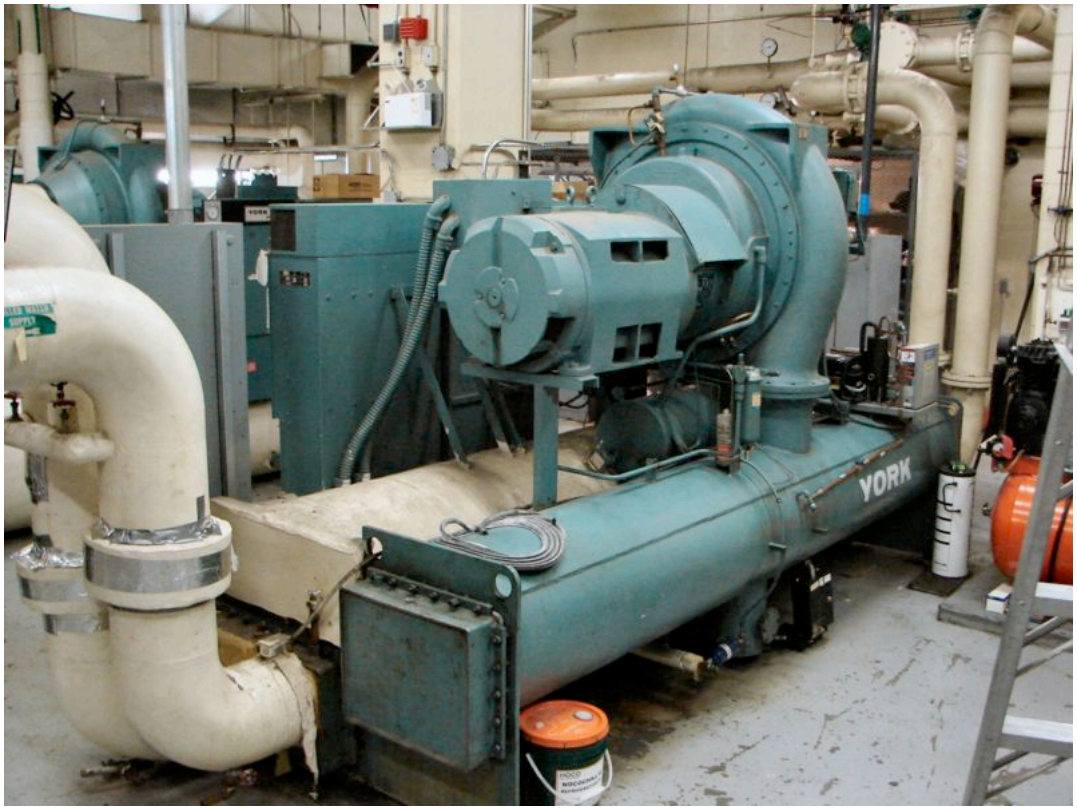
Definition

- A **heat pump** is a device that moves heat from one location (the *source*) to another location (the *sink* or *heat sink*) using work
- Most commonly realized using a refrigerant cycle

A window air conditioner is a heat pump

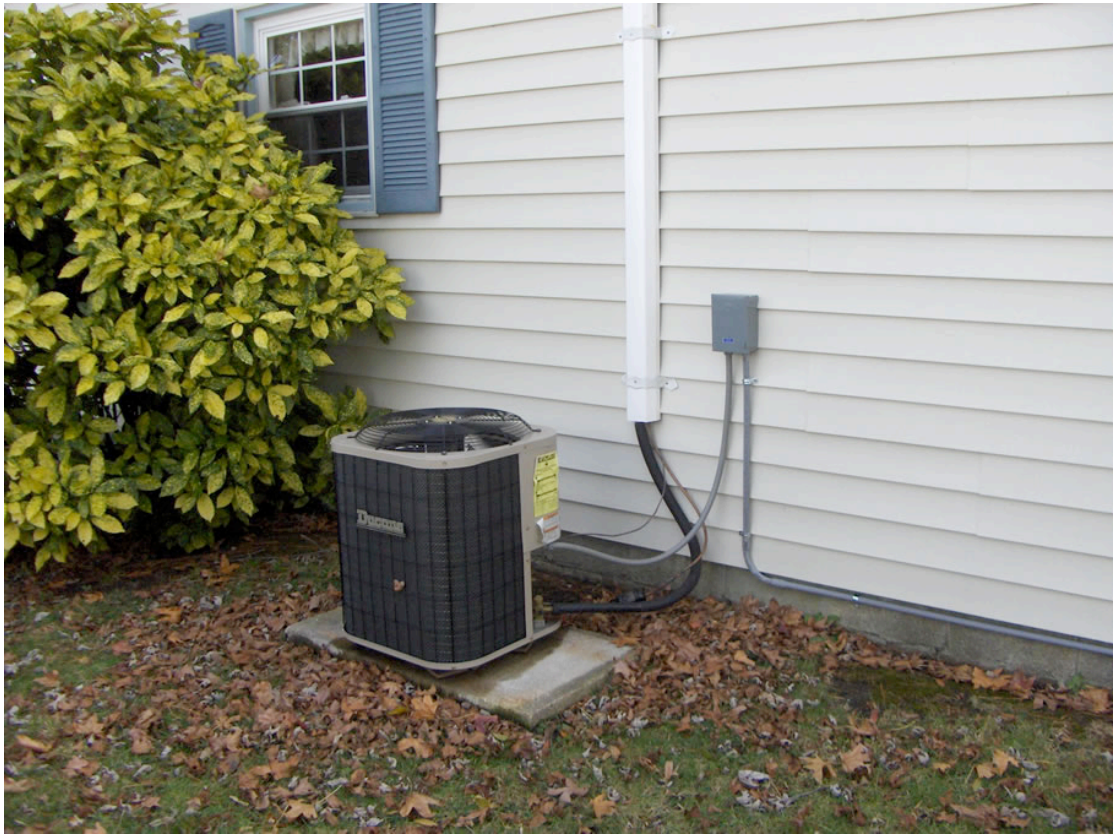
A rooftop air conditioner is a heat pump

Large chillers are heat pumps



In common usage, the term *heat pump* is applied to devices that heat *and* cool

Residential air source heat pump



The previous examples are all *air source heat pumps*

- They transfer heat between the building interior and the outdoor air
- Outdoor air provides the heat sink (or heat source)
- A compressor moves refrigerant around a circuit to achieve cooling and/or heating

Definition

- A **geothermal heat pump** (GHP) is a heat pump that uses the earth as the heat source and heat sink, as opposed to ambient air

The technology goes by many different names

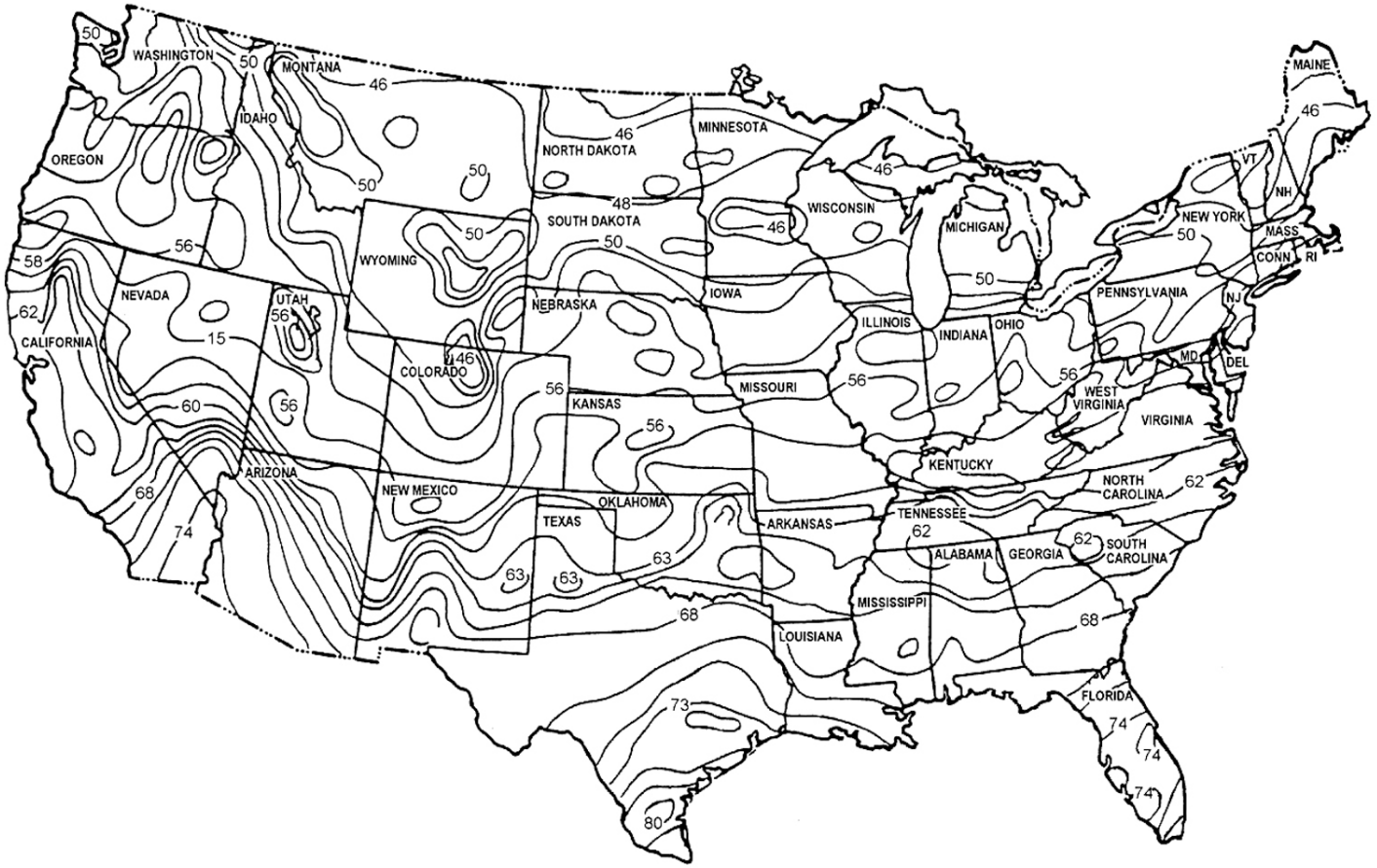
- Ground source heat pumps (GSHP)
- Ground coupled heat pumps (GCHP)
- Geothermal heat pumps (GHP)
- GeoExchange
- Earth energy systems

Why GHPs are more efficient than other HVAC equipment

- Heat pumps are most efficient when the heat source and heat sink are at nearly the same temperature
- Indoor air is usually conditioned to 20-27 ºC
- Outdoor air temperatures vary greatly: 0-45 ºC in some locations
- As outdoor air temperature varies, temperature of the earth just a few meters below the surface remains constant throughout the year
- Earth temperature is close to indoor air temperature, providing an efficient heat source for heating and heat sink for cooling

Deep earth temperatures generally follow average annual air temperatures

ORNL 2001-03084/abh

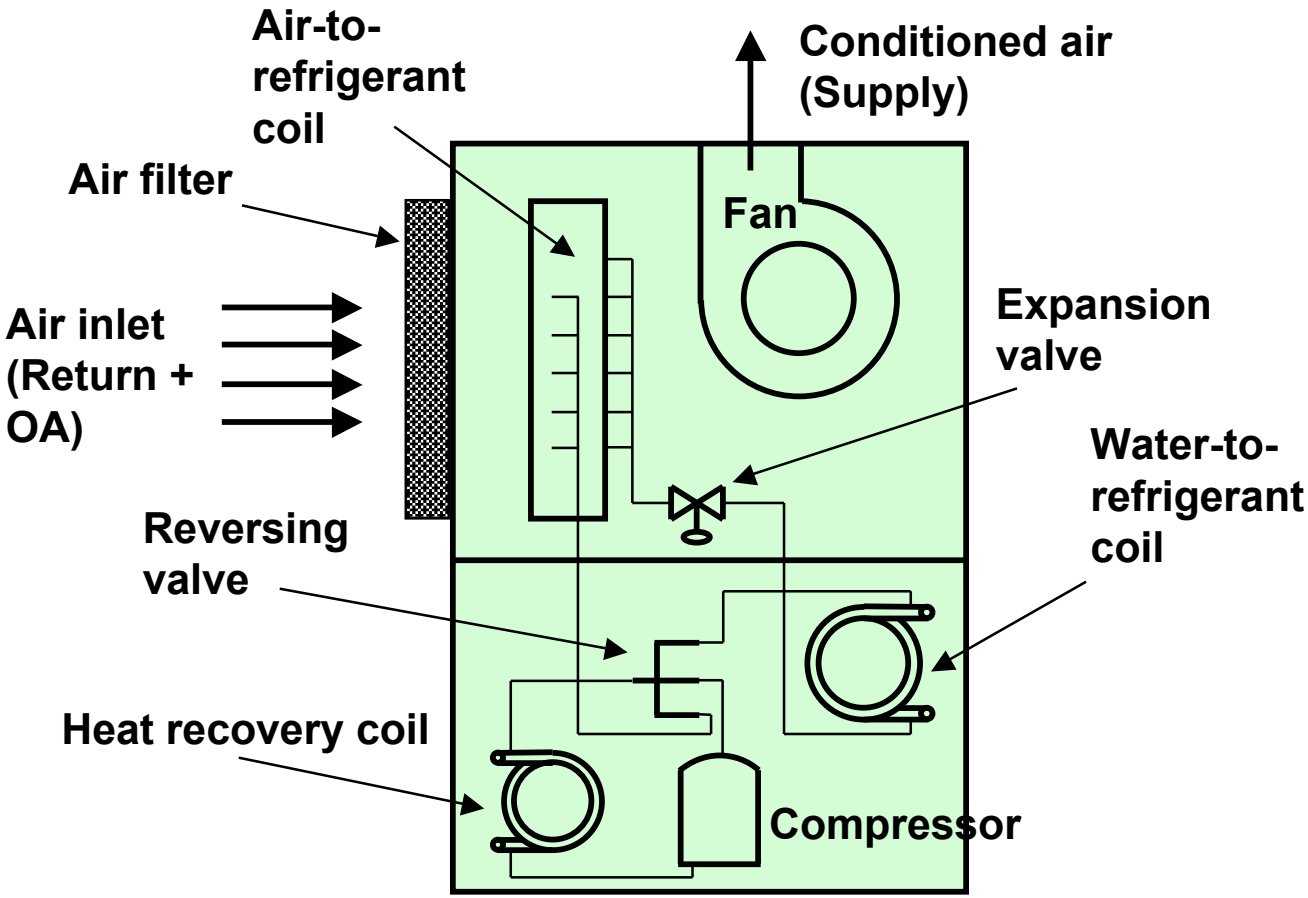


Typical GHP in mechanical room

Basic components of a GHP

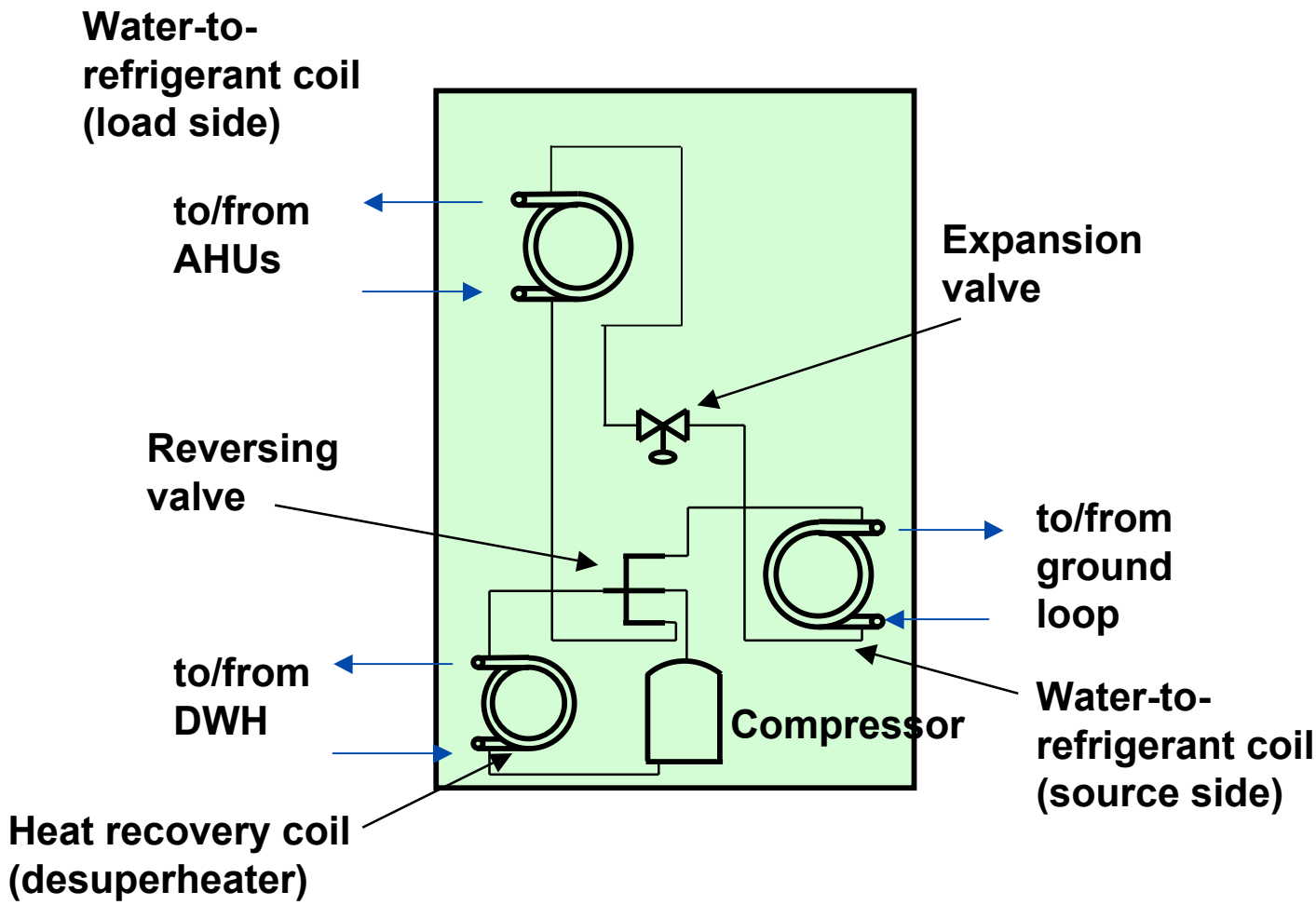
- Refrigerant compressor
- Refrigerant-to-air or refrigerant-to-water coil (load-side)
- Water-to-refrigerant coil (water-side)
- Water pump

Water-to-air geothermal heat pump



Typical water-to-air heat pump

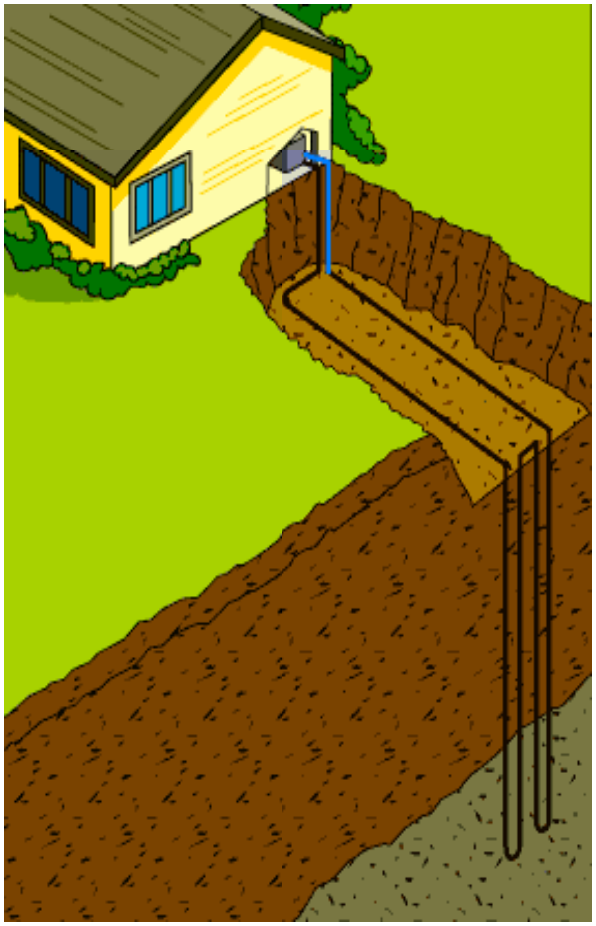
Water-to-water geothermal heat pump



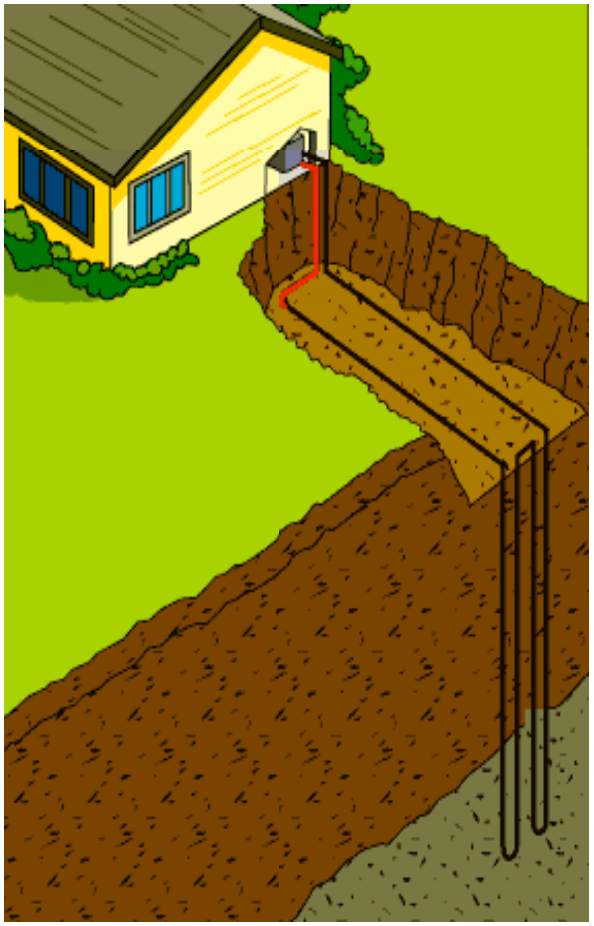
Typical water-to-water heat pump

- Αωαιλαβλε ιν α ωαριετψ οφ σιζεσ (2–20 τονσ)
- Ηιγη εφφιχιενχψ, ΧΟΠ ρανγε οφ 3.5 – 4.5 (δεπενδινγ ον ΕΩΤ)

Operation in Heating Mode

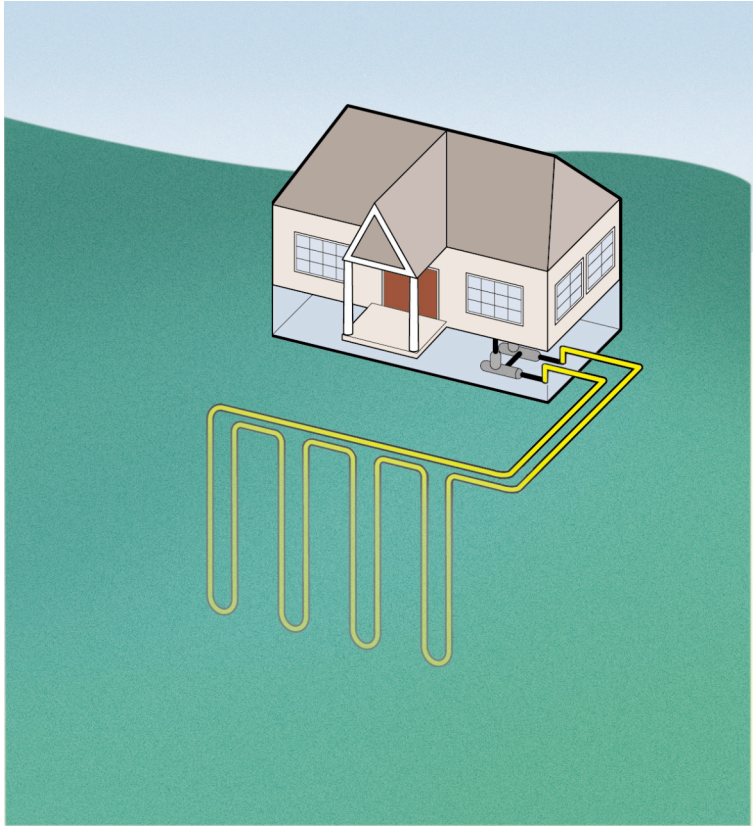


Operation in Cooling Mode

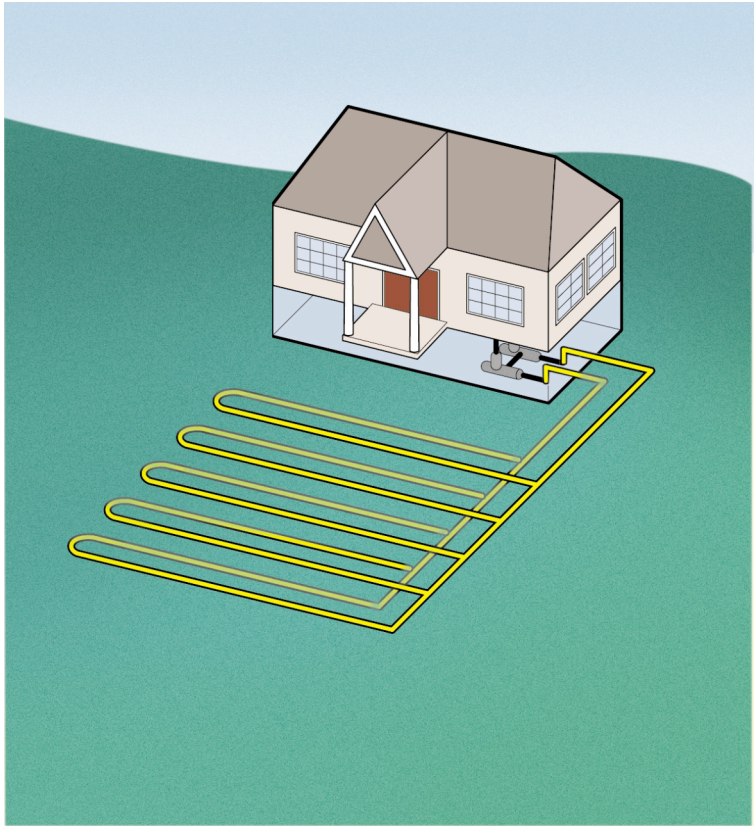


GHP System Options

Residential vertical loop system

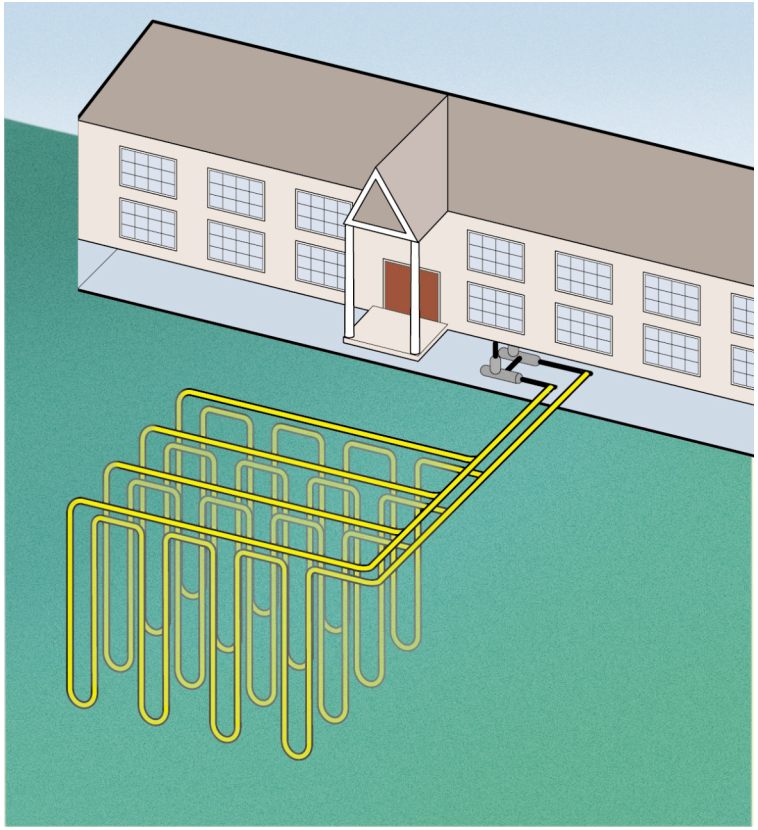


Residential horizontal loop system



Horizontal loops generally require 1500-3000 ft^2 land area per ton

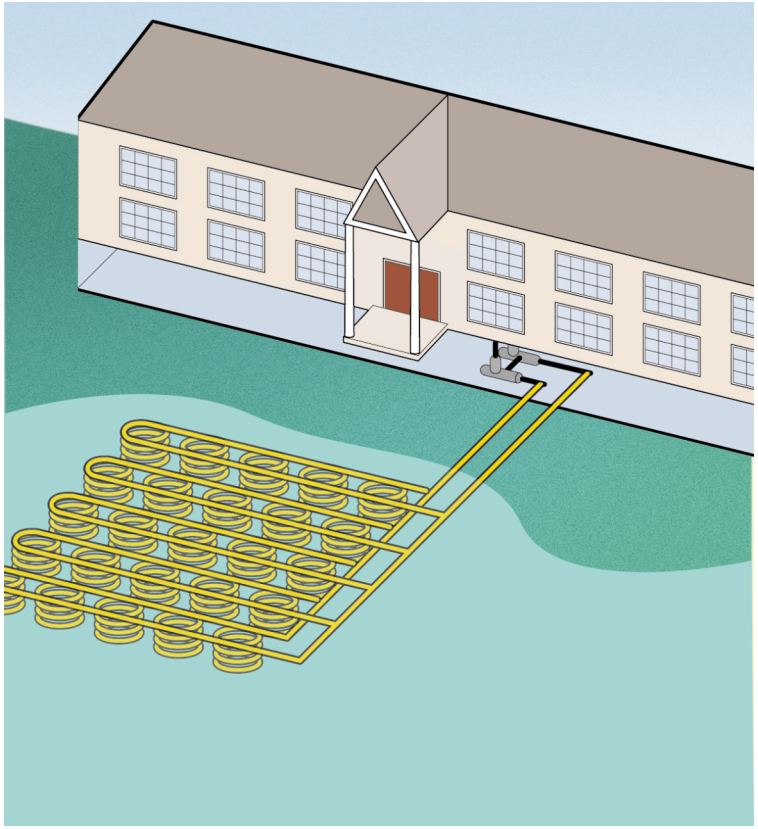
Commercial vertical bore system



Generally requires 250-300 ft^2 of land area per ton

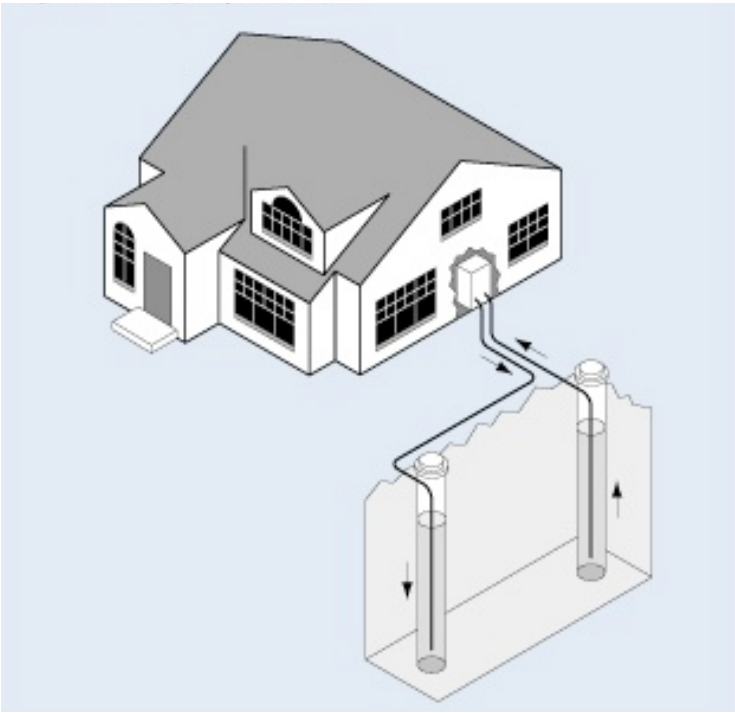
School with vertical bore loop field

Commercial pond loop system

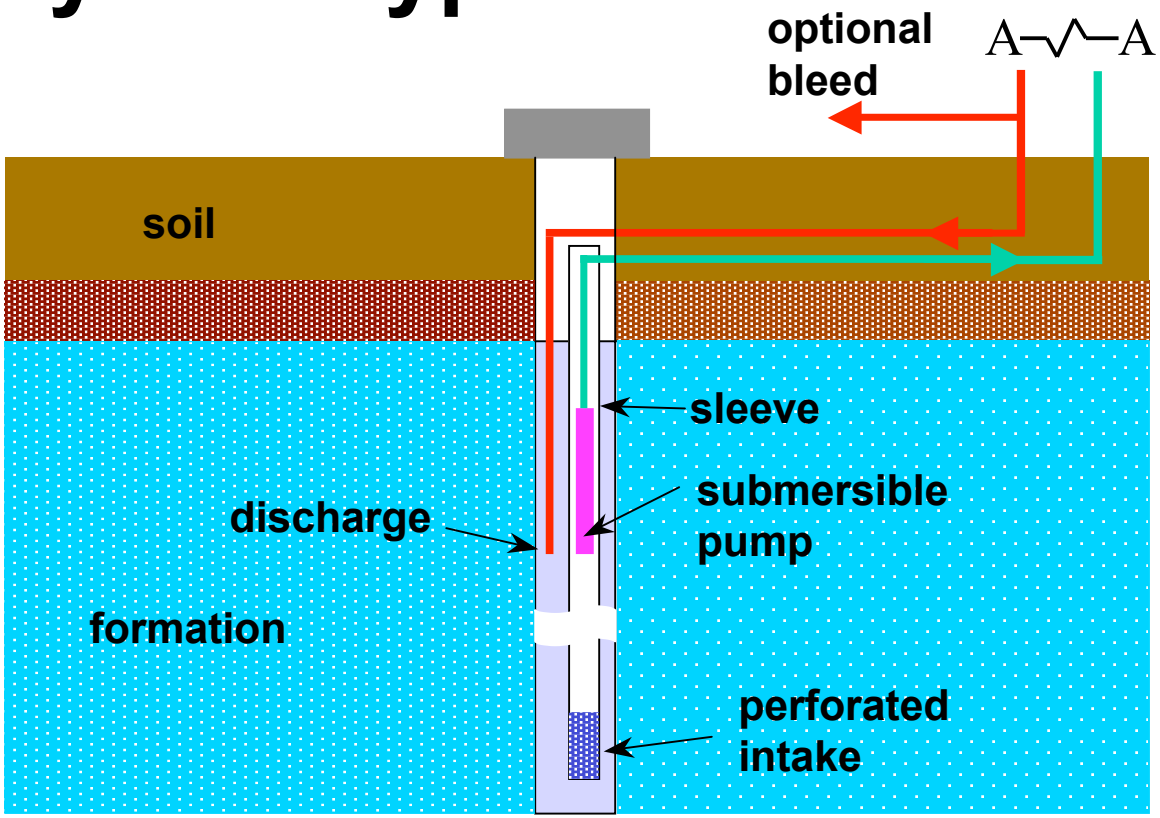


School with pond loop system

Open loop system



Standing column well is another GHP system type



Carlisle Barracks, PA is the site of a large standing column well retrofit

- Equipment installed in 87 residential and commercial buildings
- 847 total tons of heat pump capacity
- 69 wells ranging from 180 to 855 ft deep (average 455')

Commercial applications most commonly use vertical loops

- Vertical *boreholes* are drilled 75m - 150m deep with a drilling rig
- High density polyethylene u-tube pipes are inserted into the bores
- The boreholes are filled with *grout* to ensure good heat transfer and protect groundwater
- Boreholes are then connected together in parallel

Installation of GHP Systems

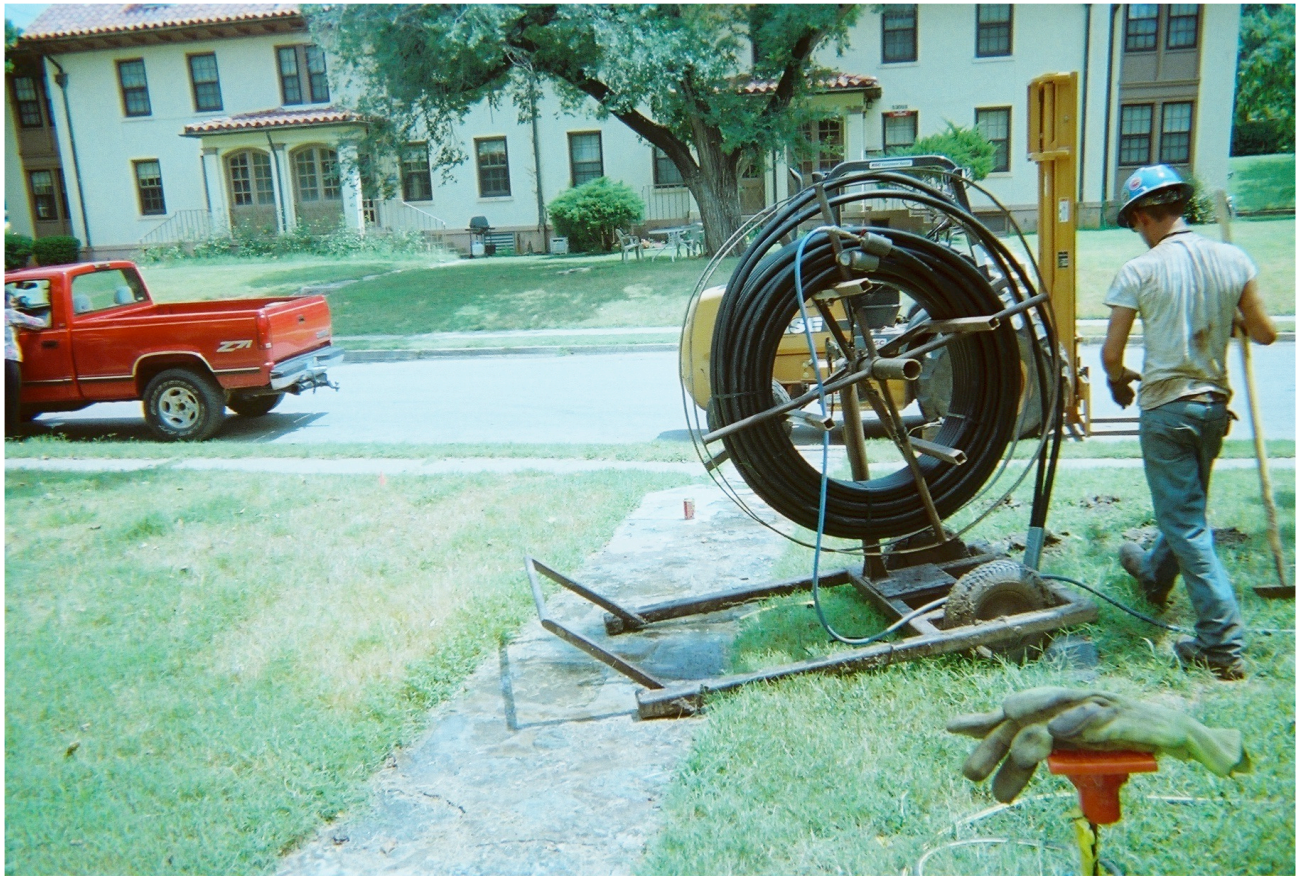
Air hammer drill rig

Drilling boreholes for a school

Commercial site under construction

HDPE u-tube on spool

U-tube installation



Holes are then grouted

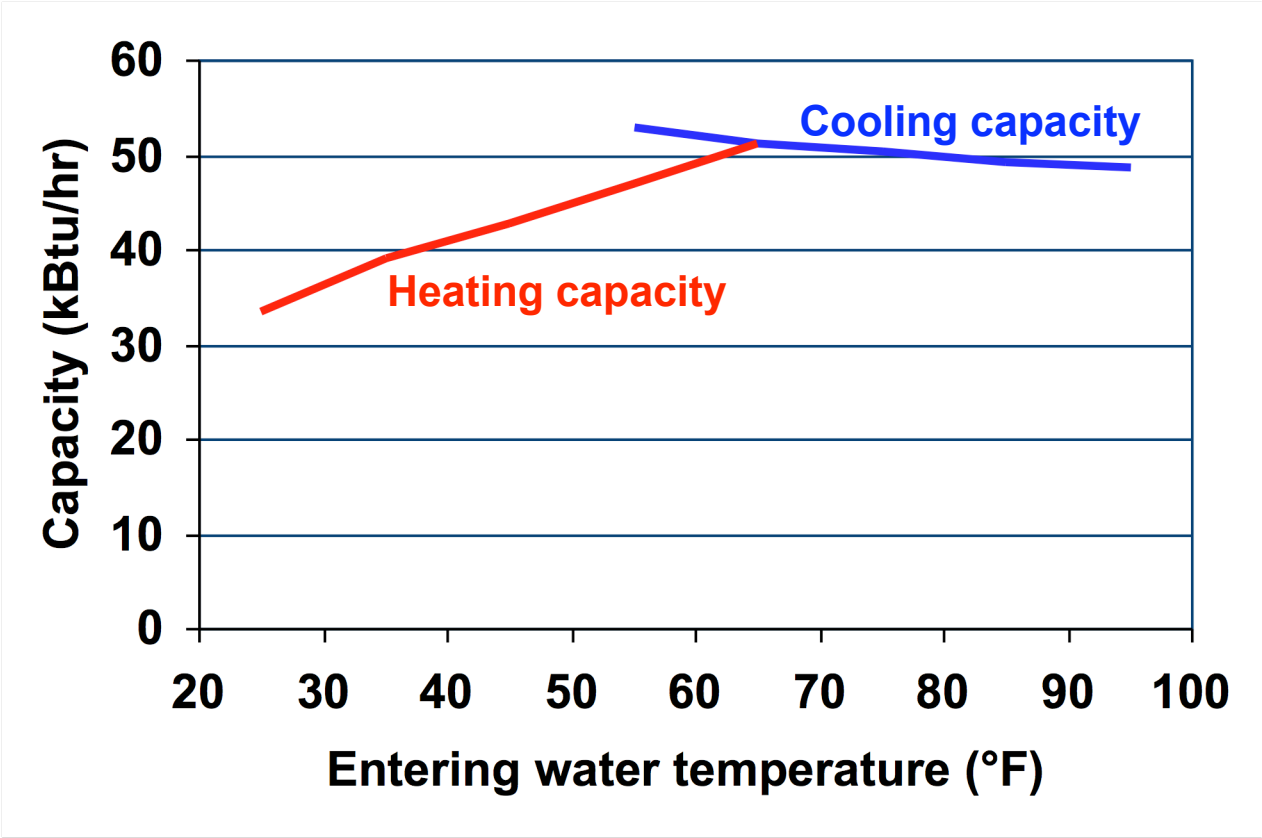
Borehole grouted bottom to top

Important Factors in Design of GHP Systems

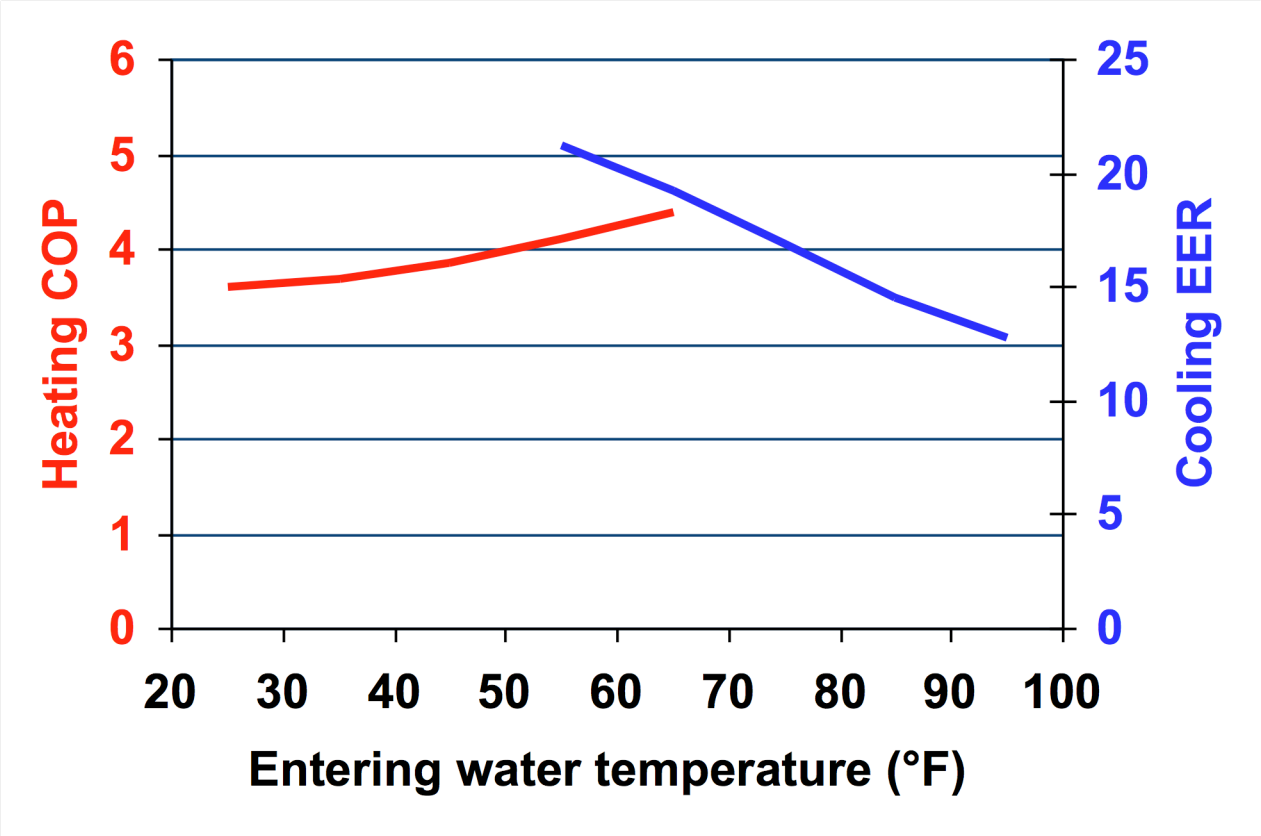
Inside the building: Similar to the design of any conventional HVAC system

- Determine peak heating and peak cooling load for each zone of the building
- Select heat pumps to meet design loads (remember that capacity depends on EWT)
- Heat pumps should be located with due consideration for serviceability
- Size ventilation system components: ductwork, fans, preheating coils, etc.

Capacity of a typical 4-ton geothermal heat pump vs. EWT



Efficiency of a typical 4-ton GHP as a function of EWT



Outdoor air pre-treatment is a concern in commercial designs

- In US, ventilation air requirements often drive design
- A number of options for outdoor air
  - Dedicated water-to-water heat pump supplying OA preheat coil
  - Sensible heat recovery unit to absorb heat from exhaust air
  - Conventional heat source (gas boiler, electric resistance, etc.)
  - Each method has advantages and disadvantages in terms of first costs and operating costs

Retrofits: Existing equipment influences cost-effectiveness of various GHP designs

- Central/terminal systems (ductwork or no)
- Water loop for two- or four-pipe system? If so, potential for re-use as GHP water loop
- What space is available in zones for individual heat pumps?
  - Above dropped ceiling → horizontal units
  - Mechanical closets → vertical units
  - Through-wall PTAC units & perimeter → console units

Outside the building: Further tests are required to optimize the design

- Vertical loop: Thermal Conductivity Test
  - Measures deep earth temperature as well
  - Important for loop field design
- Open loop: Well Test
  - Water flow
  - Water quality (including chemistry)

Outside the building: Borefield sizing (for vertical bore systems)

- Decide on borehole and u-tube size, grouting
- Determine ground properties from in-situ test
- Design borefield layout (rows × columns, spacing)
- Determine whether antifreeze is required
- Select design EWT
- Enter all information (including loads) into borefield design program — iterate if necessary
- Design exterior headers

Borefield sizing is a critical issue

- Rejecting heat to borehole tends to heat the earth in the borefield
- The earth dissipates heat very slowly
- Borefield must be sized so that the temperature rise is limited to some design value
- Opposite problem in heating-dominated climates: heat is extracted, so temperature drop must be limited to a design value

Borefield must be sized correctly

- Undersized borefield will may cause temperature of water returning to building to rise to the point where heat pumps no longer operate
- Oversized borefield is costly -- drilling and manpower cost money
- Design borefield length is determined by solving a rather complicated heat conduction problem

Commercial software is available for borefield sizing

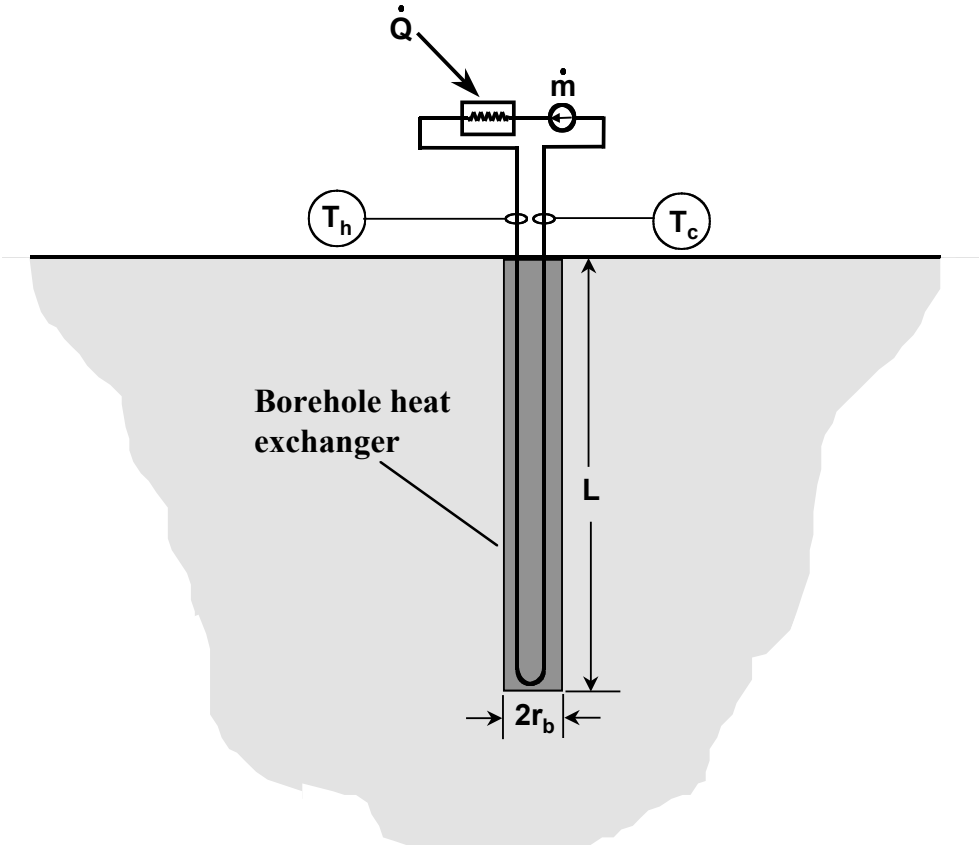
- GCHPCalc (www.geokiss.com)
- GLHEPro (www.hvac.okstate.edu/glhepro/)
- GLD (http://www.gaiageo.com/)

Design depends on soil thermal properties

- Thermal conductivity
- Deep earth temperature
- Borehole resistance
- For commercial projects, these properties are measured in the field with an *in situ* test

Thermal Conductivity Testing

Schematic of test

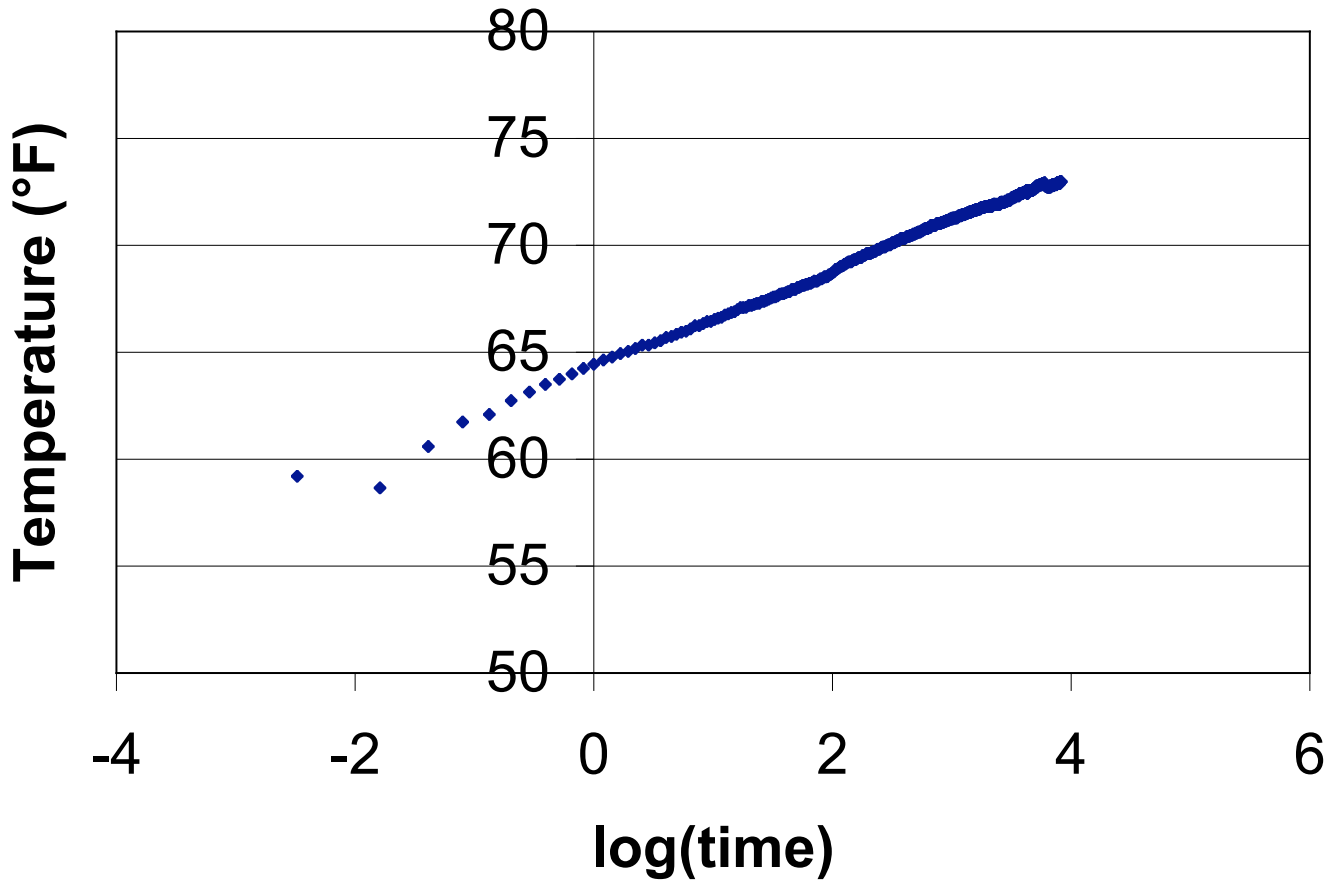


Test Rig for thermal conductivity test

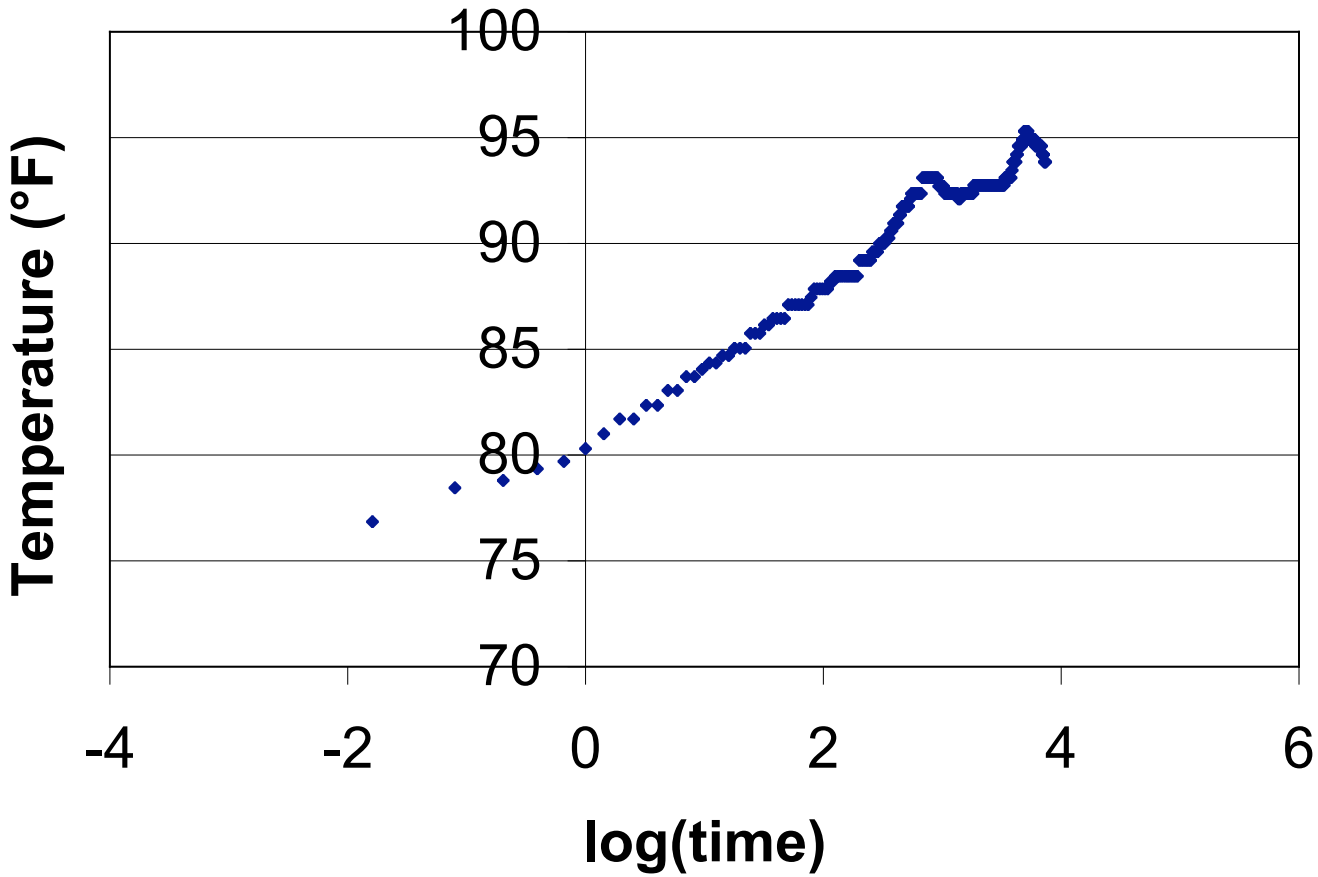
Measurements taken during test

- Inlet and Outlet Temperature
- Deep Earth Temperature
- Water Flow Rate
- Power Input to Water Heater
- Power Input to Pump

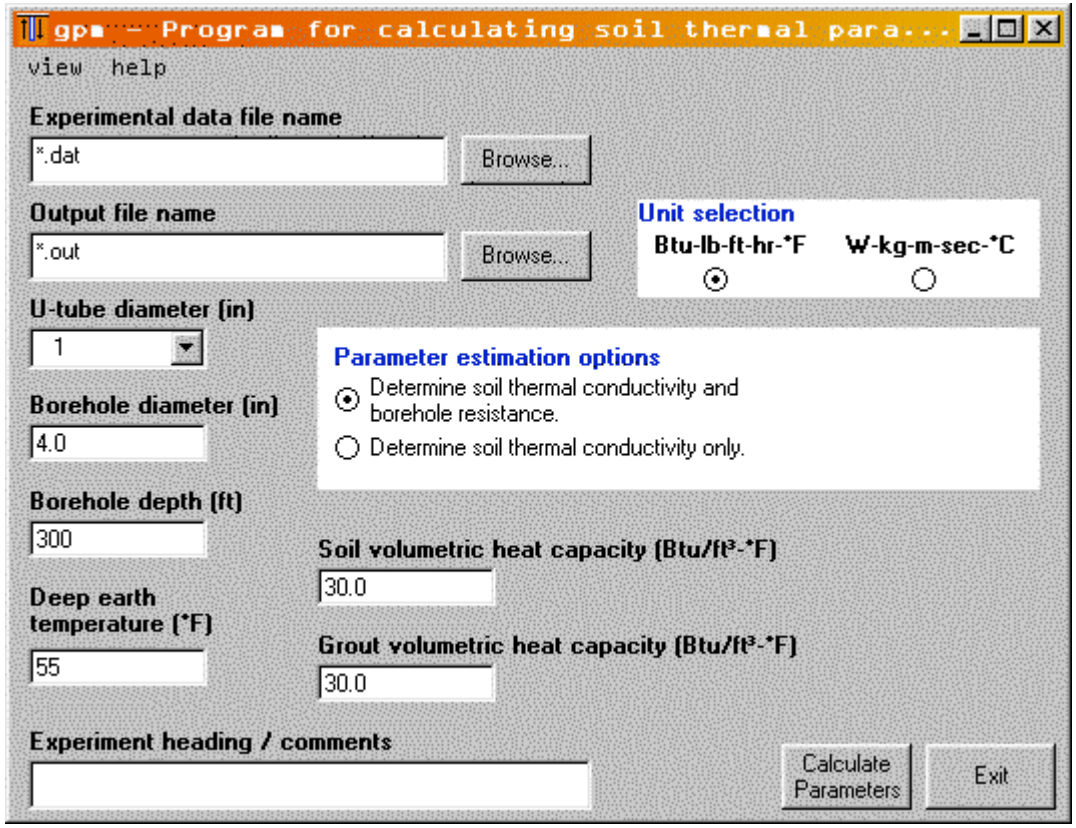
"Good" test data



"Bad" test data



ORNL has free software available to analyze field test data



Case Studies

Fort Polk Residential Project

Project background

- Fort Polk is a US Army base in the State of Louisiana
- Climate is hot and humid during much of the year
- Contains a small city with residential housng for 4000 soldiers and their families

Scope of Fort Polk Project

- Entire stock of 4,000 family housing units (1,292 individual buildings)
- Residences range in size from 1,073 to 2,746 square feet (1,393 average)
- 3,243 (or 81%) of residences were served by air-source heat pumps and electric water heaters
- Remainder (761) used gas heat with central air conditioning, and gas-fired water heaters

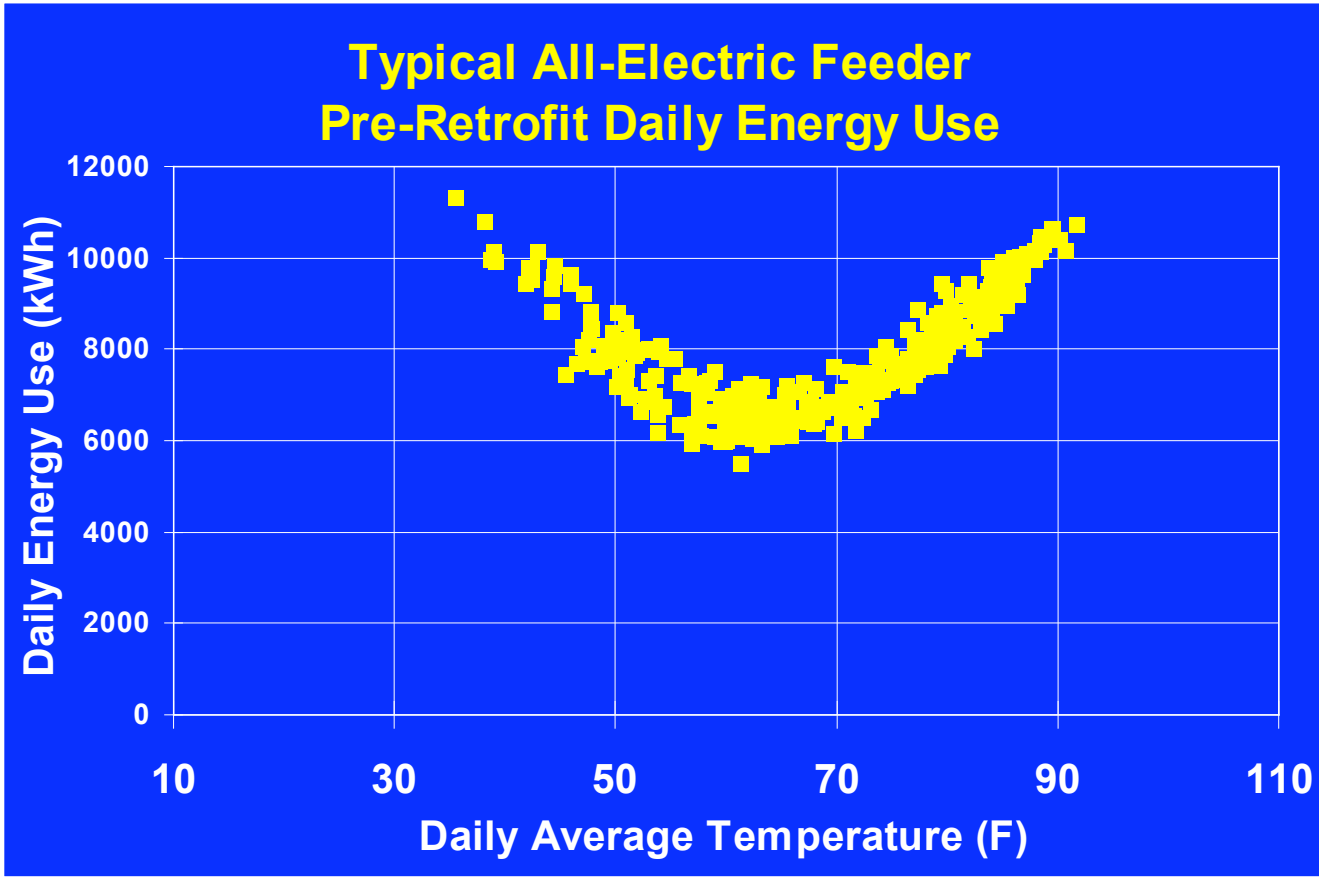
Conservation Measures Included

- Air-source heat pumps and gas/central air systems replaced with GHP in all residences
- Gas-fired water heaters replaced with electric resistance
- GHPs included desuperheaters to supplement water heating in 75% of residences
- Interior/exterior lighting replaced with compact fluorescent lights; some fixtures delamped
- Low-flow shower heads
- Attic insulation upgraded as needed in upstairs residences

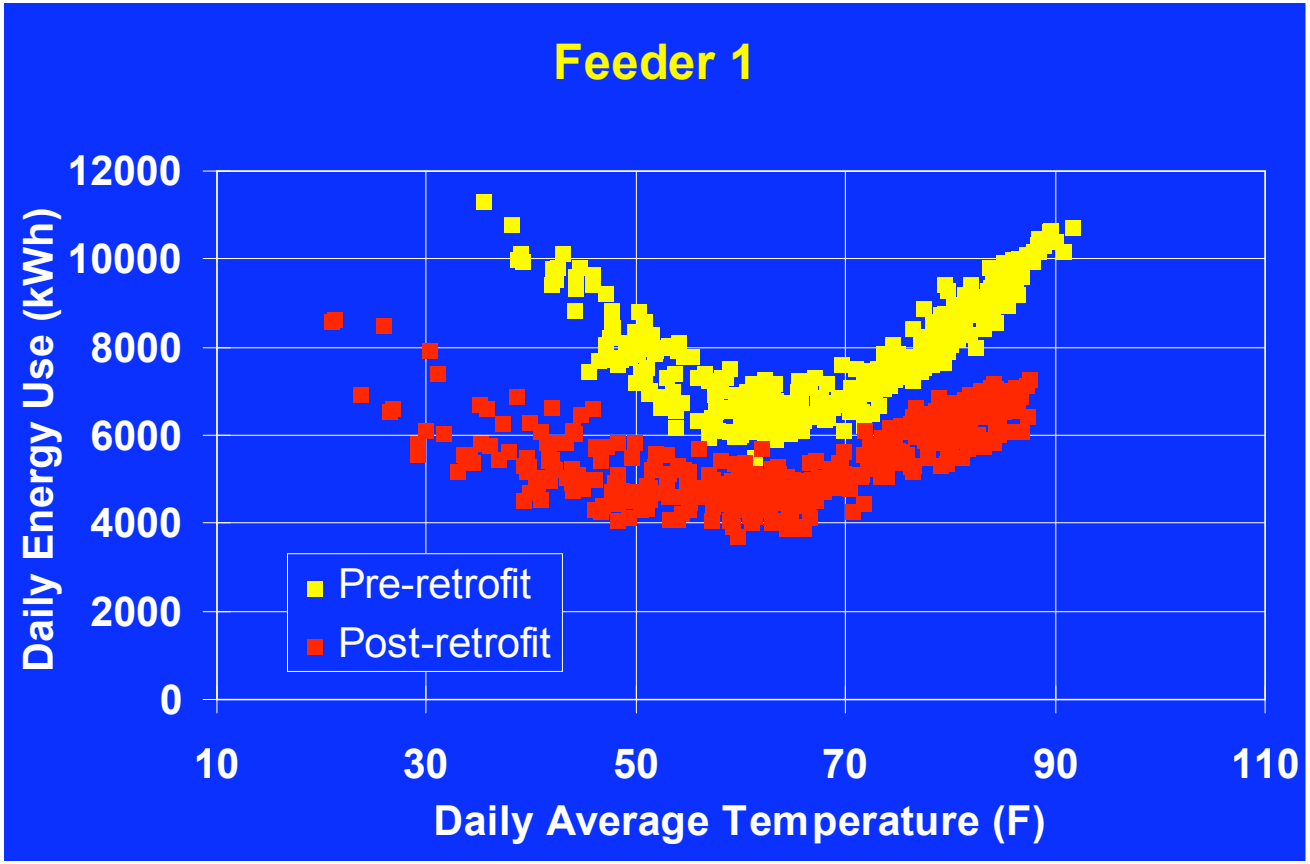
Geothermal Heat Pumps Installed

- Total of 6,600 tons of GHP capacity installed in nominal capacities of 1.5, 2, and 2.5 tons
- Each with its own vertical u-tube type ground heat exchanger with one circuit per bore and two circuits in parallel
- Average 275 feet of bore per ton
- Total of 3,621,256 feet (685 miles) of 1-inch SRD 11 high-density polyethylene pipe installed at site
- Bores backfilled with standard bentonite grout with no thermal enhancement

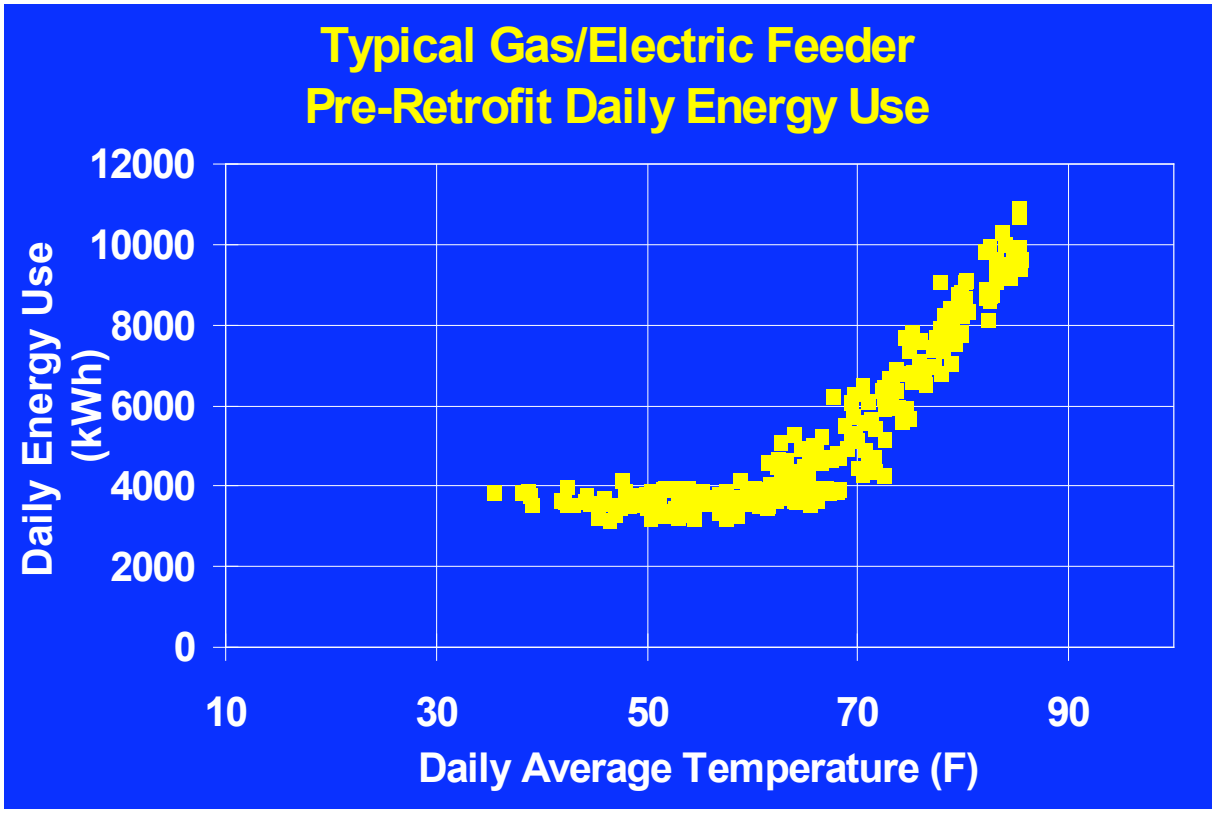
Pre-retrofit electricity use for all-electric feeder



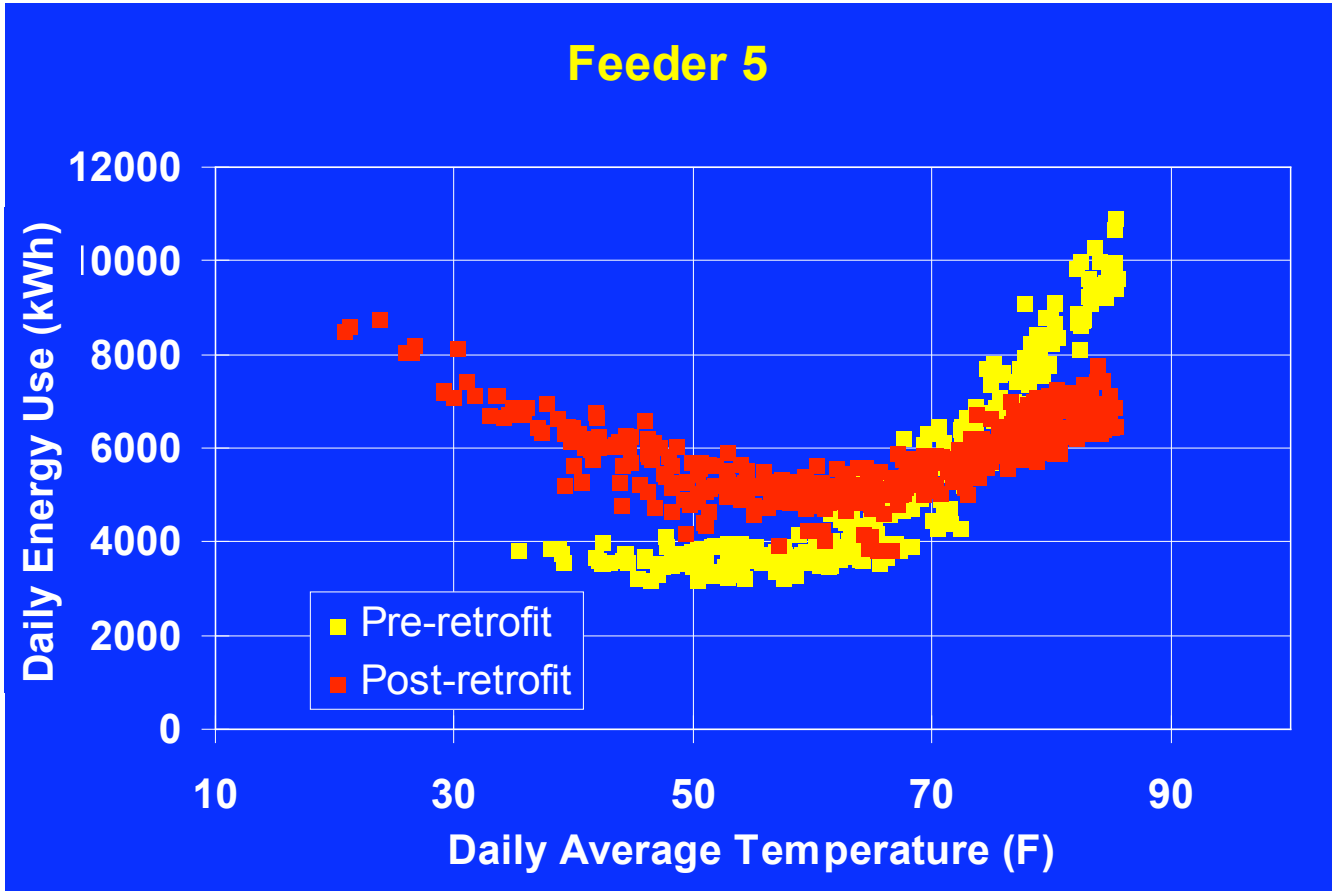
On all-electric feeders, GHPs reduced energy use every day of the year



Pre-retrofit electricity use for gas-electric feeder



Electrical energy saved on this feeder as well because most days are cooling

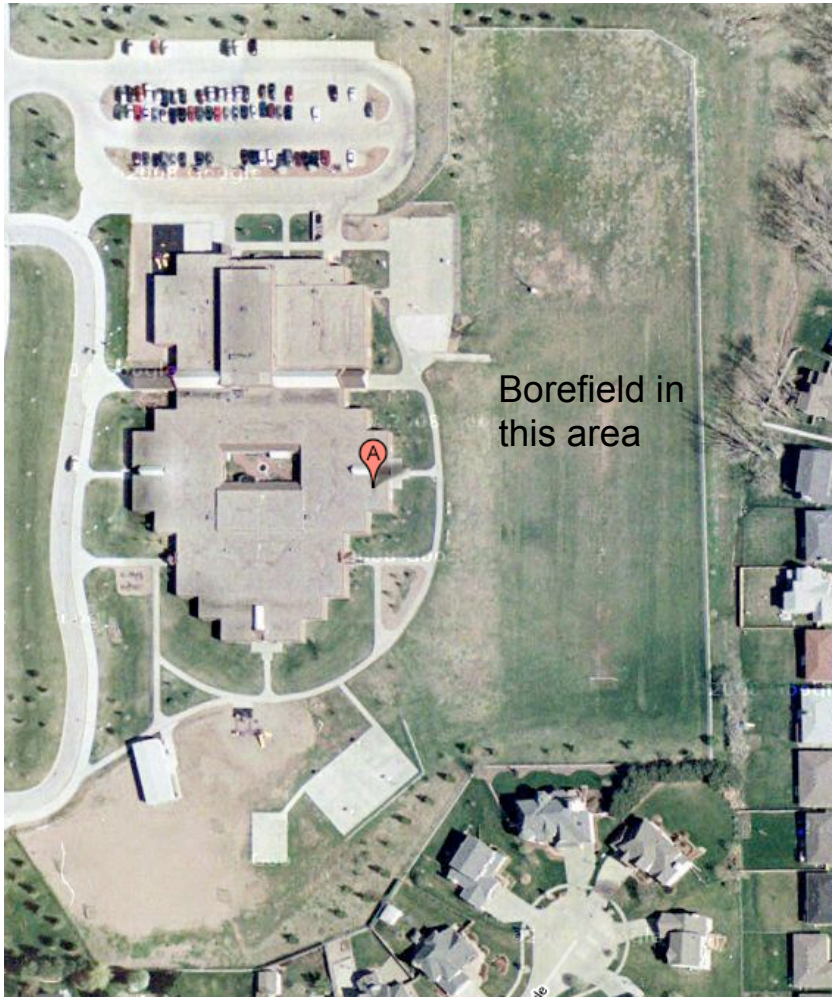


Summary of savings achieved at Fort Polk

- Electrical energy savings 25.6 million kWh, or 32.4% of annual pre-retrofit electrical energy in a typical year
- Electrical demand reduction estimated at 6.7 MW, or 40.2% of pre-retrofit demand for peak cooling day during utility peak hour
- Annual natural gas savings estimated at 260,000 therms
- 29% reduction in maintenance costs ($4.5 million over 20 years)
- As a result of the ESPC, family housing at Fort Polk is exceeding federal mandates which direct facilities to reduce energy consumption by 30% compared to 1985 energy use

Maxey Elementary School

Aerial view



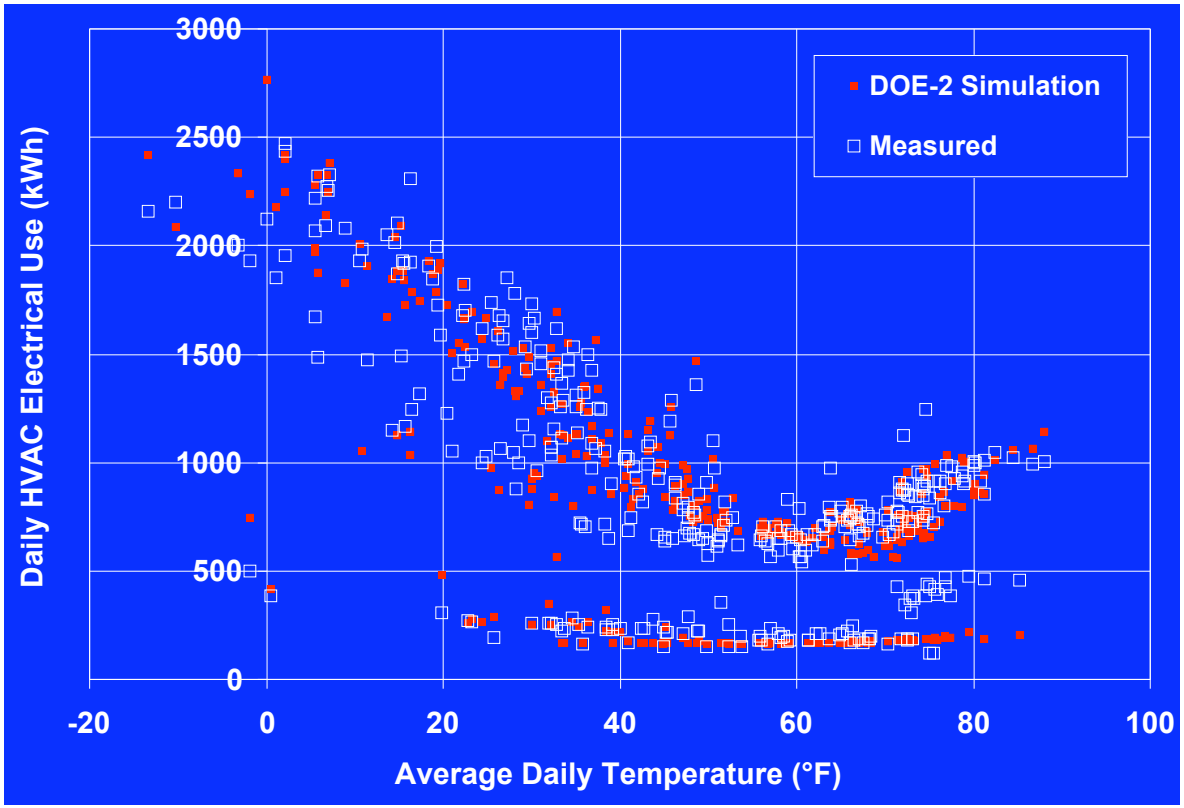
Maxey GHP System Design

- Total of 54 GHP units
- 200 tons total nominal cooling capacity
- Two 15-ton WWHP units provide pre-conditioned OA with HW coil for cold days
- Unit heaters in corridors with HW coils
- Four 333,000 BTU/hr gas-fired boilers; gas DHW

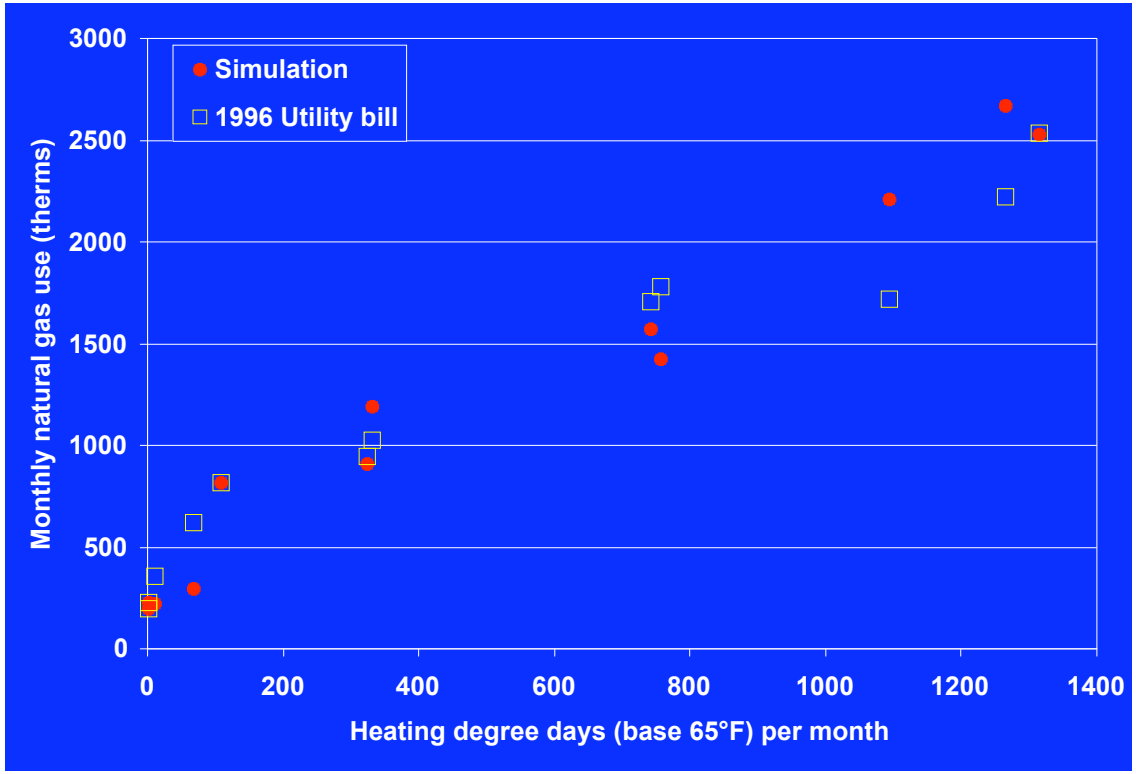
Study is based on a calibrated simulation

- Developed simulation model beginning with as-built construction plans
- Estimated internal loads from occupancy, fixture counts
- Developed occupancy schedule based on school calendar
- Adjusted model parameters until performance matched site-monitored data (daily electrical use, monthly gas use)

Simulated and monitored daily HVAC electrical use



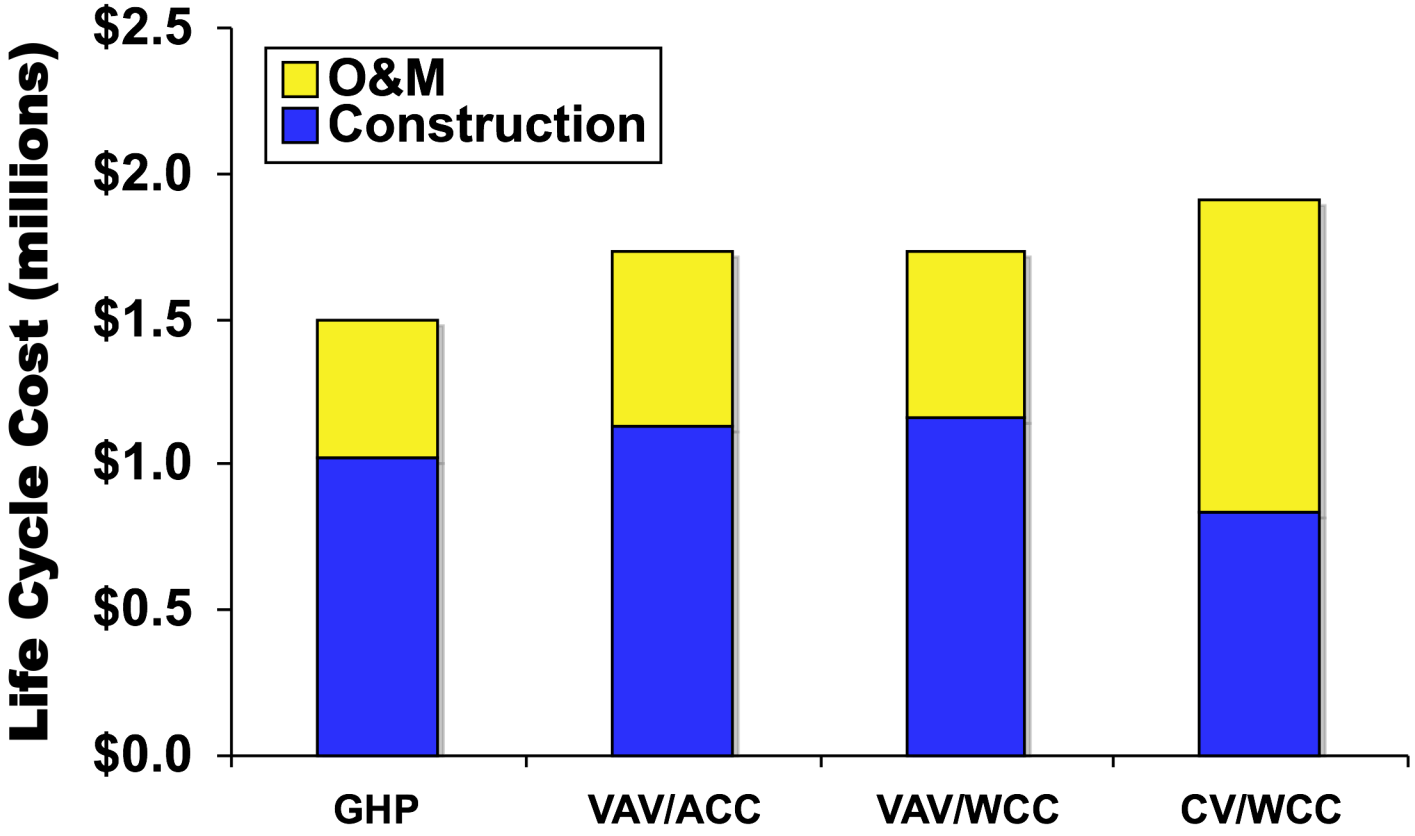
Simulated and monitored monthly total natural gas use



Maxey life cycle cost study

- Once we had a calibrated model, we replaced the GHPs (in software) with
  - Water-cooled chiller with VAV air handling system
  - Air-cooled chiller with VAV air handling system
  - Water-cooled chiller with constant volume air handling system
- Calculated installed cost of each system
- Estimated energy use of each type
- Calculated life cycle cost of each type

GHP had lowest LCC and lower first cost than widely-used VAV systems



Cost Containment in GHP Projects

Value engineering in GHP projects

- Like most renewable technologies, GHP systems have a cost premium
- This can be as much as $2000-$3000 per ton of capacity compared with conventional equipment
- For this reason, it is important to minimize costs and maximize benefits

Optimizing the Cost/Benefit Ratio of GHP Projects

- In vertical bore projects, minimize bore length by using industry-standard borefield design program
- Perform in-situ thermal conductivity test
- Avoid complex control systems
- Minimize pumping power
  - Water flow rate <3 gpm per ton peak block load
  - Minimize pipe friction
  - Operate pumps within 5% of max efficiency
  - Avoid excessive antifreeze
- Bundle with other ECMs such as lighting, envelope
- Consider the benefit of maintenance savings

GHPs should also be considered for domestic water heating

- A heat pump is the most efficient technology for water heating
- Can use dedicated water-to-water heat pump, or desuperheaters on selected heat pumps supplementing conventional DHW
- In cooling-dominated applications, using desuperheaters can reduce required bore length and system costs

Summary -- Advantages and Disadvantages of GHP Systems

Advantages of GHPs

- High efficiency
  - Lower energy consumption
  - Lower energy cost
  - Lower electrical demand
- Low maintenance cost
- Low life cycle cost
- No outdoor equipment
- Better humidity control
- Greater occupant comfort

Disadvantages of GHP

- First cost can be higher than for conventional systems
- Not all system types feasible in all locations
- Limited pool of designers

Resources for GHP Designers

- *Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings,* Kavanaugh and Rafferty (ASHRAE, 1997)
- *Commercial/Institutional Ground Source Heat Pump Engineering Manual*, Caneta Research (ASHRAE, 1995)
- *Closed Loop/Ground Source Heat Pump Systems: Installation Guide* (IGSHPA)
- *Learning from Experiences with Commercial/Institutional Heat Pump Systems in Cold Climates*, Caneta Research (CADDET, 2000)
- Chapter 32: Geothermal Energy, *2003 HVAC Applications Handbook* (ASHRAE)
- eQuest simulation program (www.doe2.com)

US and International Organizations

- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)
- International Ground Source Heat Pump Association (IGSHPA)

Web sites with information on GHPs

- www.ornl.gov/sci/femp
- http://www.eere.energy.gov/femp/financing/superespcs_geothermal.cfm
- www.igshpa.okstate.edu/
- www.ghpc.org
- http://geoheat.oit.edu/
- www.geokiss.com

Questions?

John Shonder
shonderja@ornl.gov
865-574-2015