Design of Commercial Ground Source Heat Pumps

Kirk Mescher, PE, LEED® AP
Steps to Improving Ground Source Design

Kirk Mescher, PE, LEED® AP
Learning Objectives

• What documents are required to effectively communicate a ground source system design?
• Energy simulations
• Ground Loop 101
• What makes water source heat pump installations unique?
• What makes a good ground source installation?
Heat Exchanger Configurations

- Open Loop
- Surface Water
- Horizontal Bore
- Vertical Bore

Courtesy Water Furnace
Getting Started:

• References
  – ASHRAE CHAPTER 34 – HVAC Applications Volume
  – ASHRAE TC 6.8 Geothermal Heat Pump and Energy Recovery Applications
  – Various Journal articles

• Attend seminars like this
Recommended ASHRAE Design Guide for Commercial and Institutional Buildings
Improving System Design: Simplicity

Everything should be made as simple as possible, but not simpler. ~Albert Einstein
Why Simple?

• Designs should be challenged
  – Everything in the system should be challenged to add VALUE
  – Clear project definition and goals
    • Energy Efficiency
    • Ease of Maintenance
    • Longevity
  – What do we NEED in controls?
  – What kind of service staff does the client have?
  – How close are emergency service resources?
Codes and Standards (US)

• International Mechanical Code
  – Chapter 12
• IGSHPA - Closed-Loop/Geothermal Heat Pump Systems
  - Design and Installation Standards
• ASHRAE Standard 90.1
  – Variable flow requirements
  – Isolation valves
• CSA C448 - Design and Installation of Earth Energy Systems
Ground Source

- What is it?
  - Efficient system connected with the ground?
- Heat recovery system?
  - Recover energy from season to season?
Are Ground Source Systems a Renewable Energy Source?

RENEWABLE ENERGY

The term “Renewable Energy” means electric or thermal energy, generated from or avoided by solar, wind, biomass, landfill gas, ocean (including tidal, wave, current, and thermal), geothermal (including ground source, reclaimed water, or ground water), municipal solid waste, or new hydroelectric generation capacity achieved from increased efficiency or additions of new capacity at an existing hydroelectric project.

And for the purposes of determining compliance with renewable portfolio and/or efficiency standard requirements, “Renewable Energy” is deemed any energy consumption that is avoided through the use of renewable energy, and shall be considered as renewable energy produced.
The earth absorbs nearly half of the sun’s energy.

The earth is like a “solar battery,” absorbing nearly half of the sun’s energy. The ground stays a relatively constant temperature throughout the seasons, providing a warm heat source in the winter and a cool heat sink in the summer.
Energy Efficient Heating: Coefficient of Performance

1 unit of energy from utility company

3 to 4 units of “free” energy from the earth

4 to 5 units of energy delivered into home
Key to Good System Design

A. Is ground source a proper selection?
B. Interior Design
C. Physical Constraints of the Ground
Opportunities for Improving Design

- **Efficiency**
  - Pumping power
  - Heat pumps
  - Ground loop design

- **Simplicity**
  - One-pipe systems
Developing 12-Steps

A. Proper selection
   1. Calculate peak and OFF-peak loads
   2. Estimate energy to and from the bore field

B. Interior Design
   3. Select operating temperatures
   4. Correct heat pump operation for actual conditions
   5. Select HPs for peak load (heating or cooling) and minimize duct runs
   6. Arrange HPs into building circuits
Developing 12-Steps

C. Physical Constraints of the Ground
   7. Conduct investigation for thermal properties and drilling conditions
   8. Determine ground heat exchanger arrangement
   9. Calculate optimum ground heat exchanger dimensions

D. Integration of indoor and outdoor design
   10. Iterate to determine optimum operating temperatures, flows, materials
   11. Layout Interior piping for minimum head loss
   12. Select pumps and control methodology
Is Ground Source A A Proper Selection?
Ground Source
“The Efficiency Silver Bullet”

- The most efficient HVAC system there is!!!
- It works everywhere!!!
- XXX m/kW (xx ft/ton) is adequate everywhere!!!
Applicability

• Depends on:
  – Building energy balance
  – Undisturbed ground temps
  – Site characteristics

• Is there a hybrid design opportunity?
  – High heating and low cooling demand
  – High cooling with low heating demand
Ground Source Sizing

• Building energy estimate
• Idea of how the building will operate
• Drilling requirements
• Some reference of ground thermal conductivity and thermal diffusivity
Estimating Energy Usage

• Don’t use ‘Rules of Dumb’
• Equipment efficiency affects bore field sizing
• Perform the Calculations!
  – Bin data or 8760 hour simulation to understand the energy coming into the facility and going out
Energy Recycling

Bore field acts as a battery, storing heating energy in the summer and releasing it in the winter.
Real-World Loading

Cooling Energy >> Heating Energy

Heat in bore field is likely to increase
Hybrid Geo-Exchange Systems

Excess Heat

FLUID COOLER

Cooling Dominated
Calculate Peak and Off-Peak Loads
## Peak and Off Peak loads

### Energy Pulses

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Winnebago School</th>
<th>Location</th>
<th>Rockford IL 10 Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Area</td>
<td>40000 SQ. FT.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COOLING</td>
<td>91 TONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEAT</td>
<td>800.9 MBTUH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### COOLING LOAD

<table>
<thead>
<tr>
<th>FLCH</th>
<th>9-12</th>
<th>1-4</th>
<th>5-8</th>
<th>8-8</th>
<th>Tons</th>
<th>Ton Hours</th>
<th>Cool. Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>930</td>
<td>1095</td>
<td>371</td>
<td>221</td>
<td>91</td>
<td>29127</td>
<td>349528</td>
</tr>
</tbody>
</table>

### HEATING LOAD

<table>
<thead>
<tr>
<th>FLHH</th>
<th>9-12</th>
<th>1-4</th>
<th>5-8</th>
<th>8-8</th>
<th>438 sq ft/ton</th>
<th>BTUH/FT^2</th>
<th>Ton Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-801</td>
<td>-736</td>
<td>-668</td>
<td>-658</td>
<td>20.02</td>
<td>71543</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat. Energy</th>
<th>1340</th>
<th>53</th>
</tr>
</thead>
</table>
Estimate Energy To and From the Bore Field
Building uses more energy for cooling than for heating.

Seasonal Energy Usage

Seasonally Stored Energy for Cooling

Seasonally Stored Energy for Heating
10-Month School In Colder Climate
Interior Design
Interior Design Concerns

- The interior is where most of the $ are spent on Ground source systems
- Controls should be minimal and add value
- Systems operate in a temperature range, unlike chilled and hot water
- Flow should be controlled with Heating and cooling demand
Components of Commercial Ground Source System

KEY:
- Ground Coupled heat exchanger
- Piping Network
- Pumps
- Water source heat pumps
- Controls

Do We Need All of This???????
Please do your own pump pressure drop calculations!!!
Pumping Power

**Pumping Power Benchmarks**

<table>
<thead>
<tr>
<th>Pumping Pwr / Clg Cap. Pump kWe/100 kWe</th>
<th>Grade</th>
<th>Allowable Pump Head (m) w/ 60% Eff Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 or Less</td>
<td>1.06 or less</td>
<td>A- Excellent</td>
</tr>
<tr>
<td>50-75</td>
<td>1.06-1.59</td>
<td>B- Good</td>
</tr>
<tr>
<td>75-100</td>
<td>1.59-2.12</td>
<td>C- Mediocre</td>
</tr>
<tr>
<td>100-150</td>
<td>2.12-3.18</td>
<td>D- Poor</td>
</tr>
<tr>
<td>&gt;150</td>
<td>&gt;3.18</td>
<td>F- BAD</td>
</tr>
</tbody>
</table>

Pump Heads are calculated at 2.69 LPM/kW for 3.23 lpm / kW reduce values by 17%.
Direct Flow without Loop Temp Control

Attributes
- Heat Pump flow managed by regulator valves
- Demand Fluid Control
- Flow Regulator volume control

Challenges
- System changes managed with flow regulators
- Pipe Length/ pressure loss
- Heat/cool energy exchange at bore field
- Last heat pump can be short of water flow
- Central pump must be sized for connected load
Reverse Return
without Loop Temp Control

Attributes
- Demand Fluid Control
- Flow regulator volume control
- Equal pipe length to each heat pump

Challenges
- System changes managed with flow regulator valves
- Pipe Length/ pressure loss
- Heat/cool energy exchange at bore field
- Central Pump must be sized for connected load
One-Pipe Loop
Distributed Primary Secondary Loop

Attributes
- Demand Fluid Control
- Secondary pump flow control
- Little loop temp control
- Unit by unit diversity
- No flow regulators
- Low system pump head
- Primary pump can be sized for BLOCK load conditions
- No drive/pump/static control head inefficiency

Challenges
- Temperature control
- Pipe Length/pressure loss
- Last heat pump will have warmer/cooler water
“Heat Recovery, Anyone????”

Attribute

One-pipe loop allows heat pumps to recover energy from the other units in the system.

Cooling units add heat to the loop, heating units extract heat…

It doesn’t take VRF to have heat recovery.
Piping Diagrams

Traditional 2-pipe arrangement

1-pipe arrangement

Heat pump
Parallel Pump Curve

Parallel pump operating point
2.3 kW (8.1 Wm/kWt)

Individual pump operating point
1.3 kW (4.5 Wm/kWt)

Single pump and parallel pump operation allow for greatly reduced pump horsepower usage during normal operation. No speed control is required.

757 lpm @ 12.2m Parallel pumps
625 lpm @ 8.2m Single pump
Heat Pumps
Effect of Temperature Control on Performance

System EER

- UNIT EER
- Variable Flow EER
- UNIT COP
- Variable Flow COP

TEMP (F) vs EER vs COP

- EER: 0, 5, 10, 15, 20, 25, 30
- COP: 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7

Graph highlights the relationship between temperature and performance metrics for system EER.
Water Source Heat Pumps
(Self-Contained Approach)

• Many consider: Traditional Equipment
  • Horizontal Units
  • Vertical Units
  • Water to Water
  • Console Units
Water Source HP’s, Traditionally

- “100’s of noisy boxes” above the ceiling
- “Require” cooling towers or boilers “to work right”
- 2-pipe controlled water distribution
  - Water flow control
  - Motorized isolation valves
  - Variable speed drives
- Have maintenance issues
  - Low flow at the end of the distribution
  - Low temp difference
New Paradigm

• Many different heat pump systems
• When properly designed and implemented, ground loops can provide all system heat rejection and heat addition
• Water distribution
  – Traditional 2-pipe variable capacity
  – Individual circulations
  – Circulators with central pumps
  – One pipe
• Lower maintenance costs
  – Simpler distribution
  – Managing flow to the units
Preliminary Loop Operating Temperatures and Flow Rate
Selecting Operating Temperatures

- A good starting point
  - Undisturbed ground temp
    - Cooling 10-20°C (20-35°F) Above
    - Heating 5-10°C (10-15°F) Below
- Generally, max cooling inlet temps should be below 32.2°C (90°F)
- Generally, min heating above 0°C (Use 7-8°C to start)
- Final selection based on energy balance
- It’s ALL about SYSTEM EER and COP
Correct Heat Pump Operation for Actual Conditions
HP Performance Ratings

- AHRI/ISO/ASHRAE/ANSI 13256-1 - Water-source heat pumps - testing and rating for performance - Part 1: Water-to-air and brine-to-air heat pumps
- EN 14825 - Air Conditioners, Liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling – Testing and rating at part-load conditions and calculations of seasonal performance
Why Adjust Unit Capacity?

• Under ISO 13256-1
  – What is the system fan static pressure for rating?
  – What is the pumping energy based upon?

• What are the entering water and air conditions?
Adjusting Unit Capacity

- ISO 13256-1
  - 0 kPa static pressure
  - 25°C (77°F EWTc) / 0°C (32°F) EWTh
  - 19°C (66.2°F) EWB Cooling
  - 20°C (68°F) EDB Heating
  - Pumping power is included

Some manufacturer’s programs properly adjust the capacity based on your operating conditions, some do not. The point is, capacity adjustment is required to properly select the required equipment.
# Heat Pump Ratings

## Performance Summary

**ARI/ISO/ASHRAE/ANSI 13256-1**

**Performance Ratings**

**English (IP) Units**

<table>
<thead>
<tr>
<th>Model</th>
<th>Capacity Modulation</th>
<th>Flow Rate</th>
<th>Water Loop Heat Pump</th>
<th>Ground Water Heat Pump</th>
<th>Ground Loop Heat Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gpm</td>
<td>cfm</td>
<td>Capacity</td>
<td>EER</td>
<td>Capacity</td>
</tr>
<tr>
<td>026</td>
<td></td>
<td></td>
<td>Btu/h</td>
<td>Btu/h/W</td>
<td>Btu/h</td>
</tr>
<tr>
<td>Full</td>
<td>8</td>
<td>900</td>
<td>25,000</td>
<td>14.6</td>
<td>30,500</td>
</tr>
<tr>
<td>Part</td>
<td>7</td>
<td>700</td>
<td>18,500</td>
<td>16.6</td>
<td>22,000</td>
</tr>
<tr>
<td>038</td>
<td></td>
<td></td>
<td>34,000</td>
<td>14.6</td>
<td>40,100</td>
</tr>
<tr>
<td>Full</td>
<td>6</td>
<td>800</td>
<td>25,000</td>
<td>16.6</td>
<td>30,000</td>
</tr>
<tr>
<td>Part</td>
<td>6</td>
<td>800</td>
<td>25,000</td>
<td>16.6</td>
<td>30,000</td>
</tr>
<tr>
<td>049</td>
<td></td>
<td></td>
<td>45,000</td>
<td>14.0</td>
<td>55,800</td>
</tr>
<tr>
<td>Full</td>
<td>12</td>
<td>1500</td>
<td>50,300</td>
<td>14.7</td>
<td>67,100</td>
</tr>
<tr>
<td>Part</td>
<td>11</td>
<td>1300</td>
<td>50,300</td>
<td>14.7</td>
<td>67,100</td>
</tr>
<tr>
<td>064</td>
<td></td>
<td></td>
<td>60,400</td>
<td>13.3</td>
<td>80,600</td>
</tr>
<tr>
<td>Full</td>
<td>15</td>
<td>1800</td>
<td>60,400</td>
<td>13.3</td>
<td>80,600</td>
</tr>
<tr>
<td>Part</td>
<td>15</td>
<td>1800</td>
<td>60,400</td>
<td>13.3</td>
<td>80,600</td>
</tr>
</tbody>
</table>
Select HPs for Peak Load (Heating or Cooling) and Minimize Duct Runs
### HEAT PUMP UNIT SCHEDULE

<table>
<thead>
<tr>
<th>S.A. (CFM)</th>
<th>ESP (IN W.C.)</th>
<th>COOLING</th>
<th>HEATING</th>
<th>WATER FLOW (GPM)</th>
<th>H.P. WPD (FT)</th>
<th>PUMP HEAD (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CAPACITY (BTH)</td>
<td>EWT (°F)</td>
<td>EER</td>
<td>CAP. TOTAL (BTH)</td>
<td>EWT (°F)</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>900</td>
<td>0.55</td>
<td>25.7</td>
<td>16.7</td>
<td>90</td>
<td>14.1</td>
<td>22.7</td>
</tr>
<tr>
<td>900</td>
<td>0.55</td>
<td>25.7</td>
<td>16.7</td>
<td>90</td>
<td>14.1</td>
<td>22.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>1,830</td>
<td>0.80</td>
<td>62.6</td>
<td>46.1</td>
<td>90</td>
<td>16.1</td>
<td>54.1</td>
</tr>
<tr>
<td>1,830</td>
<td>0.80</td>
<td>62.6</td>
<td>46.1</td>
<td>90</td>
<td>16.1</td>
<td>54.1</td>
</tr>
<tr>
<td>1,050</td>
<td>0.35</td>
<td>30.1</td>
<td>20.4</td>
<td>90</td>
<td>12.9</td>
<td>26.7</td>
</tr>
<tr>
<td>3,440</td>
<td>0.50</td>
<td>113.6</td>
<td>79.1</td>
<td>90</td>
<td>13.3</td>
<td>109.3</td>
</tr>
<tr>
<td>3,440</td>
<td>0.50</td>
<td>113.6</td>
<td>79.1</td>
<td>90</td>
<td>13.3</td>
<td>109.3</td>
</tr>
</tbody>
</table>
Is this sufficient to define the System requirements?
System Definition Requirements

• Design parameters
  – Flow
  – Pressure loss
  – Water quality and volume
  – Antifreeze solution and volume, if required

• Header pipe definition
  – Material
  – Diameter
  – Pressure class rating
  – Circuit isolation requirements
  – Flush/purge provisions
System Definition Requirements

• Vertical bore definition
  – Drilling technique if available
  – Casing requirements, if any
  – Bore depth and approximate bore diameter
  – Grout Definition
    • Thermal Conductivity
    • Placement method

• Equipment specification
  – Airflow and pressure drop
  – Heating and cooling capacity
  – EER and COP
  – Water flow and pressure drop
  – Electrical characteristics
  – Air filtration specification
System Definition Requirements

- **Inside Building**
  - Piping specification
  - Pumping system
  - Control Specification
  - System diagram
    - Air separation
    - Compression
    - Make-up

- **Commissioning**
  - Piping installation inspections and testing
  - Purge volume and flow
  - Purge procedure
  - System start-up procedure
  - Start-up documentation
Cleaning and Flushing

GENERAL NOTES:

1. PIPE CLEANING AND CLEANING PROCEDURE:
   THE CLOSED LOOP SYSTEM WATER PIPING MUST BE THOROUGHLY CLEANED AND FLUSHED TO REMOVE DIRT, CHIPS, AND
   OTHER FOREIGN MATERIALS PRIOR TO CONNECTING THE HEAT PUMPS TO PIPING SYSTEM. COUPLE THE HEAT PUMP
   SUPPLY & RETURN PIPING CROSS CONNECTIONS AND FILL LOOP WITH A SOLUTION CONSISTING OF 1% TO 2% OF LIQUID
   TRISODIUM PHOSPHATE DETERGENT AND FRESH CLEAN WATER. REPAIR LEAKS AS REQUIRED. USE VALVES TO BYPASS
   HEAT REJECTOR AND SUPPLEMENTARY WATER HEATER (WHERE APPLICABLE). FLUSH SYSTEM FOR A MINIMUM OF TWO
   HOURS MONITORING SYSTEM BLOW DOWN UNTIL WATER RUNS CLEAR. ONCE CLEAN, STOP THE PUMP AND CLEAN ALL
   SYSTEM STRAINERS. REMOVE TEMPORARY CROSS CONNECTION AND CONNECT LOOP SUPPLY AND RETURN PIPING TO
   HEAT PUMP UNITS.

2. ANTI-FREEZE SOLUTION BY INTERIOR BUILDING CONTRACTOR (FOR INTERIOR & EXTERIOR PIPING):
   AFTER COMPLETION OF THE PIPE CLEANING AND CLEANING PROCEDURES SPECIFIED ABOVE, SYSTEM SHALL BE FILLED
   WITH A SOLUTION OF 15% PROPYLENE GLYCOL AND 85% WATER BY VOLUME. PROPYLENE GLYCOL SHALL BE DOWNFROST
   HD PHOSPHATE-BASED INDUSTRIALLY INHIBITED HEAT TRANSFER FLUID OR APPROVED EQUAL. DESIGN FREEZING POINT
   OF MIXED SOLUTION SHALL BE APPROX. 19.0 DEG. F. USING A HAND HELD OPTIC REFRACTOMETER INSTRUMENT, THE
   CONTRACTOR SHALL TEST, ADJUST AND RECORD FINAL FREEZING POINT OF MIXED SOLUTION OF PROPYLENE GLYCOL.
   SUBMIT "FREEZING POINT OF SOLUTION" TEST RESULTS TO ENGINEER FOR REVIEW AND APPROVAL.

3. CHEMICAL TREATMENT:
   a. GENERAL: CHEMICALS SHALL BE SPECIALLY FORMULATED TO PREVENT ACCUMULATION OF SCALE AND CORROSION
      IN CLOSED LOOP PIPING SYSTEMS AND CONNECTED EQUIPMENT. CHEMICAL FORMULATION DEVELOPED SHALL BE
      BASED ON A LABORATORY ANALYSIS OF THE SYSTEM MAKE-UP WATER SUPPLY CHEMISTRY.
   b. CORROSION INHIBITOR: PROVIDE SODIUM NITRITE/BORATE, MOLYBDENUM-BASED INHIBITOR OR OTHER APPROVED
      PROPRIETARY FORMULATION SUITABLE FOR WATER MAKE-UP QUALITY AND QUANTITY REQUIRED. INHIBITOR
      FORMULATION SHALL INCLUDE ADEQUATE BUFFER TO MAINTAIN A SYSTEM pH RANGE OF 8.0 TO 10.5. INTRODUCE
      INHIBITOR COMPOUNDS INTO SYSTEM MANUALLY THROUGH THE BY-PASS TYPE SHOT FEEDER/FILTER ASSEMBLY
      PROVIDED IN THE SYSTEM.
   c. CORROSION INHIBITOR PERFORMANCE: INHIBITOR PROVIDED SHALL PROTECT VARIOUS WETTED MATERIALS OF
      CONSTRUCTION INCLUDING FERROUS, RED & YELLOW METALS & MAINTAIN THE SYSTEM ESSENTIALLY FREE OF SCALE,
      CORROSION AND FOULING. CORROSION RATES OF THE FOLLOWING METALS SHALL NOT EXCEED THE PENETRATION
      SPECIFIED IN MILS/YEAR: FERROUS, 0.20; BRASS, 0.10; COPPER, 0.10. INHIBITOR SHALL REMAIN STABLE THROUGH
      THE SYSTEM OPERATING TEMPERATURE RANGE. HEAT EXCHANGE FOULING AND CAPACITY REDUCTION SHALL NOT
      EXCEED THAT ALLOWED BY A FOULING FACTOR OF 0.0005.
Why Is Pumping Power Important?

<table>
<thead>
<tr>
<th>kW_{m}/100kW_t</th>
<th>HP/100 tons</th>
<th>watts</th>
<th>HP/watts</th>
<th>Total Watts</th>
<th>Effective EER</th>
<th>%loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.06</td>
<td>5.0</td>
<td>3730</td>
<td>66667</td>
<td>70397</td>
<td>17.0</td>
<td>5.30%</td>
</tr>
<tr>
<td>1.59</td>
<td>7.5</td>
<td>5595</td>
<td>66667</td>
<td>72262</td>
<td>16.6</td>
<td>7.74%</td>
</tr>
<tr>
<td>2.12</td>
<td>10.0</td>
<td>7460</td>
<td>66667</td>
<td>74127</td>
<td>16.2</td>
<td>10.06%</td>
</tr>
<tr>
<td>3.18</td>
<td>15.0</td>
<td>11190</td>
<td>66667</td>
<td>77857</td>
<td>15.4</td>
<td>14.37%</td>
</tr>
<tr>
<td>4.24</td>
<td>20.0</td>
<td>14920</td>
<td>66667</td>
<td>81587</td>
<td>14.7</td>
<td>18.29%</td>
</tr>
<tr>
<td>5.30</td>
<td>25.0</td>
<td>18650</td>
<td>66667</td>
<td>85317</td>
<td>14.1</td>
<td>21.86%</td>
</tr>
</tbody>
</table>

HP watts based on EER 18
Physical Constraints of the Ground
Bore field Arrangements
Conduct Investigation for Thermal Properties and Drilling Conditions
Thermal Properties for Design

- Thermal Conductivity
- Deep Earth Temperature
- Thermal Diffusivity
The purpose of the test is to determine the physical properties of the ground surrounding the bore hole.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Slope</th>
<th>Average He (Btu/hr-ft)</th>
<th>at Input (W/ft)</th>
<th>Thermal Conductivity (Btu/hr-ft°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10—44</td>
<td>4.3</td>
<td>21.25</td>
<td></td>
<td>1.34</td>
</tr>
</tbody>
</table>
Typical Bore Detail

1.2m

100m

(1) U PE100 PN 16

**LOCAL DRILL LOG INFORMATION**

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>DEPTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOOSE DIRT</td>
<td>0' - 5'</td>
</tr>
<tr>
<td>BROWN CLAY</td>
<td>5' - 11'</td>
</tr>
<tr>
<td>GREY CLAY</td>
<td>11' - 24'</td>
</tr>
<tr>
<td>BLACK PEAT</td>
<td>24' - 28'</td>
</tr>
<tr>
<td>SOFT GREY CLAY</td>
<td>28' - 51'</td>
</tr>
<tr>
<td>SANDY GREY CLAY</td>
<td>51' - 55'</td>
</tr>
<tr>
<td>SAND STREAK</td>
<td>55' - 56'</td>
</tr>
<tr>
<td>SOFT GREY CLAY</td>
<td>56' - 64'</td>
</tr>
<tr>
<td>ROCKY GREY CLAY</td>
<td>64' - 76'</td>
</tr>
<tr>
<td>LIMESTONE &amp; SHALE</td>
<td>76' - 91'</td>
</tr>
<tr>
<td>SOFT GREY SHALE</td>
<td>91' - 93'</td>
</tr>
<tr>
<td>LIMESTONE</td>
<td>93' - 94'</td>
</tr>
<tr>
<td>GREY SHALE</td>
<td>94' - 155'</td>
</tr>
</tbody>
</table>

FOIL BACKED WARNING TAPE (ALONG ENTIRE LENGTH OF HEADER TRENCH)

PROVIDE #14 TRACER WIRE ABOVE HEADERS

FINAL GRADE (DIRT OR HARD SURFACE)

12" - 18"

BACK FILL WITH PEA GRAVEL OR COURSE SAND. 3" ABOVE PIPING & 3" BELOW PIPING.

BEND RADIUS PER PIPE

SUPPLIERS SPECIFICATIONS

PUMPED CONTINUOUS GROUT WITH "TRIMMIE PIPE", THERMALLY ENHANCED GROUT 1.9 MIN, SEE SPECIFICATIONS.
Calculate GLHX Requirements
Output from Loop Sizing Routine

Required BORE length with minimal groundwater movement = 14770 ft (492 ft/bore)
(Design based on COOLING mode - net annual heat rejection to ground)

Required BORE lengths with high rates of groundwater movement (or year 1)
Cooling: L = 13490 ft (450 ft/bore), Heating: L = 11640 ft (395 ft/bore)

Unit Inlet (cooling) = 85.0 degrees F
Unit Outlet (cooling) = 97.2 degrees F
Unit Inlet (heating) = 45.0 degrees F
Unit Outlet (heating) = 37.8 degrees F
Normal ground temp = 55.0 degrees F

Cooling Load/Demand = 850 kBtu/h / 67 kW
Heating Load/Demand = 448 kBtu/h / 33 kW
Cooling EER (Ht Pump/Sys) = 12.8 / 12.2
Heating COP (Ht Pump/Sys) = 4.0 / 3.8
Loop Pump Head/Flow Rate = 40 ft / 177 gpm
Loop Pump Power/Demand = 2.8 hp / 2.2 kW

Total Heat Pump Capacity = 876.6 kBtu/h (cooling)
Total Heat Pump Capacity = 916.4 kBtu/h (heating)

U-tube Diameter = 1.00 inch
Separation dist. = 20.0 ft
Grid = 5 wide by 6 deep
Grout Conductivity = 1.00 Btu/hr-ft- degrees F
Bore Diameter = 5.30 inches

Bore Resistance = 0.173 hr-ft-F/Btu
Ground Resistance (Cooling) = 0.439 hr-ft-F/Btu
Ground Resistance (Heating) = 0.486 hr-ft-F/Btu

Thermal Conductivity = 1.30 Btu/hr-ft-degrees F
Thermal Diffusivity = 1.05 ft²/day

Ground Temperature = 55.0 degrees F
Iterate to Optimize GLHX

1- Balancing length with operating Temperatures

Required BORE length with minimal groundwater movement = 11880 ft (396 ft/bore)
(Design based on COOLING mode - net annual heat rejection to ground)

Required BORE lengths with high rates of groundwater movement (or year 1)
Cooling: L= 10810 ft (361 ft/bore), Heating: L= 10880 ft (363 ft/bore)

Unit Inlet (cooling) = 95.0 degrees F
Unit Outlet (cooling) = 107.5 degrees F
Unit Inlet (heating) = 44.0 degrees F
Unit Outlet (heating) = 36.8 degrees F
Normal ground temp = 55.0 degrees F

Required BORE length with minimal groundwater movement = 12150 ft (405 ft/bore)
(Design based on COOLING mode - net annual heat rejection to ground)

Required BORE lengths with high rates of groundwater movement (or year 1)
Cooling: L= 11010 ft (387 ft/bore), Heating: L= 10370 ft (346 ft/bore)

Unit Inlet (cooling) = 95.0 degrees F
Unit Outlet (cooling) = 107.8 degrees F
Unit Inlet (heating) = 44.0 degrees F
Unit Outlet (heating) = 37.2 degrees F
Normal ground temp = 55.0 degrees F

Required BORE length with minimal groundwater movement = 11540 ft (385 ft/bore)
(Design based on COOLING mode - net annual heat rejection to ground)

Required BORE lengths with high rates of groundwater movement (or year 1)
Cooling: L= 10460 ft (349 ft/bore), Heating: L= 10240 ft (342 ft/bore)

Unit Inlet (cooling) = 97.0 degrees F
Unit Outlet (cooling) = 109.6 degrees F
Unit Inlet (heating) = 44.0 degrees F
Unit Outlet (heating) = 37.3 degrees F
Normal ground temp = 55.0 degrees F

2- Changing to Different Equipment

3- Balancing with Different Equipment
Determine Ground Heat Exchanger (GLHX) Arrangement
Ground loop design Parameters

- Pressure loss under 20 ft tdh
- Ability to purge ALL piping at 2 fps
- Allow the bore field to be self balancing
- Consider proper water chemistry
  - Anti freeze protection
  - Corrosion inhibitors
Basic Header Types

• None
  – Loop connected directly to equipment

• Close Coupled
  – U-loops connected to end of the pipe

• Vaults
  – Reverse return circuits connected to headers in valve vaults

• Reverse Return
  – Header piping connected to circuits with reverse return piping and underground valves

• Direct Return
  – Header piping connected to circuits with direct return piping and underground valves
Close Coupled
Vaults
Inexperienced design keys

Trenching shown on both sides of the string of bores

Balance is affected by lack of reverse return
Balancing considerations are problematic

Cross trenching, direct supply and return
Fix the balance issue by adding valves
Reverse Return

- Circuits are generally pressure balanced throughout the system
- First supplied is last returned
- Each bore sees the same length of piping material
Direct Return

• The U-loops are in control of the pressure loss throughout the system

• The valve authority of the U-loop control flow
Header Configurations

Vault

Reverse Return

Direct Return
Header Configurations

Carlson relationship
Circuit pressure loss >80% of overall PD = balanced flow
Bore Field Don’ts

•---- use vaults
•---- require cross-trenching
•---- use pure Bentonite grout
•---- put bores any closer than 20 ft (6.1m) OC.
•---- put flow controls on loops
Use good design practices for header design
Close coupled
Reverse return
Direct return with knowledge of U-loop flow control

- Bore Field and Building Purge Assembly
- Connecting Piping
  - DR 15.5 HDPE
- HDPE SDR 11 UNI-LOOP
- Total Field Pressure Loss
  - 20 ft $H_2O$ (60 kPa)
- Thermally enhanced grout
Energy Expectations

• What happens if you follow these guidelines......
Washington Elementary School
Belvidere, Illinois

Geothermal HVAC System retrofit
105,000 sq. ft.
60+ classrooms
One Pipe Design
Energy recovery ventilation
Digital control system
Lighting retrofit throughout the classrooms
VRF (Variable Refrigerant Flow) in office area
Annual operating cost savings -$64,000
Renovation over 1 summer

$26.12/ sq ft

Client:
Belvidere Community Unit
School District 100
1201 5th Avenue
Belvidere, IL 61008
815-544-0301
Contact: Michael Houselog, Superintendent
Ground Source System
One-Pipe Design
Retrofit of existing school
23,980 sq. ft.
15 Classrooms
Approximately 192 students (08-09)
Retrofit cost under $20.00/sq ft
Ground Source System
One-Pipe Design
Retrofit of existing school
29,090 sq. ft.
19 Classrooms
237 students (2007-2008)
Installation cost- Under $20.00/sq ft
Annual energy usage-30.1 KBTU/Sq ft
Geothermal HVAC System retrofit
One Pipe Design
27,110 sq. ft.
14 classrooms
Installation Cost - $15.75/sq ft
Energy Star 99
Geothermal HVAC System retrofit
35,125 sq. ft.
24 classrooms
One Pipe Design
Provided heating and cooling system retrofit of existing hot water unit vent system
Operating cost for heating and cooling to be under heating only costs
Energy Star Rating of 98
Geothermal HVAC System
One-Pipe Design
44,168 sq. ft.
28 classrooms
Former operating cost $.99/ft^2
New Operating cost $.76 ft.^2 ($0.45 ft^2 lights)
$.23/ft.^2/year in HVAC energy savings
Carbon equivalent savings 13-14 #/sq. ft./year
Energy Star Rating of 96
Geothermal HVAC system retrofit
One Pipe Design
Well Field Design
Water Loop specification and design
Control System Design
Specification of test boring
Power distribution to
Ground Source System
Grades K-2
362 students
36,000 sq. ft. (School was built in 1957.)
23 classrooms
Geothermal HVAC system retrofit
One-Pipe Design
Well Field Design
Water Loop specification and design
Control System Design
Specification of test boring
Thermal Conductivity Analysis
Power distribution to Ground Source System

39,020 sq. ft.
26 classrooms
427 students (2007)

Client:
Sterling Community Unit District No. 5
410 E. LeFevre
Sterling, IL 61081
815-626-5050
Contact: Dr. Wil Booker, Superintendent
Case Study:

MEM Independence
Case Study: MEM Independence

- Missouri Employers Mutual
- Independence, Missouri
- 557 m² office facility renovated from rooftop A/C to Ground Source
- First 2 years of results – Less than impressive $600 per year in additional operating cost.
Building Energy Consumption
As Designed
1. Install variable speed circulators to pump the bore field based on temperature differential
2. Install hydronic de-coupler (bridge)
3. Install circulators on each heat pump
Ultimate Solution: Building Energy Consumption

<table>
<thead>
<tr>
<th>Degree days</th>
<th>% savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>52.64%</td>
</tr>
<tr>
<td>200</td>
<td>53.65%</td>
</tr>
<tr>
<td>300</td>
<td>54.51%</td>
</tr>
<tr>
<td>400</td>
<td>55.31%</td>
</tr>
<tr>
<td>500</td>
<td>56.11%</td>
</tr>
<tr>
<td>600</td>
<td>56.91%</td>
</tr>
<tr>
<td>700</td>
<td>57.74%</td>
</tr>
<tr>
<td>800</td>
<td>58.60%</td>
</tr>
<tr>
<td>900</td>
<td>59.50%</td>
</tr>
<tr>
<td>1000</td>
<td>60.46%</td>
</tr>
<tr>
<td>1100</td>
<td>61.48%</td>
</tr>
<tr>
<td>1200</td>
<td>62.58%</td>
</tr>
</tbody>
</table>
What have we learned?
Lessons Learned

• Pumping energy use is not an insignificant issue.

• Decoupling bore field and using temperature differential to control bore field capacity offers significant benefits.

• Minimizing head on unit circulators is beneficial.

• Low efficiency circulators can provide high efficiency.
Questions
HVAC System Designer

• Responsible for
  – Thermodynamics of the system
  – Design of system hydronics
  – Specification of the entire HVAC system
    • The ground HX is part of it!
  – The entire system performance
Some Background

- Vocabulary
- Codes and Standards
- References
Geothermal resources classification by temperature:

**High Temperature** \( t > 150 \, ^\circ C \) \( (300 \, ^\circ F) \)

**Intermediate Temperature**
\( 90 \, ^\circ C \) \( (195 \, ^\circ F) < t < 150 \, ^\circ C \) \( (300 \, ^\circ F) \)

**Low Temperature** \( t < 90 \, ^\circ C \) \( (195 \, ^\circ F) \)

- Direct Use
- Ground-Coupling
Vocabulary

• Ground Source, Geo-Exchange, Ground Coupled – A heating and cooling system that uses the ground as a moderator. The ground acts as a heat sink for heating and cooling energy.

• Geothermal – A heating system that typically uses “hot rocks” or a high temperature aquifer for direct heating or energy production.

• Central Plant – A heating and/or cooling system where multiple facilities are tied together such that the single plant can produce the necessary energy or resource.
Vocabulary

• Well – A water-producing bore typically with a submersible pump.
• Bore – An approximately 15 cm (6 in.) hole drilled into the geological formation.
• Borehole, U-loop Heat Exchanger, etc. – A typically vertical u-loop pipe (or ground probe) placed into a bore and grouted into position.
• Bore Field – Accumulation bores designed to be connected with header piping to support a ground source heating and cooling system.
Vocabulary

- **GCHP** – Ground Coupled Heat Pump
- **EER** – Energy Efficiency Ratio
- **SEER** – Seasonal Energy Efficiency Ratio
  - Does NOT apply to GCHP
- **COP** – Coefficient of Performance

**WARNING**

When making comparisons, be sure you are comparing equal terms. These terms can be applied to equipment or SYSTEMS. It is best to compare SYSTEM performance.
Energy Simulation Should Generate System Parameters

**Building Name**: Belvidere Washington Schc  
**Location**: Chicago Data

**Building Area** 96370 SQ. FT.  
**COOLING** 138 TONS  
**HEAT** 1531.7 MBTUH

**Base Electrical Usage**

- **Lights and Other Electrical Usage**: 427208.21 Kwh  
- **Annual Energy $**: 27768.534  
- **$0.29 $/ft^2**

**Geothermal One Pipe System Output**

- **HVAC Energy Use**: 265435.6 KWH  
  - **$17,253.32**  
  - **$0.18 $/ft^2**

- **Other Energy Use**: **$0.29 $/ft^2**  
  - **$0.47 $/ft^2**

**Kbtu/sq. ft./yr**: 24.53

**System EER**: 13.89  
**System COP**: 3.84

**SYSTEM HEATING AND COOLING EFFICIENCY AFFECTS PERFORMANCE, DESIGN AND SIZING**
System Integration
Layout Interior Piping for Minimum Head Loss
System Layouts

• Direct Flow
  – With 3-way control
  – With 3-way control and VFD
  – With secondary geo pump
  – Without loop temp control

• Reverse Return
  – With 3-way valve control
  – With secondary geo pump
  – Without loop temp control
Direct Flow with 3-Way Control

Attributes
- Control of water temp
  Summer and Winter 30/7
- Demand Fluid Control
- Flow Balance managed by Regulator Valves

Challenges
- System changes with each device added or subtracted from duty
- Pipe Length/pressure loss
- Control valve pressure loss/authority
- Heat/cool energy exchange at bore field
- Central pump must be sized for connected load
- Last Heat Pump can be short of water flow
Select Pumps and Control Method, Determine System Efficiency
Original Pumping Strategy

• Continuous pumping through all heat pumps
Solutions?

• What will make the system operate more efficiently?
  – Distributed pumping?
  – ASHRAE 90.1 variable flow solution?
  – One-pipe solution?
  – Something different?
Solution Considerations: Distributed Pumping
Solution Considerations:

ASHRAE 90.1

Install motorized isolation valves and variable speed primary pumps
Solution Considerations:

One-Pipe Solution

Required re-piping of the building