Design of Commercial Ground Source Heat Pumps

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- and -

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Steps to Improving Ground Source Design

Kirk Mescherer, 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?
Seminar Scope Limitation

• Today’s Seminar will concentrate on:
  – Design considerations for vertical ground loop heat exchanger systems
  – The design will be applicable to horizontal bore systems, surface water systems and open loop systems
  – We will not discuss, other than to introduce, the concept of a standing column system
Some Background

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

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

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

**Low Temperature** \( t < 90 \, ^\circ C \) (195 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 >>>>>>>>WARNING >>>>>>>>WARNING >>>>>>>>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.
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
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
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.
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
What is a Geo-Exchange Heating and Cooling System?

KEY:
- Ground Coupled heat exchanger
- Piping Network
- Pumps
- Water source heat pumps
- Controls
How Geo-Exchange Works

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

Geothermal Bore Field

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

Excess Heat

FLUID COOLER

Cooling Dominated
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
Key to Good System Design

A. Is ground source a proper selection?
B. Interior Design
C. Physical Constraints of the Ground
D. System Integration
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. System Integration
   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
Preliminary Ground Source Sizing

- Building energy estimate
- Idea of how the building will operate
- Drilling requirements
- Some reference of ground thermal conductivity and thermal diffusivity
Preliminary Estimates

• Don’t use ‘Rules of Dumb’

• Perform the Calculations!
  – Bin data or 8760 hour simulation to understand the energy coming into the facility and going out
## Energy Estimates

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<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
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<td>Building Name</td>
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<td>Building Area</td>
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<td>COOLING</td>
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<td>HEAT</td>
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<td>Occupancy</td>
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<td>Minimum Ventilation</td>
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<tr>
<td>Min Vent</td>
<td>2000 cfm</td>
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<td>Occupancy Ventilation</td>
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<td>Summer design temp</td>
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<td>Wetbulb</td>
<td>63 F</td>
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<td>Specific Humidity</td>
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<td>Wet Bulb</td>
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Calculate Peak and Off-Peak Loads
## Calculation of Peak and Off-Peak Loads

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<td>tons</td>
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<tr>
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## Annual Energy Usage

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### Base Electrical Usage

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<th>Annual Energy $</th>
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<tr>
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<td>Base Electrical Usage $/ft^2</td>
<td>$0.29</td>
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### Geothermal One Pipe System Output

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<th>HVAC Energy Use</th>
<th>265435.6 KWH</th>
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<td>$0.18 $/ft^2</td>
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<tr>
<td>Other Energy Use</td>
<td>$0.29 $/ft^2</td>
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<td></td>
<td>$0.47 $/ft^2</td>
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System EER 13.89
System COP 3.84

### System Efficiency

System heating and cooling efficiency affects performance, design, and sizing.
Estimate Energy To and From the Bore Field
Bore field acts as a battery, storing heating energy in the summer and releasing it in the winter.
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
## Loop Sizing Inputs

### Energy Pulses

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Interior Design
Heat Pumps
Effect of Temperature Control on Performance

System EER

Graph showing the effect of temperature control on system EER and COP for different flow rates. The graph includes lines for UNIT EER, Variable Flow EER, UNIT COP, and Variable Flow COP, plotted against temperature (F) on the x-axis and EER and COP on the y-axis.
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
Heat Exchanger Configurations

Open Loop

Surface Water

Horizontal Bore

Vertical Bore

Courtesy Water Furnace
Improving System Design: Simplicity

Everything should be made as simple as possible, but not simpler. \textit{\textasciitilde Albert Einstein}
Why Simple?

- Complexity adds $; does it add value?
  - How many control points do we need?
  - Does variable speed pumping add enough value?
  - Do we require digital control?

- Why ask the question – It’s $
  - Maintenance
  - Operation
  - Installation
Select 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 (77ºF EWTc) / 0ºC (32ºF) EWTh
  - 19°C (66.2ºF) EWB Cooling
  - 20°C (68ºF) 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**

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

*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>
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<td></td>
<td></td>
<td>gpm</td>
<td>cfm</td>
<td>Capacity Btuh</td>
<td>EER Btuh/W</td>
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Select HPs for Peak Load (Heating or Cooling) and Minimize Duct Runs
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<th>S.A. (CFM)</th>
<th>ESP (IN W.C.)</th>
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<th>HEATING</th>
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<th>H.P. WPD (FT)</th>
<th>PUMP HEAD (FT)</th>
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<td>EER</td>
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<td>20.4</td>
<td>90</td>
<td>12.9</td>
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<td>79.1</td>
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<td>109.3</td>
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<tr>
<td>3,440</td>
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<td>113.6</td>
<td>79.1</td>
<td>90</td>
<td>13.3</td>
<td>109.3</td>
</tr>
</tbody>
</table>
Arrange HPs into Building Circuits
Physical Constraints of the Ground
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.

This will be explained in further detail in Module 2.

<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>
Determine Ground Heat Exchanger (GLHX) Arrangement
Heat Exchanger Configurations

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

Courtesy Water Furnace
Typical Bore Detail

- 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 "trimmif pipe", thermally enhanced grout 1.9 min, see specifications.

(1) U PE100 PN 16

Local drill log information:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Depth</th>
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</thead>
<tbody>
<tr>
<td>Loose dirt</td>
<td>0' - 5'</td>
</tr>
<tr>
<td>Brown clay</td>
<td>5' - 17'</td>
</tr>
<tr>
<td>Grey clay</td>
<td>17' - 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>

100m
1.2m
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= 11840 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 / 67 kW
Heating Load/Demand = 449 kBtu / 33 kW
Cooling EER (Ht Pump/Sys) = 12.6 / 12.2
Heating COP (Ht Pump/Sys) = 4.0 / 3.8
Loop Pump Head/Flow Rate = 40 ft / 177 gpm
Loop Pump Power/Demand = 2.6 hp / 2.2 kW

Total Heat Pump Capacity = 876.6 kBtu (cooling)
Total Heat Pump Capacity = 916.4 kBtu (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 ft^2/day

Ground Temperature = 55.0 degrees F
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

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

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

HDPE SDR 11 UNI-LOOP

Total Field Pressure Loss
20 ft H₂O (60 kPa)

Connecting Piping
DR 15.5 HDPE

Thermally enhanced grout
System Integration
Iterate to Optimize GLHX

1- Balancing length with operating Temperatures

2- Changing to Different Equipment

3- Balancing with Different Equipment
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
Please do your own pump pressure drop calculations!!!
Select Pumps and Control Method, Determine System Efficiency

But more about this in Module 3...
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

GEO HEAT PUMP

M

FCV
Parallel Pump Curve

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
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.
Original Pumping Strategy

• Continuous pumping through all heat pumps
Building Energy Consumption

\[ y = -8.214 \ln(x) + 66.64 \]
• 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

P-1
62.5 GPM
71.0/70.5 FT

P-2
62.5 GPM
71.0/70.5 FT

AS -1

ET-1
7.3 GAL

HSS-1
189300/355400 BTU/H
62.5 GPM
39°F
96.4°F

P-1

HSS-1

Solution Considerations:

One-Pipe Solution

Required re-piping of the building
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>
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<tr>
<td>500</td>
<td>56.11%</td>
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<td>700</td>
<td>57.74%</td>
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<td>900</td>
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<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>
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</table>

\[ y = -4.226 \ln(x) + 33.107 \]

\[ y = -8.214 \ln(x) + 66.64 \]

After November 2011
Before November 2011
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.
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