New Technologies Increasing Geothermal System Efficiencies

Breakout Session Category: Commercial
Learning Objectives

• Understand how pumping Watts affects system efficiency
• Learn how new pumping technologies can change design considerations
• Learn about ASHRAE 90.1 considerations and ASHRAE Pumping Class categories
• Understand how component selection can impact system efficiency
• Traditional WSHP/Geothermal Pumping
  • Example constant speed application
  • Heat pump EER vs. system EER
• New Technologies
  • Large ECM variable speed circulators
  • Pumping Watts (ASHRAE)
  • System types
  • Part load heat pump operation
• Adding it all together
  • Component selection
  • Conclusions
• Q & A
Traditional WSHP / Geothermal Pumping

Example Constant Speed Application
Example Application – Central System*

- 56 ton geothermal application
- Various heat pump sizes (2 to 6 ton units)
- Three 5 HP system pumps (27 HP/100 tons)
  - Pumps were running 24 hours per day
- Estimated annual kWh was 40,978 (each pump)
  - $1680 @ $0.041/kWh + $465 in demand charge ($8.50/kW)
  - $2145 total per pump
- Replacement:
  - One dual head variable speed circulator in cascade operation (lead-lag)
  - Added zone valve to each heat pump

*Actual job in U.S. Midwest
Example Application – Central System

- 168 GPM @ 42 ft. of hd. (all heat pumps running)
- 2100 Watts (both pumps)
- 1 – 3.5 ton heat pump (50 Watts)
- 4 – 6 ton heat pumps running (350 Watts)
Example Application – Central System

- Even if new pumps ran 24 hours per day, it would be 60% of the Watts of just one of the 3 pumps (20% of 3 pumps)

- Adding differential pressure control allowed pump to lower RPM based upon number of heat pump zone valves open

- Lower RPM and higher efficiency pump lowered demand kW

- ECM circulators cost less than VFD driven closed-coupled pumps and are quieter when operating

- Final Outcome: 38 Watts/ton (original was 188 Watts/ton)
Traditional WSHP / Geothermal Pumping

Heat Pump EER vs. System EER
### Single Speed Heat Pump

**Ground Loop Heat Pump**

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<th>Fan Motor</th>
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Cooling capacities based upon 80.6°F DB, 66.2°F WB entering air temperature.
Heating capacities based upon 68°F DB, 59°F WB entering air temperature.
All ratings based upon operation at the lower voltage of dual voltage rated models.
Pumping contribution to system efficiency

- Manufacturers catalog data for COP/EER does not include pumping watts
- AHRI/ISO/ASHRAE 13256-1 certified data for COP/EER includes pump watts based on the following formula:
  - Pump power correction (W) = (gpm x 0.0631) x (Press Drop x 2990) / 300
  - Where "Press Drop" is the pressure drop through the unit’s heat exchanger at rated water flow in feet of head
- Example: 4 ton system with 10.5 ft-hd @12 gpm
  - Pump power correction = 79.2 Watts
  - This is incredibly low, and causes AHRI efficiency to be overstated in many cases
- Pumping watts can be significant, and will affect system COP/EER
System 1 (original):
10.5 kW ÷ 56 tons = 188 W/ton
188 x 4 tons = 752 Watts

System 2 (retrofit):
2100 W ÷ 56 tons = 37.5 W/ton
37.5 x 4 tons = 150 Watts*

\[
\text{System 1 EER} = \frac{50,300}{3230 + 752} = 12.6
\]

\[
\text{System 2 EER F/L}^* = \frac{50,300}{3230 + 150} = 14.9
\]

\[
\text{System 2 EER P/L}^* = \frac{50,300}{3230 + 58} = 15.3
\]

*2100 Watts occurs when all heat pumps are running. At 50%, power is 350W (less than AHRI correction) → See next slide
Part Load Operation – Big Opportunity for Savings

Moving from 168 gpm to 142 gpm reduces pump Watts to 1300 (one pump @ max instead of two pumps operating).

How often will the building load be at 47 tons (142 gpm) or less?
New Technologies

Large ECM Circulators
Large ECM Circulators

• Built-in pressure differential control
• Wet rotor circulator design (like small residential flow center)
• ECM motor
• Lead-lag or primary-backup (typically dual head)
• Wireless communication (e.g. backup pump can “talk” wirelessly to primary pump)
• BMS capable
• Large range of sizes
Single Head Pump Curves

1 pump = up to 100 tons
2 pumps = up to 200 tons
**Dual Head**

- **Alternating Operation**
  - Also provides backup if one pump fails
  - Dual head or two separate pumps

- **Back-up Operation**
  - Backup pump only operates during a failure of main pump
  - Backup pump is operated periodically to prevent seize-up
  - Dual head or two separate pumps

- **Cascade Operation**
  - Sometimes called Lead-Lag
  - Dual head or two separate pumps
  - Both pumps must be same size
Operating Modes

Constant Pressure

Maintain constant head across the system independent of flow in the system.

Geo units with zone valves
Operating Modes

Differential Temperature

Geothermal ground loop in a primary-secondary application

Maintain Constant Temperature
Delta across load
Operating Modes

External Setpoint

Use with controller for ground loop pump (separate htg/clg delta-T set points) on primary-secondary application

If an external 0–10V controller is installed, the pump is able to change from one constant curve to another, depending on the value of the external 0-10V signal. A 0V input represents the minimum constant curve. A 10V input represents the constant curve of the set point.
New Technologies

Pumping Watts
6.5.4.2 Hydronic Variable Flow Systems. HVAC pumping systems having a total pump system power exceeding 10 hp that include control valves designed to modulate or step open and close as a function of load shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to 50% or less of the design flow rate. Individual chilled-water pumps serving variable-flow systems having motors exceeding 5 hp shall have controls and/or devices (such as variable-speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The controls or devices shall be controlled as a function of desired flow or to maintain a minimum required differential pressure. Differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure. The differential pressure setpoint shall be no more than 110% of that required to achieve design flow through the heat

ASHRAE budget
Pumping Watts
= 22 W/gpm
(66 W/ton)

Earlier 4 ton unit
@ 12 gpm = 264 Watts
### ASHRAE RP-1674 (Kavanaugh/Rafferty)

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<td>65 &lt; Watts/ton ≤ 85 (7.5 &lt; HP/100 ≤ 10)</td>
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<td>85 &lt; Watts/ton ≤ 125 (10 &lt; HP/100 ≤ 15)</td>
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<td>&gt; 125 (&gt; 15 HP/100)</td>
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**ASHRAE 90.1 budget**

Pumping Watts = 22 W/gpm  
(66 W/ton)

**Earlier Example**

(27 HP/100 tons)  
Grade ??
Pump Watts for Constant Speed Circulators

UP26-99 = about 180 Watts
UP26-116 = about 280 Watts

180 or 280 Watts

Earlier 4 ton example could not use more than one 26-99 to meet ASHRAE budget of 264 Watts (22 W/gpm) – Grade C

Grade A = <45 W/ton = 180 Watts for 4 ton unit
ECM vs. VFD

The chart compares the power consumption (Watts) of two types of pumps:
- ECM Var. Spd. Dual Head Circulator
- Vertical Multi-Stage Close Coupled Pump w/VFD

The graph illustrates the relationship between U.S. GPM and Watts for both pump types.
New Technologies

System Types
With the cost of variable speed pumping solutions coming down in cost, it no longer makes sense to design a central system without variable speed pump(s), *even those under 5 hp*.

As the motorized ball valves open and close based upon the operation of the heat pump (on/off or modulating), the system pressure changes, causing the pump to adjust speed to attain the water flow needed for the number of heat pumps running.
Central System

- Central pump is easily controlled based upon pressure differential
- A backup second pump may be included to add redundancy
- Pump Watts are substantially lower than constant speed or staged pumping systems
- System is scalable for virtually any system size
- Expansion tank, air separation, and pumps are centrally located in the mechanical room
- Piping may be stepped down (smaller diameter) after each heat pump/group of heat pumps
The primary pump is controlled based upon temperature difference, typically 6 to 10 deg F., depending upon climate and building load profile (most cost effective solution is a heating TD and a cooling TD). The secondary pumps are energized only when the heat pump is running.
Primary-Secondary System

- Pump Watts are typically less than a two-pipe system, since primary pump is sized for only part of the piping, and secondary pump need only overcome the pressure drop of the heat pump heat exchangers and piping
- Primary pump is easily controlled based upon temperature differential; secondary pump(s) is controlled based upon the number of heat pumps operating
- A backup second pump may be included to add redundancy
- System is scalable for virtually any system size
- Expansion tank, air separation, and pumps are centrally located in the mechanical room
- Hydraulic separator simplifies piping (cross-over bridge may also be used)
The primary pump is controlled based upon temperature difference, typically 6 to 10 deg F. (most cost effective solution is a heating TD and a cooling TD). The secondary pump is controlled on pressure differential. As the motorized ball valves open and close based upon the operation of the heat pump (on/off or modulating), the system pressure changes, causing the secondary pump to adjust speed to attain the water flow needed for the number of heat pumps running.
Primary Pump Selection

• Pressure drop calculation for primary pump is just the ground loop piping, supply/return piping, and piping to the hydraulic separator

• Flow rate of primary pump should be between the minimum total flow rate for all of the heat pumps when running (typically 2.25 GPM/ton) and nominal flow (typically 3 GPM/ton)

• The lower pressure drop of the primary system allows a small variable speed circulator
  • Keeps controls simple
  • Keeps pump cost low
Secondary Pump Selection

- Pressure drop calculation for secondary pumps includes the heat pump heat exchanger, hose kits, check valves, ball valves, and inside piping to the hydraulic separator (when all heat pumps are running)

- Flow rate of secondary pump for each heat pump should be between the minimum flow rate (typically 2.25 GPM/ton) and nominal flow (typically 3 GPM/ton) of each heat pump
  - For example
    - 3 ton = 7 to 9 GPM
    - 4 ton = 9 to 12 GPM
    - 5 ton = 12 to 15 GPM

- The lower pressure drop of the secondary system allows small 3-speed circulators in many cases
  - Allows adjustment (e.g. 3 ton can operate on med. spd.)
**Secondary Pump Selection**

**Typical 3-speed pump**

Pump is mounted in an insulated box and installed at the heat pump.

When heat pump is operating, pump will be energized (completely independent of primary pump).
Pump Watts, Primary-Secondary

- Watts for primary pump can vary between about 40 Watts (depending upon pump model) to max. pump Watts (all heat pumps running)

- Secondary Pump Examples:
  - 3 ton: UPS26-99, med. spd. = 151 Watts
  - 4 ton: UPS26-99, high spd. = 178 Watts
  - 5 ton: UPS26-99, high spd. = 183 Watts
Primary-Secondary Considerations

- Small circulator per heat pump is simpler than variable speed pump on both sides, but higher Watts

- If heat pumps are two-stage, consider variable speed for secondary circuit (pressure differential / modulating zone valves) or variable speed pumps at each heat pump

Typical variable speed pump for two-stage heat pump
One Pipe System

- Expan. Tank
- VFD
- Heat Pump
- Small Circulator
- Ball Valve
- Closely Spaced T's
- ΔT
- Ground Loop Piping
One Pipe System

- Similar to primary-secondary, but only one pipe for primary loop
- Pump Watts are typically less than a two-pipe system, since primary pump is sized for only part of the piping, and the secondary pumps need only overcome the pressure drop of the heat pump heat exchanger and small amount of piping
- Primary pump is easily controlled based upon temperature differential
- System is scalable for virtually any system size
- Expansion tank, air separation, and pumps are centrally located in the mechanical room
- One pipe system uses larger piping for building loop (must maintain size for full flow)
Distributed System

Typically 180 Watts per pump
Distributed System

- No central pump is needed
- Flow center pump(s) is easily controlled by heat pump
- Built-in redundancy
- Pumping Watts may be higher than other systems due to possible upsizing of pumps related to the characteristics of parallel pumping
- Must determine where to place expansion tank, air separation, flushing valves
System Selection Guidelines

• Consider primary-secondary systems when system head for a central system will be relatively high (over 40 to 45 ft. of head) in order to stay with smaller pumps

• Multi-stage heat pumps will not realize the full energy savings potential unless ...
  • Each heat pump has a two-stage (or modulating) zone valve and variable speed system pump(s)
  • Each heat pump has a variable speed secondary pump

• Consider a backup pump for redundancy on central systems, primary-secondary, and one-pipe systems

• Parallel flow centers (or internal pumps) should be a last resort for 3+ heat pump systems
New Technologies

Part Load Heat Pump Operation
## Two-Stage Heat Pump

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<th>Model</th>
<th>Capacity Modulation</th>
<th>Cooling Full Load 77°F</th>
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Ground Loop Heat Pump ratings based on 15% methanol antifreeze solution
All ratings based upon operation at lower voltage of dual voltage rated models
### Two-Stage Heat Pump (Part Load)

**Performance capacities shown in thousands of Btuh**

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**System 1 (original):**
10.5 kW ÷ 56 tons = 188 W/ton
188 x 4 tons = 752 Watts

**System 2 (retrofit):**
1300 W ÷ 56 tons = 23 W/ton**
23 x 4 tons x 0.67 P/L = 62 Watts

**System 1 EER =** \[
\frac{39,500}{(1600 + 752)} = 16.8
\]

**System 2 EER* =** \[
\frac{39,500}{(1600 + 62)} = 23.8
\]

*With 2-stg. or modul. valve
**At 150 gpm, only one is needed (1300 W max)

Lower than AHRI pump penalty!
Two-Stage Heat Pump

- Most of the year heat pump can satisfy building load in part load operation
- Two-stage (or modulating) zone valve allows decrease in flow rate at part load
- Additional run time increases occupant comfort, and could result in higher summer / lower winter space set points, reducing operating costs
Adding It All Together

Component Selection
Circulator Selection

• Not all pumps are designed for geothermal operation
  - Condensate weep/drain hole(s)
  - Pumps for chilled water have coated windings
• Even similar circulators may not be approved for geo.
• Some are only designed for hot water (boiler) operation
• Very important when selecting a geo pump (examples in next slides)
• Very important when considering replacement pumps or troubleshooting a failed pump
Which Pump Is Approved For Geo?

Weep holes
There are 3 total...
3’o-clock (this one)
6’o-clock (bottom)
9’o-clock (left side)
Zone Valve Selection: Cv

- The Cv (Flow Coefficient) of a valve is determined by the flow rate in U.S. GPM that will pass through with a pressure drop of 1 psi (2.31 ft. of head)

- Example:
  - 3 ton heat pump @ 3 GPM/ton = 9 GPM
  - Valve Cv = 9
  - When 9 GPM is flowing through the valve, the pressure drop through the valve = 1 psi (2.31 ft. of head)

- Good design practice:
  - No more than 25% to 50% of circuit pressure drop
    - Typical heat pump heat exch. press. drop = 10 ft. of hd.
    - 25% to 50% = 2.5 to 5.0 ft. of head
Zone Valve Selection: Cv

- From previous slide:
  - 25% to 50% = 2.5 to 5.0 ft. of head
  - = 1.1 to 2.2 psi
  - Cv = GPM @ 1 psi

- **Guideline:** Try to select a Cv that is between 75% and 100% of nominal flow rate, rounded to nearest whole number

- Example:
  - 3 ton heat pump = 9 GPM nominal flow / 7 GPM min.
  - 75% of 9 GPM = 6.75 (rounded = 7)
  - Valve with Cv of 7 @ 9 GPM = 3.8 ft. of hd. (1.6 psi)
  - 100% of 9 GPM = 9
  - Valve with Cv of 9 @ 9 GPM = 2.31 ft. of hd. (1 psi)
  - Selection should be at least a Cv of 7 (9 is better)
Zone Valve Selection: Types

ON/OFF Zone Valves

Modulating Zone Valve
Hydraulic Separator Selection

• Creates low velocity zone with very little head loss

• Similar to a buffer tank for hydronic applications, but much smaller
  • Not concerned about storage, simply for decoupling the two piping systems

• Side benefits:
  • Low velocity causes dirt particles to drop to the bottom of the tank for removal via a drain-down valve
  • Low velocity allows air bubbles to rise to the top, vented by an automatic air vent

• Diameter of body is usually 3 times the diameter of the connected piping
Hydraulic Separator Selection

Typical Geothermal Hydraulic Separator

Automatic Air Vent

Low Velocity Tank

2 ft./sec. or less

In/Out from Primary Circuit

In/Out from Secondary Circuit

Blow-down Valve
Adding It All Together

Conclusions
Conclusions: $1 + 1 = 3$

- New ECM pumps with can ...
  - Lower system pump Watts / increase system EER
  - Operate stand-alone or with BMS interface
  - Lower installation costs
  - Be retrofitted, especially for systems with constant speed pumps
  - Meet/exceed ASHRAE 90.1 requirements

- Two-stage/multi-stage/variable speed heat pumps can ...
  - Lower operating costs
  - Increase occupant comfort
  - Further decrease pump Watts (with two-stage or modulating valves)

- Energy modeling can determine most cost-effective choices
Conclusions: Final Thoughts

• There are many pumping applications available today that can take advantage of the latest technology (variable speed pumps/controls)

• Consider the most cost effective system based upon...
  • Operating costs
  • Heat pump type (single speed, multi-stage)
  • Keeping pumps as small as possible
  • System type (e.g. primary-secondary, one-pipe)

• Make sure that system components are optimized (zone valves, hydraulic separators, expansion tanks, etc.)
Questions?

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