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Conference Paper Session 9
Geothermal Systems:
Simulation, Design, and Operation

Development of Residential Ground-Source Integrated Heat Pump (GSIHP)

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Learning Objectives

- Learn to distinguish between the types of underground condensers, their application and previous use.
- Apply the thermosiphon effect to defrosting of air-source heat pumps.
- **Explain how integrated heat pumps and variable-speed BPM motors are a good match to obtain high-efficiency equipment for both space conditioning and water heating.**
- Describe relationship between the entering water temperature of a heat pump and its heating and/or cooling performance.

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Objective

- Development of advanced HVAC/WH options saving over 50% in energy use
  - Relative to a baseline suite of minimum efficiency equipment
- Collaborative development with U.S. manufacturer on GSIHP equipment
  - For new and existing residential housing

Outline

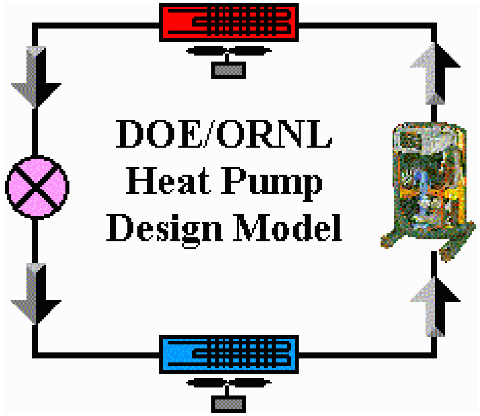
- GSIHP Characteristics
- Performance Simulation Approach
- Annual Energy Use Comparisons
  - Baseline of minimum efficiency ASHP and electric WH
  - 2-capacity state-of-art GSHP w desuperheater
  - 1^{st}-generation prototype GSIHP
  - Over a range of U.S. climate regions
    - Mixed-humid, hot-humid, hot-dry, marine, and cold

GSIHP Characteristics

- High-Efficiency Variable-Speed Components
  - Brushless Permanent Magnet (BPM) Motors
    - For Compressor, Blower, Loop and Water Pumps
  - Suction-gas-cooled compressor inverter
  - Wide-speed range for space conditioning
    - Overspeed in heating mode
    - RH control in cooling mode
  - Provide reduced capacity for WH loads
- Four Modes of Operation
  - Space cooling and heating
  - Space cooling and water heating
  - Dedicated water heating (ground loop source)

GSIHP Modeling Approach

- Model equipment for each operating mode with HPDM
  - Calibrate each mode against lab test data
  - Optimize and implement internal control logics
    - for compressor speed versus blower and pump flow controls
    - over range of ground loop and DHW entering water temps (EWTs)
- Generate performance maps for each mode
  - As a function of all independent variables
  - e.g., compressor speed, indoor DB/RH, EWT in space cooling



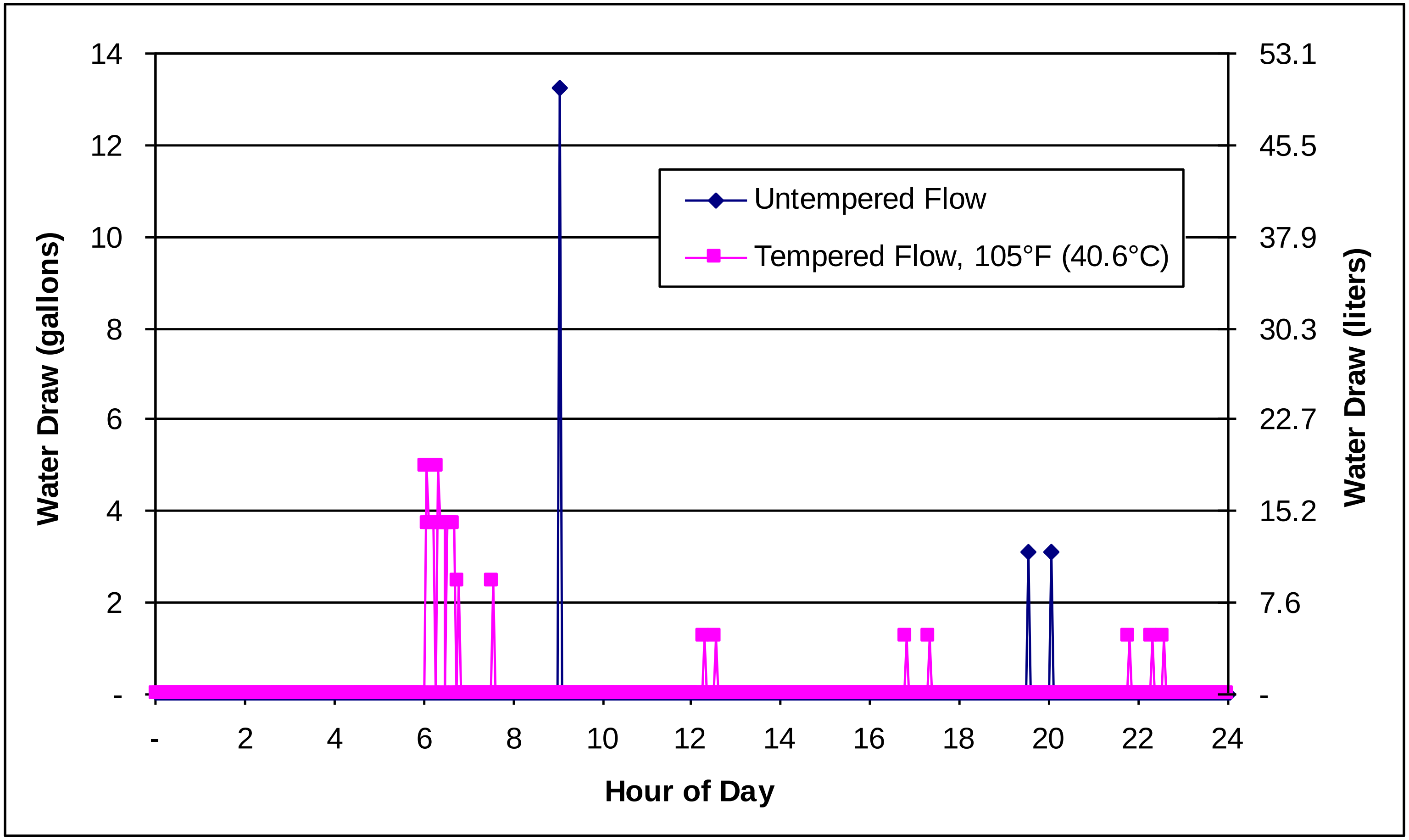
GSIHP Modeling Approach (Cont.)

- Apply space conditioning and WH t-stat controls in TRNSYS
  - Link with house and DHW tank model
  - Use time steps of 3 min between t-stat call priority decisions
- Size ground loops with TRNSYS to stay within 10-year min and max EWT targets
- Evaluate annual energy savings in selected U.S. climates
  - For a tight, well insulated 2600 ft^2 ($242 m^2$) house
    - ~2-ton (7.0 kW) design cooling capacity
  - Relative to baseline 13 SEER ASHP with resistance WH
  - Relative to 2-capacity GSHP with desuperheater

TRNSYS Modeling Assumptions -- Water Heating

- Common Assumptions
  - Nominal 50-gallon (189 L) tank, 64.3 gal/d (202.5 L/d) hot water draw
  - 120ºF (~49ºC) set point
- GSHP Control Assumptions
  - Desuperheater setup as described per manufacturer specifications
- GSIHP Control Assumptions
  - Priority operation in water heating mode if within 2ºF (1.1ºC) of set point
  - No desuperheating operation

Daily Hot Water Use Schedule



TRNSYS Ground Loop Modeling Assumptions

- Vertical Well Configuration
  - 2 wells in parallel, 15 ft (4.6m) apart, ¾”(1.9cm) HDPE, 4.5”(11.4cm) bore
  - location-dependent soil properties
    - details given in paper
  - standard grout for GSHP, enhanced grout for GSIHP
- Bore Lengths Sized for 10-year Min and Max EWTs
  - min 42ºF(5.6ºC), max 95ºF(35ºC) for water ground-loops -- Atlanta, Houston, Phoenix, SF
  - min 30ºF(-1.1ºC), max 95ºF(35ºC) for PG20 ground-loop -- Chicago

Equipment Comparison Cases

- Single-Speed Air-Source Heat Pump (ASHP)
  - 13 SEER / 7.7 HSPF
    - Using manuf's performance data vs ambient
  - 0.9 EF electric water heater
- Two-Capacity Ground-Source Heat Pump (GSHP)
  - Full capacity,18.5 EER / 4.0 COP
  - Part capacity, 26.0 EER / 4.6 COP
- 1st-gen GSIHP prototype
  - Manuf's internal control algorithms and approx. t-stat control
    - enhanced DH control capability not simulated
- All have nominal 2-ton (7kW) cooling capacity

Annual Energy Savings Predictions

2-Ton Design Cooling Capacity		
Baseline ASHP with 0.9 EF DWH	Ground-Source Equipment Options	
	2-Capacity GSHP w DS	Variable-Speed GSIHP
Operation Mode	% Energy Savings From Base	% Energy Savings From Base
Atlanta		
space heating	31%	45%
space cooling	27%	48%
water heating	19%	74%
total	24%	57%
Houston		
space heating	32%	48%
space cooling	16%	34%
water heating	28%	77%
total	23%	54%
Phoenix		
space heating	29%	51%
space cooling	20%	38%
water heating	30%	78%
total	24%	53%
San Francisco		
space heating	16%	32%
space cooling	84%	49%
water heating	10%	72%
total	11%	59%
Chicago		
space heating	37%	43%
space cooling	49%	58%
water heating	20%	68%
total	31%	52%

Conclusions

- Two-Capacity GSHP with desuperheater
  - 11 to 31% total energy savings vs baseline ASHP, averaging 23%
  - Desuperheater contributions of 11 to 35% of WH load
- 1st-generation GSIHP prototype
  - 52 to 59% total energy savings, 55% on average
    - most % savings in SF and Atlanta, least in Chicago
    - most $ savings in Chicago, least in Houston and Phoenix
  - Water heating savings of 68 to 78%
  - HP contribution of 97 to 100% of delivered WH load
- Comparable indoor RH's and DHW delivered water temps
  - w/o active RH control
- 2nd-gen design increases predicted savings
  - by over 7%, giving 59% average total savings
  - exceeds 40 EER at part load cooling rating condition

Questions?

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