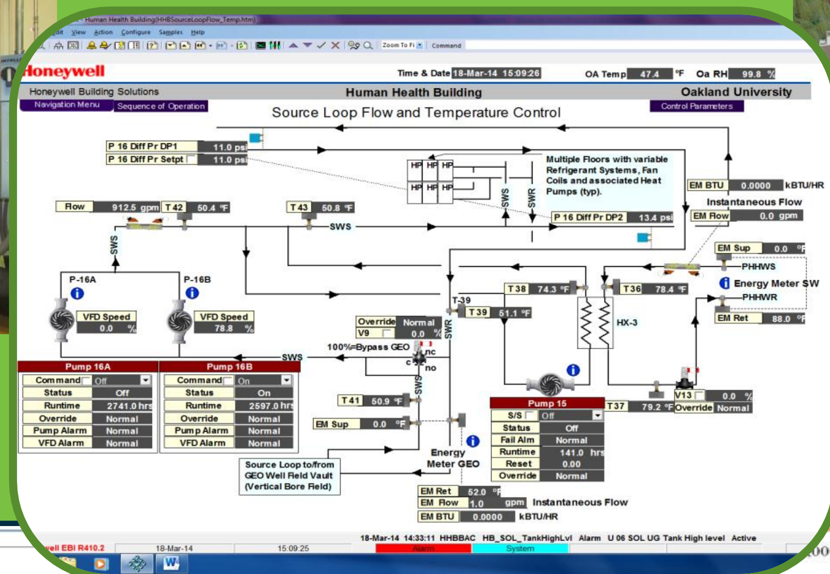
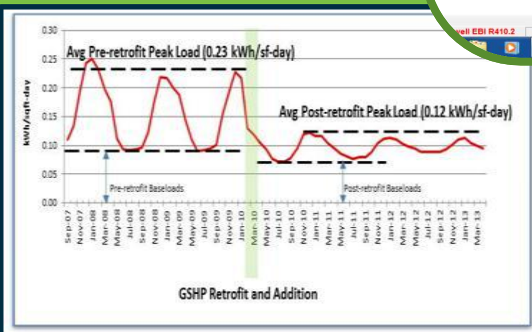
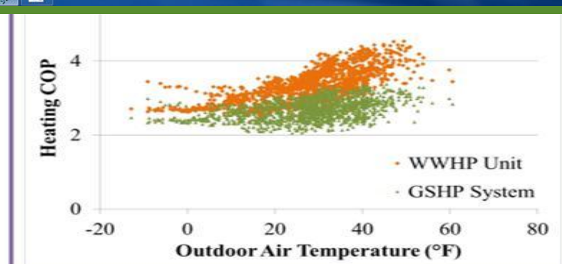
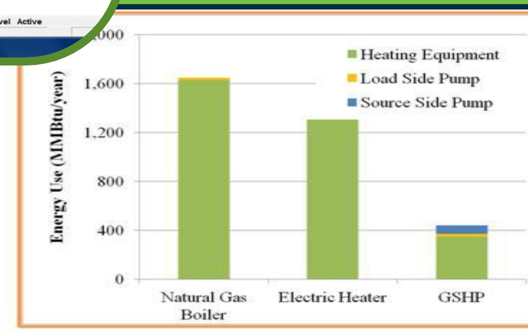
Data Analysis for ARRA-funded GSHP Demos

2014 Building Technologies Office Peer Review









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Project Summary

Timeline:

Start date: October 2012

Planned end date: September 2016

Key Milestones

1. Two case studies; October 2013
2. Four more case studies; October 2014

Key Partners:

CDH Energy (Subcontractor)	University at Albany (ARRA grantee)
Univ. of Tennessee (Subcontractor)	City of Rayleigh (ARRA grantee)
Cedarville Schools (ARRA grantee)	Indiana Tech. (ARRA grantee)
Flathead Electric (ARRA grantee)	Oakland University (ARRA grantee)

Budget:

Total DOE $ to date: $450K (FY13 - $200K; FY14 - $250K)

Total future DOE $: $250K (Expected)

Project Goal:

- Characterize the demonstrated GSHP technologies
- Evaluate measured performance data
- Assess energy savings and other benefits, as well as cost effectiveness
- Identify lessons learned and/or best practices

Target Market/Audience:

Market: space conditioning and water heating systems in commercial buildings

Audience: personnel involved in the GSHP industry and building owners

Purpose and Objectives

Problem Statement: Independent performance and cost data collection and analysis of the existing GSHP systems could drive improved practices, significant gains in future system energy efficiency, and awareness and trust in the benefits available from properly implemented GSHP systems.

Target Market and Audience: Space conditioning and water heating in commercial buildings (**6.4** quad Btu primary energy consumption per year in the US). Audience includes personnel involved in the GSHP industry and building owners.

Impact of Project: Final product is a series of in-depth case studies to characterize the demonstrated GSHP technologies, assess their costs and benefits with measured data, and identify lessons-learned and/or best practices.

a. Near-term (<1 yr): increased awareness by personnel in the industry that some systems are not properly implemented
b. Intermediate-term (1-3 yrs): improved performance and reduced cost of GSHP systems through improved practices
c. Long-term (3+ yrs): GSHPs become mainstream through improved industry practices and increased building owner awareness and trust

Approach

Approach: (1) extensive data collection from various sources, (2) in-depth analysis with several techniques, including utility bill analysis, performance data visualization, profiling and benchmarking, and computer simulations with calibrated models

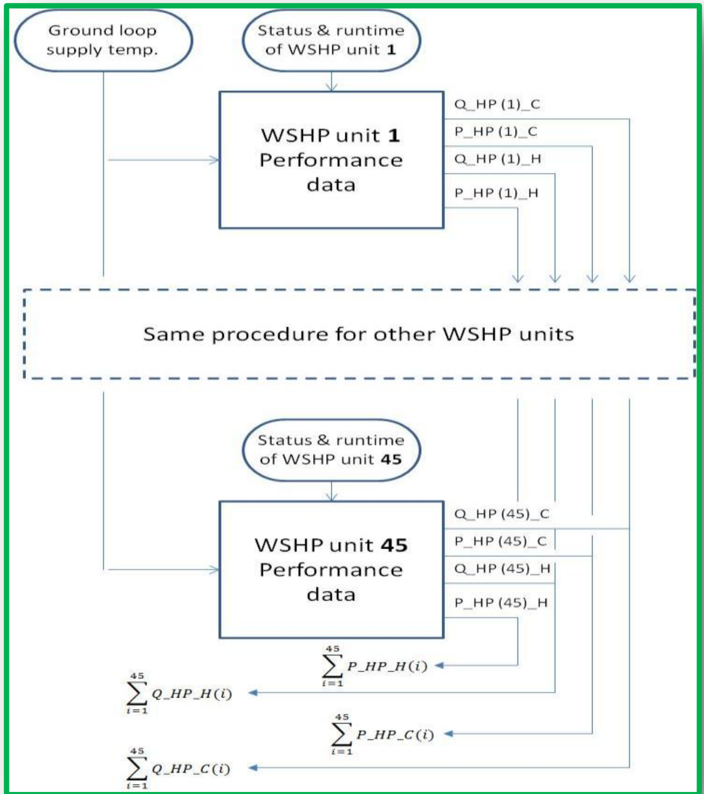
Key Issues:

- How to conduct in-depth analysis with limited data?
- How to effectively analyze large amounts of data to evaluate performance, identify faults, and determine the benefits achieved by the GSHP system?

The procedures and techniques developed in this project can lead to development of low-cost monitoring systems and "energy-saving" meters for various GSHP systems

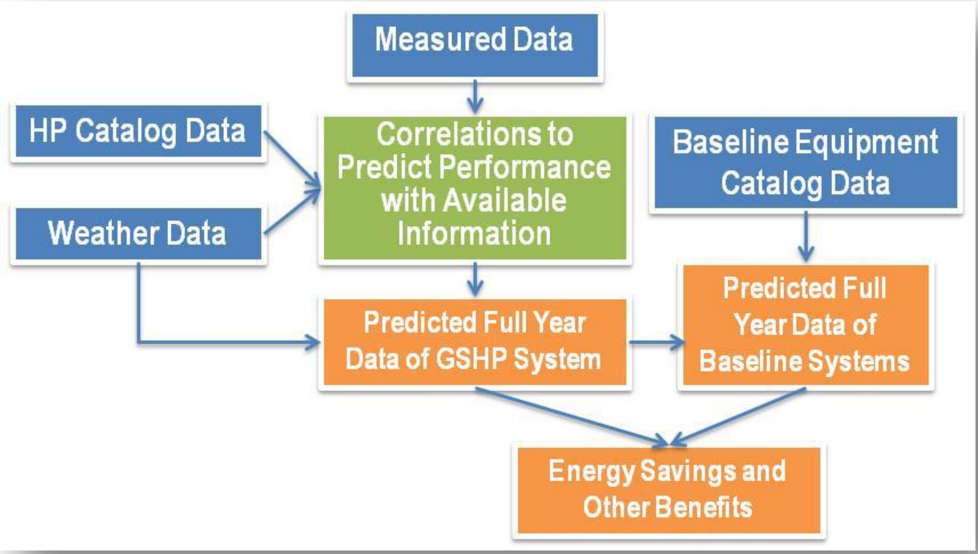
Approach

Distinctive Characteristics: Used virtual sensing techniques to fill the gap of missing/unavailable data



Estimate heating/cooling output and associated power usage with GSHP operation status data and performance map

Predict full year performance with correlations derived from short-term measurements and other available information



Progress and Accomplishments

Lessons Learned:

- Availability and quality of performance data are different in each project
- Impacts of the ARRA grant on the design and installed cost of the GHP demos
- GSHP system designs are diverse and some systems are over-complicated
- Lack of standard procedure and supporting data for calculating energy savings
- Common issues in pumping control and outdoor air ventilation

Excessive Pumping

Improperly Conditioned OA Ventilation

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Progress and Accomplishments

Accomplishments:

Case study is completed (2)

Case study is ongoing (4)

Data has been collected and initially analyzed (8)

Data collection plan has been developed (16)

Waiting for GSHP system information (9)

FY13

- Developed an automated data processing and visualization tool
- Completed two case studies

FY14 (Q1 and Q2)

- Selected four more sites for case studies
- Conducted site visits to verify measurements and collect additional information

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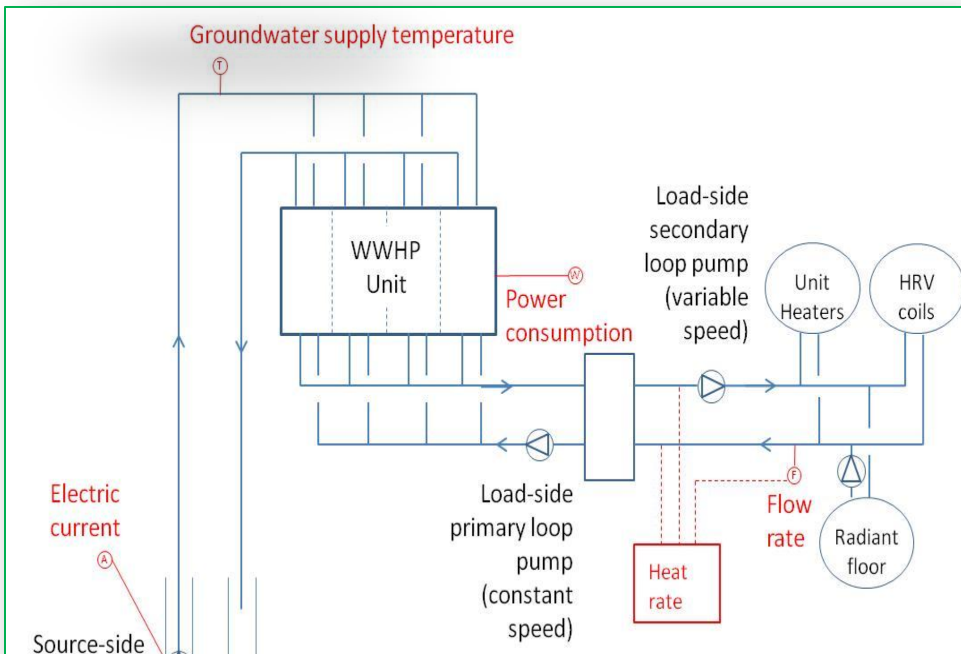
Progress and Accomplishments

Case Study #1: Flathead Electric Coop.

22,000 ft^2 retrofit and 9,300 ft^2 new addition of a warehouse at Kalispell, Montana



All-electric Heating Only Central GSHP System

Demonstrated GSHP System:

- Central modular heating only WWHP using shallow aquifer (via two 35 ft water wells) as heat source to replace existing electric resistance heaters
- Primary and secondary loop with variable speed pumping
- Hydronic unit heaters and radiant floor for space heating
- ERV and HRV for OA ventilation

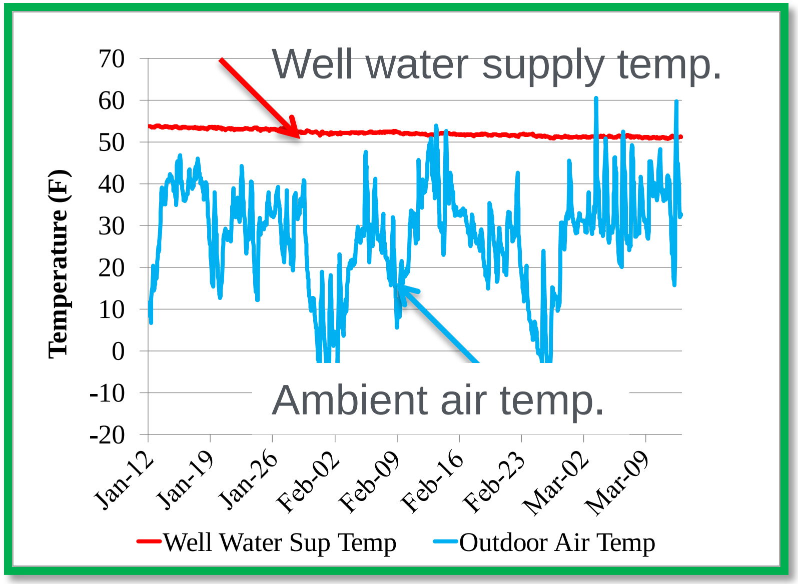
Data Collection:

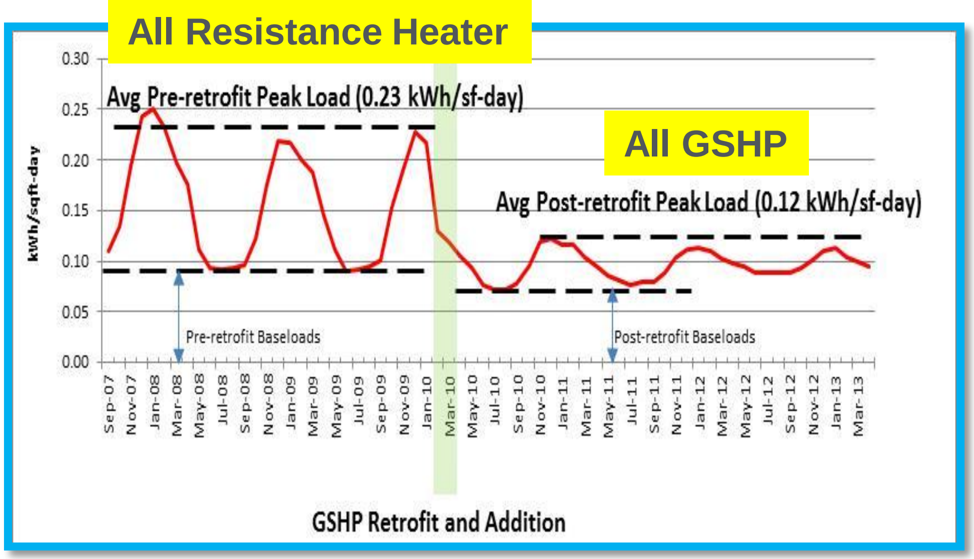
- Utility bills pre- and post retrofit
- Performance data measured with portable data loggers for 2 months
  - Well water supply temperature
  - Heat pump energy and output
  - Heat pump load side flow rate
  - Well pump current

Progress and Accomplishments

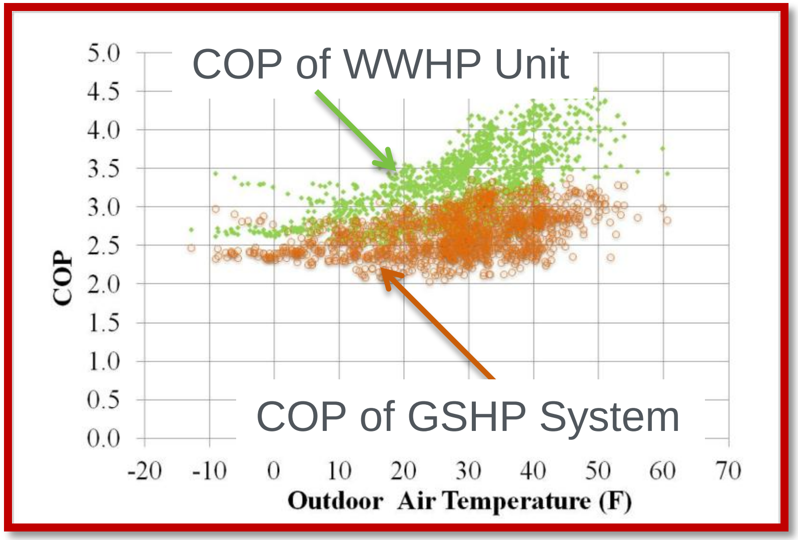
Analysis of Measured Data:

- Well water temperature: 55-50°F
- Avg. COP of the WWHP: 3.2
- Avg. COP of the GSHP system: 2.7 (due to pumping power)
- Pumping power fraction: 16.6%
- Energy use intensity (EUI) of the entire facility is reduced by 36.9% after the retrofit and addition



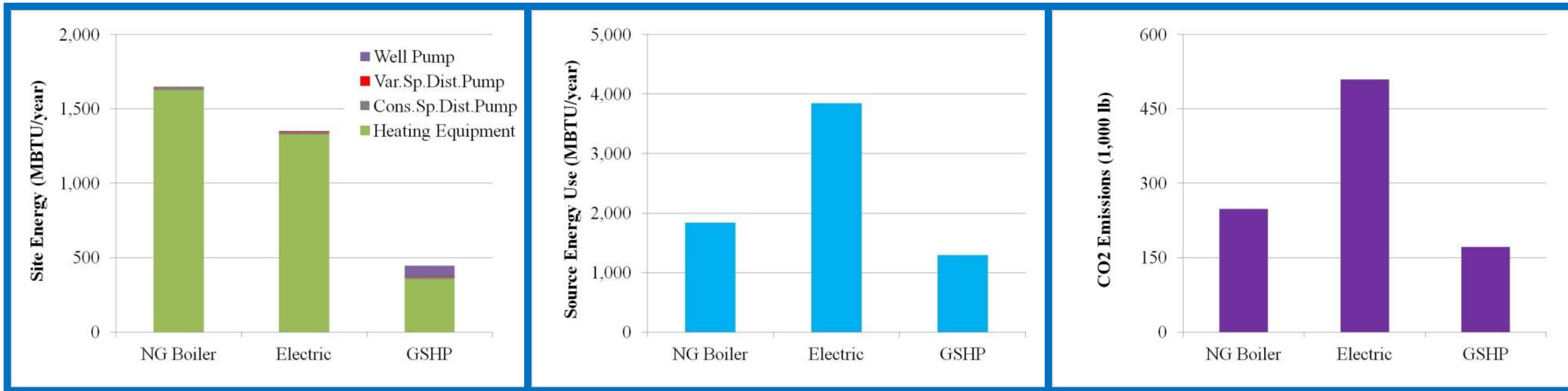


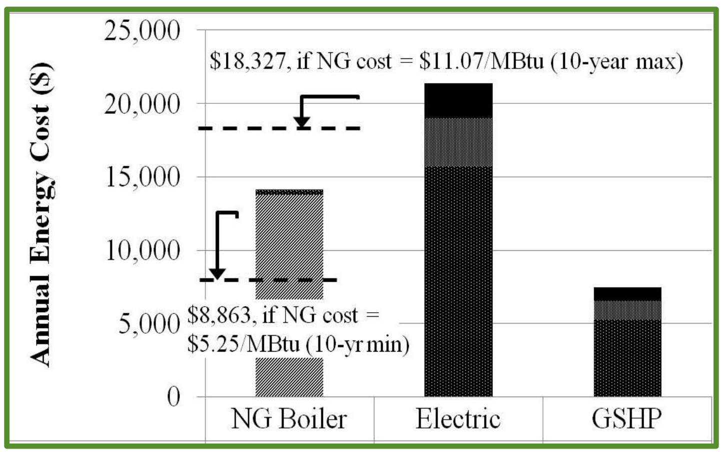
Billed Energy Use: Pre- and Post-retrofit & addition



Progress and Accomplishments

Extend to Full Year Analysis and Comparison with Baseline Systems





Annual operating cost:
GSHP vs. baseline systems, which use natural gas (NG) or electric boiler

Installed cost is $4,140/ton ($10.6/ft^2) and simple payback is: 9 and 18 years compared with the electric and natural gas baselines, respectively ←
ARRA grant effect + excessive pumping?

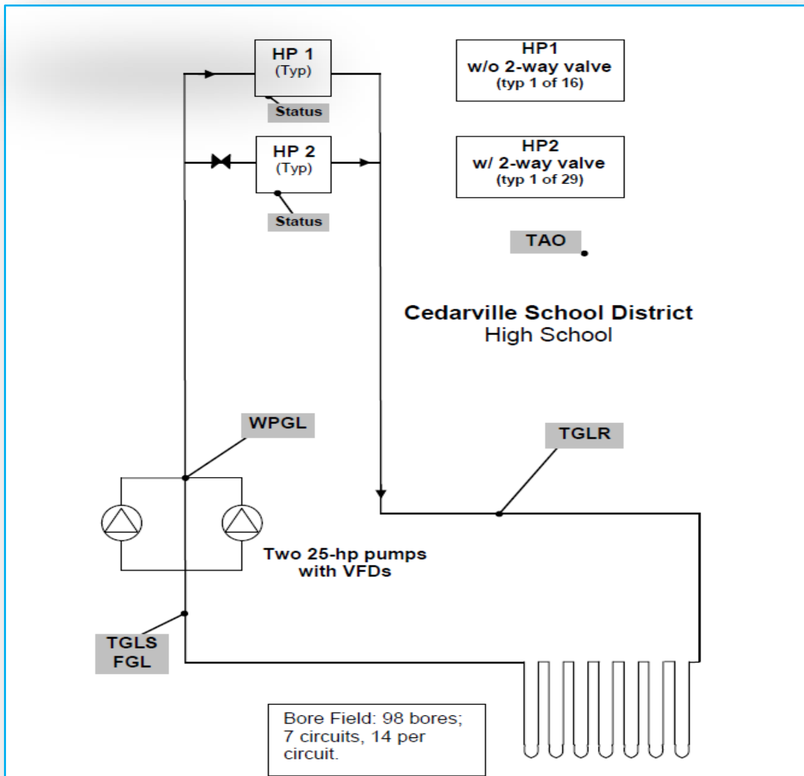
Lessons Learned/Best Practice:

- OA reset control for the WWHP to improve GSHP system operational efficiency
- Fine-tune pressure setpoint to reduce excessive pumping power

Progress and Accomplishments

Case Study #2: Cedarville High School

65,000 ft[2] retrofit and 5,500 ft[2] new addition of a high school at Cedarville, Arkansas



Distributed GSHP System

Demonstrated GSHP System:

- Distributed GSHP system with 45 WAHP units and a vertical-bore GHX (98 bores 400 ft deep)
- Replace existing WLHP system (with gas-fired boiler and cooling tower) and rooftop units (with gas heat)
- Heat & cool entire building year round
- Variable speed pumping
- OA is ducted to WAHP units and modulated based on indoor CO_2 level

Data Collection:

- Utility bills pre- and post retrofit (6 yrs)
- On-off state and operation mode of each WAHP unit (1 yr but with missing data)
- Interval measurements (1 yr)
  - Ground loop supply and return temperature, and flow rate
  - Ground loop pump power

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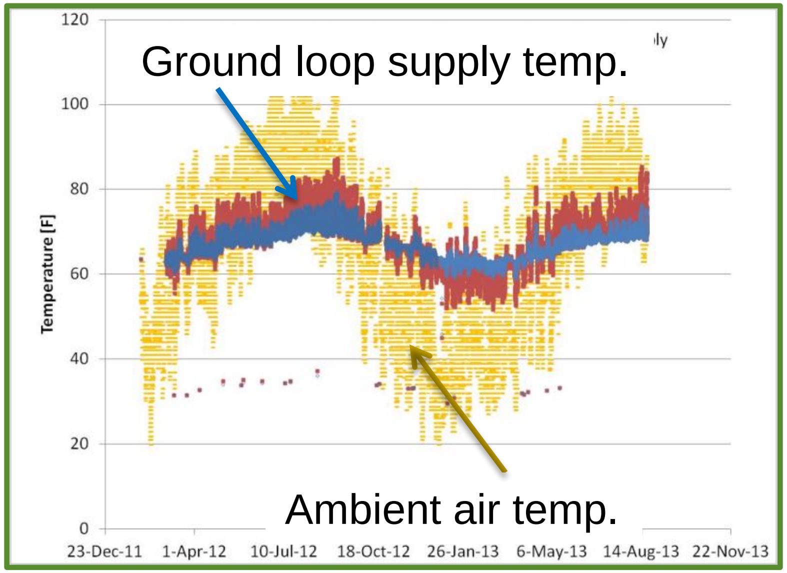
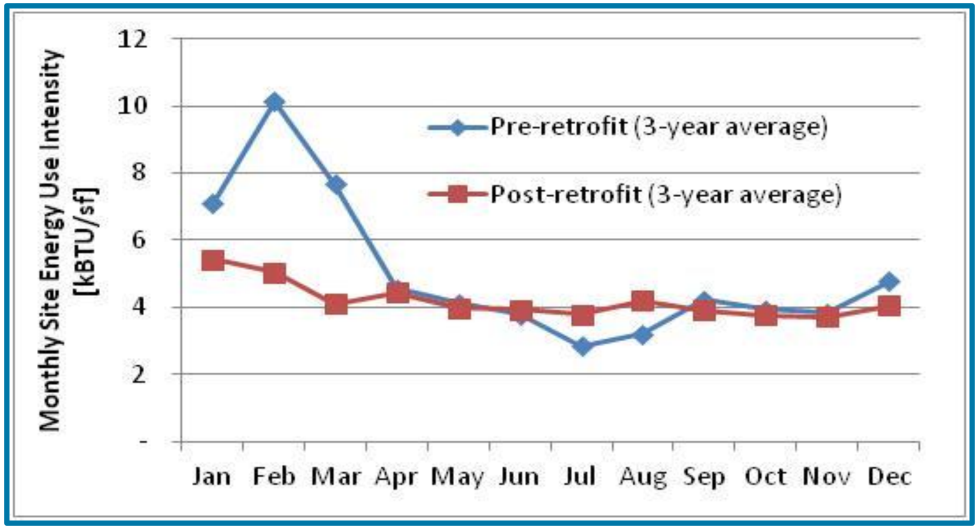
Progress and Accomplishments

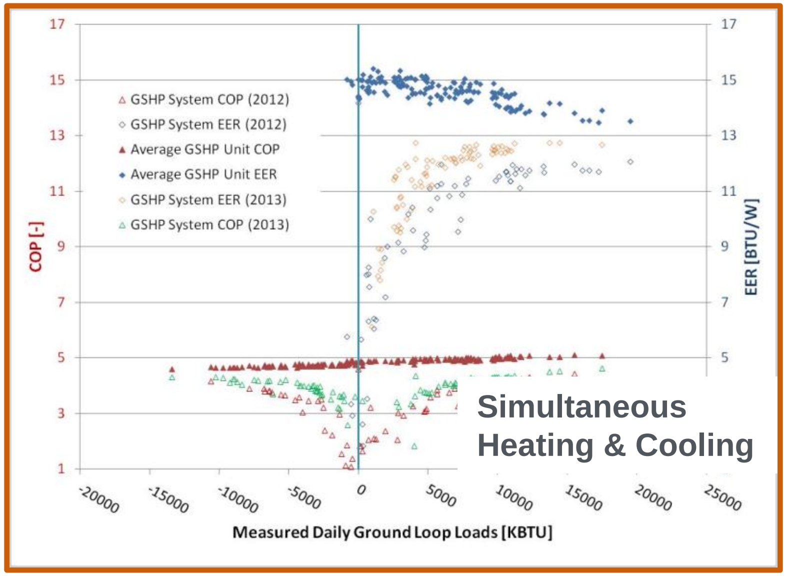
Analysis of Measured Data:

- Ground-loop supply temperature: 60 to 80°F
- Seasonal system COP and EER: 3.3 and 10.5, respectively
- Pumping power: 21% of the total GSHP system energy use
- EUI of the entire building is reduced by 21% to 48.5 kBtu/ft^2 after the retrofit





Only 57,675 ft^2 of school was cooled before, but the entire school and addition (70,500 ft^2) is cooled after the retrofit



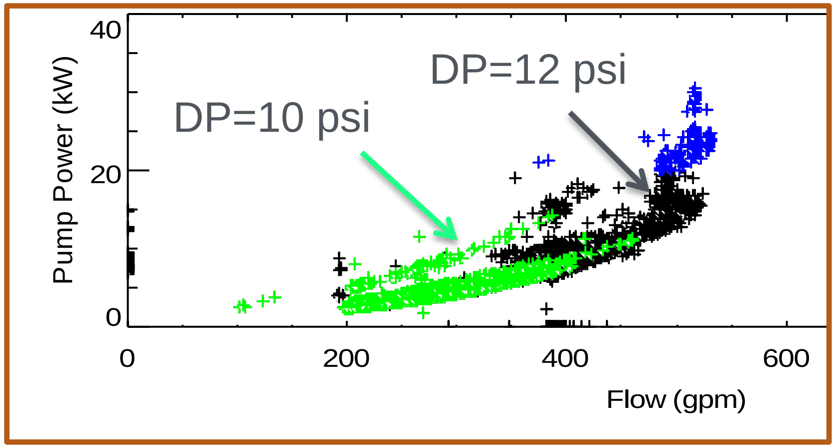
Progress and Accomplishments

Benefits Versus VAV System (most common in high schools; calibrated model estimates):

- For space conditioning: a 69.8% savings in site energy, a 52.5% savings in source energy, a 51.5% reduction in equivalent CO_2 emissions, and a 52.6% energy cost savings ($17,543 per year)
- For building peak electric demand: a 30% reduction (120 kW)

Lessons Learned/Best Practice:

- Must account for simultaneous heating and cooling when evaluating performance of distributed GSHP systems
- Need to fine-tune differential pressure (DP) setpoint for variable speed pump control
- Need controls that shut off the pump when there is not any heating or cooling demand



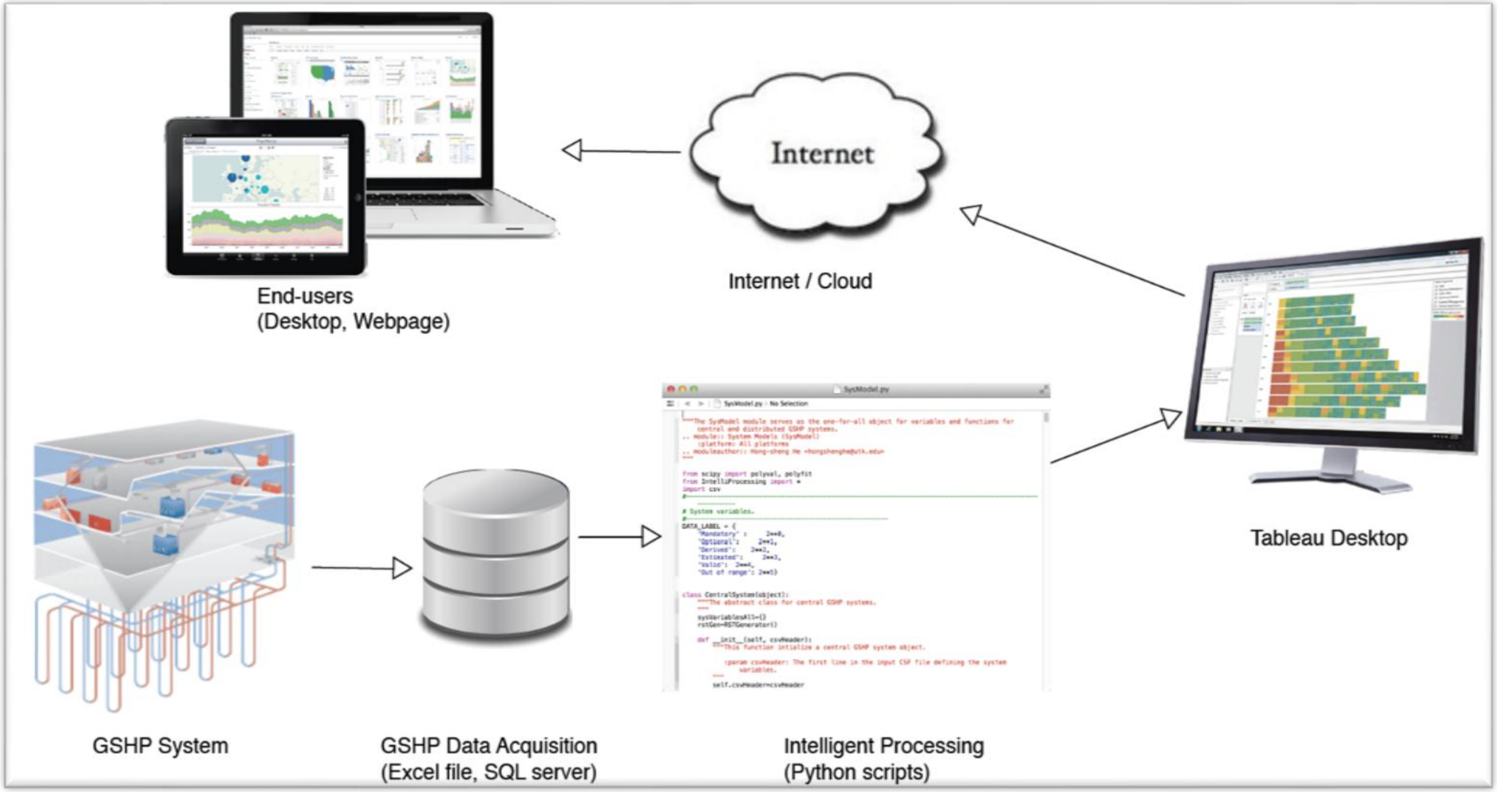
Based on available information, it is estimated that the installed cost of the GSHP system is \$7,214/ton (\$24/ft²) and the resulting simple payback is 35 years compared with the baseline VAV system ← *ARRA grant effect + oversized GHX + excessive pumping?*

Installed cost of GSHP systems in schools at Dallas area is \$15-18 (2013 dollar)/ft² (according to a GSHP case study by Frisco Independent School District, TX)

Progress and Accomplishments

Automated Data Processing and Visualization Tool

- Approximate missing/unavailable data with pre-defined algorithms
- Compute performance metrics
- Compile measured and derived data into a format for visualization



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Progress and Accomplishments

Market Impact:

- Increased awareness of the GSHP technology (the demos are the 1st GSHP application implemented by most grantees)
- Lessons learned to improve GSHP system operational efficiency (e.g., pumping control and outdoor air ventilation)
- Improved performance and reduced cost of GSHP systems through improvements in system design and operation
- Knowledge of innovative GSHP technologies (e.g., ground source VRF)

Awards/Recognition: Not yet

Project Integration and Collaboration

Project Integration: Work with industry (ASHRAE, IGSHPA, GEO) to improve practices in the design & operation of GSHP systems; disseminate case study results through publications and presentations at various venues, including ASHRAE, IGSHPA, GEO, DOE and other federal agencies

Partners, Subcontractors, and Collaborators:

Subcontractors: **CDH Energy** for assisting with data collection, and **University of Tennessee** for implementing the visualization tool

Collaborators: **Grantees of the GSHP demo projects**

Communications:

- A paper for the 1st case study will be presented at the ASHRAE conference in the summer of 2014
- Two papers are in preparation and will be presented at IGSHPA conference in the fall of 2014 and other relevant journals or conferences

Next Steps and Future Plans

Next Steps:

- Complete four more case studies in FY14
- Work with GSHP industry to improve practices and paybacks

Student Housing at University at Albany with a Distributed GSHP system

Campus-wide District GSHP System at Indiana Institute of Technology

Nursing School at Oakland University with a Ground-source VRF System

Tasks Could be Added:

- Conduct 4-6 more case studies for other GSHP demos in FY 15
- Standardize procedures and supporting data for evaluating energy savings and other benefits achieved by GSHP systems
- Investigate optimal configuration & control for circulation pump and OA ventilation

REFERENCE SLIDES

Project Budget

Project Budget: DOE total $450k FY13-FY14
Variances: No
Cost to Date: ~$232k through February 2014 (FY13-~$195k; FY14-~37k)
Additional Funding: No

Budget History					
Oct. 2012 – FY2013 (past)		FY2014 (current)		FY2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$200K		$250K		$250K	

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Project Plan and Schedule

Project Start: 01-Oct-2012		Completed Work										
Projected End: 30-Sep-2014		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Select demos for case study												
Q2 Milestone: Solve data issues												
Q3 Milestone: Complete case study #1												
Q4 Milestone: Complete case study #2												
Q1 Milestone: Select demos for case study												
Current/Future Work												
Q2 Milestone: Solve data issues												
Q3 Milestone: Complete case study #3 and #4												
Q4 Milestone: Complete case study #5 and #6												