Long-Term Performance of Commercial GSHPs

Project Sponsors:

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- Southern Company – Chris Gray
- Tennessee Valley Authority – David Dinse

Steve Kavanaugh and Josh Kavanaugh
- University of Alabama
- Energy Information Services
Long Term GSHP Project Goals

- Identify characteristics that tend to provide long-term low operating costs and dependability.
- Access the presence and extent of year-to-year performance changes resulting from alterations to the thermal properties of the earth.
- Gather field data to access satisfaction levels of occupants and service technicians.
- Compare results with other system types.
- Identify installation cost data on newer systems.
- Provide recommendation to help improve future installations.
Long Term GSHP Project Data

- Building description
- Ground Loop Description
- Equipment (HPs, Pumps, OA) description
- Ground loop temperatures during peak periods
- Information to find Energy Star Rating
- Electrical demand
- Occupant satisfaction
- Service techs satisfaction & recommendations
- Installation costs for newer systems
An Energy Star Rating of 84 Indicates That Energy Use is Less Than 84% of Buildings of a Similar Type (Offices are compared to other offices, schools are compared to other schools, etc. and results are normalized for climate, occupancy, schedules, and internal loads)
Building Occupant Comfort and Satisfaction Survey

Check the box that reflects your level of satisfaction with the summer indoor temperature and humidity

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

Check the box that reflects your level of satisfaction with the winter indoor temperature

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

Check the box that reflects your level of satisfaction with the air quality (odors, stuffiness, air "freshness")

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

Check the box that reflects your level of satisfaction with the acoustics (noise levels related to heating and cooling equipment)

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

Check the box that reflects your level of satisfaction with the lighting level

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

If are Dissatisfied or very dissatisfied, was the lighting level ☐ Too Low or ☐ Too High

Check the box that reflects your level of satisfaction with the responsiveness and ease of reporting building maintenance problems

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

Check the box that reflects your ability to adjust the thermostat settings in your space

☐ Very Dissatisfied  ☐ Dissatisfied  ☐ Acceptable  ☐ Satisfied  ☐ Very Satisfied

Other Comments:
Energy Star Rating of All GSHP Buildings

Energy Star Ratings of GSHP Buildings*
ES-Elem School, MS-Mid School, HS-High School, Off-Office, Htl-Hotel, MFa-Multi Family
*Three Engineering Firms Did 92% of the 90+ Rated Buildings

Average Building
Central Ground-Coupled Heat Pump Loop

Heat Pumps, Fan Coils, or VAV Terminals in Zones

Optional Central Chiller(s)

Central Pump(s)

Multi-Story Building

Central Multi-Circuit Ground Loop

Central Loop, Central Pump
Energy Star Ratings of Central Loop GSHP Buildings with Central Pump

Energy Star Ratings of GSHP Buildings
Central Loop and Central Pump
ES-Elem School, MS-Mid School, HS-High School, Off-Office, Htl-Hotel, MFa-Multi Family

Constant Speed
Variable Speed Drives

CWS-VAV GSHPs
HVAC Cost at $16 to $22/ft\(^2\) in Central Illinois School retrofits
Energy Star Ratings of One-Pipe Central Loop GSHP Buildings with On-Off Pumps

Energy Star Ratings of GSHP Buildings
One-Pipe Central Loop, On-Off Pumps
ES-Elem School, MS-Mid School

School Built in 1938
Loop Field Headers and Building Piping
Unitary HDPE Loops

3-Way Valves
On/Off Pump

Supply Duct
Return

Unitary Loop, Individual Pumps for Each Unit
Energy Star Ratings of GSHP Buildings
Unitary - Single Loop for Each Heat Pump, On-Off Pump
ES-Elem School, MS-Mid School HS-High School,

School district has 31 Energy Star rated schools, four rating 100 in 2011.

Warning!!! Although this design achieves outstanding results it is not compliant with ASHRAE 90.1-2010.
Loop Field Headers and Building Piping
Common HDPE Loops

Check Valve
On/Off Circ. Pump
Heat Pump

U-Tube Bores
Close Header Purge Valves
Sub-Header Isolation Valves

Common Loop, Individual Pumps for Each Unit
Energy Star Ratings of One-Pipe Central Loop GSHP Buildings with On-Off Pumps

Energy Star Ratings of GSHP Buildings
Central Loop, On-Off Pump on Each Heat Pump
ES-Elem School, MS-Mid School, HS-High School, Off-Office

- ARE-Off: 29% of Building Served by GSHP
- Dem-MS: 45% of Building Served by GSHP
- WeS-ES: 69% of Building Served by GSHP
- USJ-ES: 69% of Building Served by GSHP
- Pla-HS: 69% of Building Served by GSHP
Impact of Ground Heat Exchanger Length

Rearrange Eqn. to find $L_b/\text{ton} = L_b/\text{ton (Nor)} \times \frac{(90-t_g)/(90-t_{gavg})}{(90-t_g)}$

$t_{gavg}$ for all sites = 63°F (17°C)

For SE TN: $L_b/\text{ton} \approx 210 \text{ ft/ton} \times \frac{(90-63)/(90-60)}{\approx 190 \text{ ft/ton of capacity}}$

$L_b/\text{ton} \approx 210 \text{ ft/ton to 240 ft/ton of cooling load}$

Normalized Bore Length (Feet/Ton)

Divide Ft/Ton by 11.5 to Obtain $m/kW_{\text{Thermal}}$

Highest E-Star $\geqslant 200$ to $220$ ft/ton of Installed Equipment Capacity

Lengths per ton based building load will be 10% to 25% longer
Impact of Ventilation Air Equipment Flow Rate

Energy Star Rating vs. Ventilation Air Equipment Flow Rate

Multiply CFM by 0.472 to Obtain Lps
Impact of Control Type

GSHP Energy Star Rating
Building Automation System vs. Thermostat Control

GSHPs with BAS Control
Average Energy Star = 61

GSHPs with T-stat Control
Average Energy Star = 80
**VS Pump Drives That Work = 1 of 14**

**Ground Loop EWT & LWT, VSD Frequency**

- **E-Star = 83**, High Air Temp = 93°F
- GA Elem. School, $L_{bore} = 214$ ft/ton, $t_{grn} = 60°F$

**Ground Loop EWT and LWT**

- **E-Star = 32**, High Air Temp = 96°F
- Florida Office, $L_{bore} = 270$ ft/ton, $t_{grn} = 72°F$

**Ground Loop EWT and LWT**

- **E-Star = 11**, High Air Temp = 95°F
- TN Office, $L_{bore} = 197$ ft/ton, $t_{grn} = 61°F$

**Ground Loop EWT and LWT**

- **E-Star = 93**, High Air Temp = 97°F
- TN Elem. School, $L_{bore} = 197$ ft/ton, $t_{grn} = 61°F$
Possible Reasons VS Pump Drives Don’t Work

Many offices, public buildings, and especially schools do not have resources to maintain chemical treatment programs and automated building controls. The Austin (TX) ISD laid off 1000 employees while attempting to minimize teacher loss. Fortunately, their many older GSHP systems (20+ years) are 100% HDPE loops with on-off pumps and room thermostats.
Do Ground Loops Overheat and Die After Number of Years?

Apparently not! They will overheat if loops are too short, too close together, or improperly grouted or backfilled.
Occupant Temperature Satisfaction
5 = Very Satisfied, 4 = Satisfied, 3 = Acceptable, 2 = Dissatisfied, and 1 = Very Dissatisfied

Cool Comfort
Heat Temp
Maintenance and Control Satisfaction
5 = Very Satisfied, 4 = Satisfied, 3 = Acceptable, 2 = Dissatisfied, and 1 = Very Dissatisfied

Maint. & Control Satisfaction Rating vs. Energy Star Rating Rating

- Blue diamonds: Maintenance
- Red squares: Controllability

Legend:
- Maintenance
- Controllability
A common comment is “GSHPs cost too much”.

But few seem to know how much they cost (or they are embarrassed to share).

A common comment is “you have to get the loop cost down” (even though the loop costs in this survey were 26% of the total while the HVAC cost was 74%).

The few engineers willing to share information had the highest Energy Star ratings and modest installation costs premiums.
GSHP Loop and Total System Cost/Ton

<table>
<thead>
<tr>
<th>Year of Installation or Bid Date</th>
<th>IL-Loop</th>
<th>IL-GSHP</th>
<th>TX-Loop</th>
<th>TN/GA-Loop</th>
<th>TN/GA-GSHP</th>
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<tr>
<td>2011</td>
<td></td>
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</table>
GSHP Loop System Cost/Bore Ft.
Costs Include Headers, TX Loops Also Include Interior Piping

<table>
<thead>
<tr>
<th>Year of Installation or Bid Date</th>
<th>IL-Loop</th>
<th>TX-Loop</th>
<th>TN/GA-Loop</th>
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<tr>
<td>2011</td>
<td>$16</td>
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</tbody>
</table>
Summary

- Most GSHP systems did well (33% E-Star > 90, 61% E-Star > 75)
- Unitary loop and one-pipe GSHPs performed very well (Avg E-Star = 95)
- Central loop GSHPs performed only slightly better than the average conventional HVAC systems
- A few GSHPs don’t work very well - 19% E-Star < 50% (Short loops, dysfunctional controls, big pumps & OA units)
- Systems with simple thermostat controls performed better than those with building automated systems (BAS)
- Ventilation air flow has a significant impact on building energy rating
- VS ground loop pump drives are not working as intended
- The average cost for the inside the building HVAC was 74% of the total GSHP system cost and has increased by 175% since 1995 survey.
- The average cost for the ground loop was 26% of the total GSHP system cost and has increased by 50% since 1995 survey.
- Unlike computer simulations, measured data does not show any significant incidence of overheated loops due to long term imbalances of cooling loads compared to heating loads.
Recommendations

- Do your own design work including the ground loop and controls (controls that can’t be designed in-house are probably too complex for users).
- Use long loops separated by 20 - 25 ft. minimum with stable and conductive grout/fill (k > 0.85 Btu/h-ft-°F).
- Use multiple small and simple systems as first option, use more complex central loops as last alternative.
- Use HDPE pipe inside the building and in the ground.
- Realize the potential for system cost reductions are much greater inside the building than in the ground.
- Consider the source of all information (follow the $$$$).
- Obtain Energy Star ratings, survey occupants, and talk to the maintenance folks to improve system designs.
- Develop portfolios (kWh, $$$$,$$) that demonstrate to owners and architects that you provide high quality GSHPs.
Show last three slides if time permits
Should Experts Who Predict Energy Use and Design Buildings (and Economist) Be Paid Based on Performance Like Baseball Players?

EcoPrediction Avg. = 0.126

Joe Morgan - Cincinnati

Larry Summers - Harvard
Engineering Quality and Pay

1. High quality engineers are not paid nearly enough
2. Mediocre engineers are paid too much, especially when they default design work to vendors and contractors
3. In GSHP industry loop design frequently performed by non-engineers (vendors, loop contractors, geo-experts consultants)
4. Owners & architects usually can not tell good ones from not-so-good ones
Performance Portfolios for Architects, Engineers, & Contractors (Example)

<table>
<thead>
<tr>
<th>Building</th>
<th>Rated Year</th>
<th>Energy Star Rating</th>
<th>Mechanical Cost</th>
<th>Survey - IAQ, Light, Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Side Elementary</td>
<td>2005</td>
<td>86</td>
<td>16.67/ft²</td>
<td>3.7/5.0</td>
</tr>
<tr>
<td>Joe’s Bar &amp; Grill</td>
<td>2004</td>
<td>78</td>
<td>23.45/ft²</td>
<td>3.0/5.0</td>
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<tr>
<td>Bryant High School</td>
<td>2006</td>
<td>83</td>
<td>19.31/ft²</td>
<td>3.4/5.0</td>
</tr>
<tr>
<td>Teacher’s Credit Union</td>
<td>2003</td>
<td>78</td>
<td>23.45/ft²</td>
<td>3.9/5.0</td>
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<tr>
<td>Warrior Reality Office</td>
<td>2005</td>
<td>90</td>
<td>15.86/ft²</td>
<td>4.1/5.0</td>
</tr>
<tr>
<td>CBR Accounting Office</td>
<td>2002</td>
<td>75</td>
<td>22.11/ft²</td>
<td>3.8/5.0</td>
</tr>
<tr>
<td>Warren Tire Office</td>
<td>2005</td>
<td>77</td>
<td>15.39/ft²</td>
<td>3.3/5.0</td>
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</tbody>
</table>