TECHNICAL FEATURE

Long-Term Commercial GSHP Performance

Part 7: Achieving Quality

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This is the final installment in a series that summarizes a data collection and analysis project to identify common characteristics of successful ground source heat pump (GSHP) systems.

The goals of GSHP systems are common to conventional HVAC systems and include the following:

- Low building energy consumption and costs;
- Installation costs that are economically viable in relatively short time periods;
- Room conditions that are satisfactory to occupants; and
- Minimal maintenance requirements and costs.

Finding good data for this project was challenging because typical measures of success identified in the list of goals were either not accessible or made unavailable for GSHPs (and traditional HVAC systems) that did not perform as expected. A larger study of LEED buildings was able to obtain actual energy data for only 121 out of 585 buildings requested.[1] The authors posed the question, "Why is it so hard…to get this information for the buildings being profiled?"

Every electric utility encountered in this survey had the necessary information. The hitch was the building owner needed to approve access, and in some cases, the owner chose not to do so. The information on installation costs was even more restricted than the utility data.

From the survey, it may be surmised that:

- A reason it is so hard to obtain energy data (and costs) is that in some cases "…the buildings are using significantly more energy than predicted,"[1] so designers, contractors, and owners are unwilling to share results.
- Designers, contractors, and owners willing to share energy and costs data are likely to have completed successful GSHP projects with good energy performance (i.e., high ENERGY STAR rating) and reasonable first costs.
- The average ENERGY STAR ratings for the GSHP buildings surveyed in this study may be higher than the average of GSHP systems (because of the first two items).

However, the average could potentially be much higher if owners (and architects) were able to choose engineers based on quantifiable information. Publication of energy data, installation

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costs, and satisfaction levels will allow engineers to demonstrate GSHP quality and provide owners (and possibly architects) an effective metric for selecting outstanding designers.

Recent Projects Building Name	Year Rated	ENERGY STAR Rating	HVAC Install Cost	Occupant Satisfaction
West Side Elementary	2009	98	$22.72/ft^2	3.9/5.0
Horry Office Tower	2010	96	$19.18/ft^2	3.7/5.0
Myers Drug Store	2008	95	$17.51/ft^2	4.1/5.0
Stallings High School	2011	91	$27.18/ft^2	3.4/5.0
Harper & Lee, LLC Office	2006	94	$20.43/ft^2	3.5/5.0
King Middle School	2010	88	$23.67/ft^2	3.1/5.0
Nick's Wellness Center	2011	99	$18.65/ft^2	3.8/5.0

Table 1: Possible portfolio summary.

Engineering Portfolio

A magazine article published during the low point of the recent financial crises suggested that when economists are speaking on television, statistics should be shown for the accuracy of their predictions in a manner similar to the screen display of baseball player's statistics. This may be something to think about for design engineers.

However, architectural portfolios are probably a more professional format to follow than ball player statistics. An "engineering portfolio" would likely contain fewer pictures and more numbers than typically provided by the architectural community. *Table 1* and *Figure 1* suggest a framework for possible formats to be included in an engineering portfolio, although they undoubtedly could be enhanced by graphic artists and marketing consultants. *Table 1* presents a summary for the energy rating, mechanical system cost, and occupant satisfaction for recent projects completed by an imaginary firm. *Figure 1* provides much greater detail with text to highlight the building characteristics and energy conservation features and a succinct listing of results to show how well primary goals have been achieved.

Westside Elementary is a 38,000 ft^2 (3530 m^2), two-story structure opened in 1929. A 2008 renovation included the addition of a ground source heat pump (GSHP) system, lighting upgrade, window replacement, and an energy recovery ventilation system. Energy performance has exceeded expectations as indicated by the EPA ENERGY STAR rating of 98. The GSHP installation cost was $863,210. First year energy cost savings indicate a five year payback. Occupants have rated the comfort, air quality, lighting, acoustics, and maintenance at 3.9/5.0 (Satisfied). Client contact to verify results: John Smith (jsmith@school.edu).

Building Details	Floor Area: 38,000 ft^2 (3530 m^2), 500 occupants, 10-month operation Annual Energy Use: 307,800 (8.1 kWh/ft^2) Electrical Demand: 118 kW (3.1 W/ft^2) Annual Energy Cost: $30,475 ($0.80/ft^2)			
HVAC Equipment	32 water-to-air heat pumps (90 tons total [317 kW]), 36 circulation pumps (5.5 hp total), four 2,500 cfm (1180 L/s) energy recovery units			
Ground Loop Description	88 vertical bores at 225 ft (19,800 bore ft total), 1 in. HDPE U-tubes with thermally enhanced grout backfill, 1.25 in. and 1.5 in. HDPE headers to each heat pump			
Installation Costs Total HVAC & Loop $863,210; $22.72/ft^2	**HVAC**		**Ground Loop**	
	Heat pumps (32)	$128,000	Drilling/Installation	$158,400
	Pumps (36)	$19,800	HDPE U-tubes	$29,700
	ERUs (4)	$120,000	Exterior Headers	$27,000
	Ductwork	$144,000	Thermal Grout	$18,810
	Interior Piping	$56,000	—	—
	Controls	$66,500	Cost per Bore Foot	$11.81
	Electrical Upgrade	$95,000	—	—
	Total	$629,300	—	$233,910
	Total/ft^2	$16.56	—	$6.16
Occupant Satisfaction	Cooling Comfort	3.7/5.0	Heating Comfort	4.4/5.0
	Indoor Air Quality	3.9/5.0	Lighting	4.4/5.0
	Acoustics	3.7/5.0	Ability to Control	3.1/5.0
	Maintenance Frequency	4.2/5.0	Maintenance Response	3.5/5.0
Maintenance Staff Satisfaction	Serviceability	3.0/5.0	Quality of Installation	3.5/5.0
	Quality of Design	4.0/5.0	Quality of Equipment	2.5/5.0
	Documentation	3.0/5.0	—	—

Figure 1: Possible detailed building portfolio.

Financing Quality: Design Team as ESCo

Often, little motivation exists beyond the design phase for engineers to verify installation quality and proper system operation. The design team would have a strong incentive if it functioned as an energy service company (ESCo) by entering into a shared savings contract for the first several years of the building operation. Not only would the firm take greater care in performing high quality design, but it would monitor system installation more diligently as well as proper HVAC and building system control operation.

The process would begin with an installation cost budget that would provide an attractive return on investment for the owners using an energy cost for a system with an above average efficiency. A suggested baseline might be the energy cost for a building that received an ENERGY STAR rating of 75. The ENERGY STAR Target Finder[2] is specifically structured to provide the energy consumption to attain such a rating. Any energy savings above this value would be shared by the owner and design team at negotiated percentages. If the installation costs were higher (or lower), the base ENERGY STAR rating would be reset so that the owners received an equivalent return on their investment. For example, if the installation costs were less, the baseline rating might be 72, or if costs were higher the baseline might be 80.

Barriers and Common Sense Approaches

The first barrier to wider application of quality GSHPs is the high cost of the ground loop. This cost is significant (26% of the total in the systems surveyed in this project), but quality ground loops provide an opportunity to reduce the cost of the interior portion of the systems if engineers are wise and diligent. Experienced ground loop contractors appear to have become more effective in that their costs have risen by only 52% in the past 15 years while the HVAC industry (engineers, ASHRAE, manufacturers) seem to be less effective since this portion of the system costs has risen by 177% in the same period.

Common sense would dictate that if the HVAC interior component of GSHPs is approximately three times the cost and the percentage increase has risen over three times as much of the ground loop since 1995, efforts would be made to identify the particulars. It is also of concern that GSHPs are often perceived to be "too expensive" or "do not have acceptable life-cycle cost," but there is little published information on actual installation costs.

There continues to be insufficient information, especially itemized cost details, to identify the most prudent paths toward high performance, economic value, and owner/occupant satisfaction. Chapter 37,"Owning and Operating Cost" of the *2011 ASHRAE Handbook—HVAC Applications*, has little information on recent HVAC system costs and service life. This type of information is very important, and ASHRAE research efforts need to focus more on field surveys that collect performance and cost data for all types of HVAC systems.

Additional recommendations are provided based on the data collected during this project.

- Ground loops should be big (see sidebar, "Characteristics of Successful GSHPs");
- Pumps should be small (less than 7.5 hp/100 tons [1.6 kW/100 kW]);
- Fans should be small (less than 15 hp/100 tons [0.3 kW/100 kW]);
- Itemized costs should be required on bids;
- Individual or multiple mid-size interior circuit headers should be the first design option;
- Large central interior circuit headers should be used when smaller loops are not technically possible;
- Water-to-air heat pumps should be used unless *system* efficiency calculations demonstrate water-to-water heat pumps or chillers are a better option (see Table 13, *2011 ASHRAE Handbook—HVAC Applications*, Chapter 34);
- Controls should be simple and not be so expensive that ground loops must be made smaller for the system cost to remain within the allowable budget;
- Ventilation air equipment capacity should be near minimum ASHRAE recommended values so that when control systems fail, buildings are not excessively overventilated;
- Engineers that subcontract ground loop design should be avoided, especially those whose mechanical drawings specify the ground loop to be designed by "the contractor" or "by others"; and
- An important component in selecting a high quality design firm should the submission and review of "engineering portfolios" similar to the example provided in this article.

Changes to ASHRAE Standards

Standard 90.1-2010 Mechanical Section

It was discovered that systems with the highest ENERGY STAR ratings in this survey (unitary, one-pipe, and common loops) are now non-compliant with the recent updates to the mechanical section of ASHRAE/IES Standard 90.1-2010 (Section 6.5.4.4). However, systems with ground loops connected to VAV air-distribution systems with a fan power of 2.3 hp/1,000 cfm (0.36 kW/100 L/s) are compliant for health-care facilities and possibly other building types.[3] This fan power is approximately five times the value recommended in this article (based on 400 cfm/ton [54 L·s/100 kW), translates to a fan power of 0.76 kW/ton (0.22 kW/kW) (based on 90% efficient motors) and will result in a fan heat penalty of 22% of chiller capacity (*Table 2*).

This might explain the reason the chilled water GSHP systems surveyed attained ENERGY STAR ratings of 20 and 21. Systems with high auxiliary power demand and resulting en-

Standard 90.1 Fan Power Limit:	2.3 hp/1000 cfm × 400 cfm/ton = 0.92 hp/ton 0.746 kW/hp × 0.92 hp ÷ 90% = 0.76 kW/ton
Fan Heat Penalty:	0.76 kW/ton × 3,412 Btu/kWh = 2,600 Btu/h per ton 2,600 Btu/h ÷ 12,000 Btu/h = 22% of chiller capacity

Table 2: Changes to Standard 90.1-2010.

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Characteristics of Successful GSHPs

- The ENERGY STAR rating of the building exceeds 90.
- Maximum loop temperatures returning from the ground tend to be below 90°F (32°C) for systems in which the cooling mode determines loop length.
- The systems surveyed during this project were primarily 10-month schools and 8 a.m. to 5 p.m. offices located in areas where the measured ground thermal conductivity was between 1.0 and 1.5 Btu/h·ft·°F (1.7 and 2.6 W/m·°C). Under these circumstances, the successful vertical ground loops tend to be in the range of 200 to 240 ft of vertical bore per installed ton (17 to 21 m/kW) of cooling capacity for a ground temperature of 63°F (17°C). This corresponds to a range of 155 to 185 ft per ton (13 to 16 m/kW) for 55°F (13°C) ground temperature and 270 to 320 ft per ton (23 to 28 m/kW) for 70°F (21°C) ground.
- The ground loop lengths of systems in this survey were all dictated by the cooling mode requirements. This resulted in advantageous heating mode ground loop temperatures even at the coldest sites in Central Illinois. At the one site that was monitored continuously, the ground loop return temperature remained above 46°F when the outdoor temperature was –6°F (–21°C).
- The primary equipment type tends to be water-to-air heat pumps.
- Installed outdoor ventilation air equipment capacity tends to be 20 cfm/person (9.4 L/s per person) or less.
- Systems with heat pumps circuited to individual ground loops, small central, or multiple common loop circuits out-performed systems with large central loop circuits by a significant margin.
- Pump control tends to be on-off for these smaller loop circuits rather than variable speed.
- Ground loop pump power tends to not exceed 10 hp/100 tons ($kW_{Pump}/kW_{HeatPump}$). This value is deemed to be average (Grade = C) using recommended guidelines.[7]
- Due to the selection of piping materials and pH level of the fill water, piping systems tend to not require chemical treatment. However, caution is advised against using PVC pipe. It is not recommended for service when contact with polyolester oil is possible[8] if leaks occur in the water coils of HFC-refrigerant systems.
- Control is provided by individual thermostats or a building automation system that is simple with a clear and concise sequence of operation so program adjustments (or retrocommissioning) can be performed by the maintenance staff.
- When surveyed, occupants rate indoor comfort, indoor air quality, acoustics, lighting, maintenance responsiveness, and system controllability as satisfactory.
- When surveyed, the maintenance staff rates system serviceability, quality of design, and quality of installation as satisfactory.
- Owners and designers are satisfied with utility cost and they openly share results (and permit ENERGY STAR rating).
- Owners and designers are satisfied with the installation costs, they will openly share itemized results, and they are confident the project provides positive economic value.

ergy use cannot be recommended with GSHPs. It is recommended that the Standard 90.1 mechanical section be revised to allow the best performing GSHP systems to be compliant and to disallow systems with excessive auxiliary power requirements (i.e., 2.3 hp/1,000 cfm).

Heat Pump Efficiencies

Manufacturers of water-to-air heat pumps are currently advertising products with cooling EERs in excess of 40 Btu/W·h (11.7 W/W). These values are attained at part-load rating points that do not reflect actual operating conditions.[4]

- External static pressure: 0 in. w.g. (0 Pa);
- External water pressure: 0 ft of water (0 kPa);
- Full load airflow used with part-load capacity (no cooling dehumidification in cooling and cool air delivery in heating);
- Water temperature entering the condenser: 68°F (20°C); and
- Return air conditions: 80.6°F (27°C) db/66.2°F (19°C) wb.

(Car mileage per gallon is not rated going downhill with a tailwind, so why is heat pump cooling efficiency rated with a condenser fluid colder than the evaporator fluid?)

Figure 2 indicates cooling and heating efficiencies of constant speed heat pumps are higher than multi-capacity and variable speed units at ground loop temperatures experienced in commercial applications (cooling: >80°F [27°C], heating: <50°F [10°C]). Trends indicate ratings at higher entering water temperatures are needed since almost all the systems in this survey exceed 86°F (30°C). Furthermore, the efficiency improvements of multi-capacity and variable speed machines are minimal or non-existent when corrected to typical part-load field conditions.[5]

This field study demonstrates it is possible to achieve ENERGY STAR ratings of 95 to 100 with simple equipment. Higher cost heat pumps exacerbate the discrepancy in the cost increases of HVAC components compared to the increases in ground loops costs. A standard that rates heat

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Characteristics of Successful GSHP Engineering Design Firms

- The engineering firm performs all system design (including the ground loop and HVAC controls) and is open to feedback for suggested modifications that benefit the owner and building occupants.
- In situations where a firm has designed several buildings for an owner, the engineer(s) regularly communicates with maintenance supervisors and staff (and is not afraid to enter their breakroom at lunch).
- In situations where a firm has designed a single building for an owner, the owner regularly refers the engineer(s) because of the quality of the work product.
- The engineering firm is familiar with the capabilities of the local the ground loop and mechanical contractors and the corresponding level of monitoring to ensure systems are installed as designed.
- The engineering firm has a basic understanding of local geology, ground water regulations, drilling techniques, and ground circuit header assembly. The firm provides designs that are sensitive to the resulting constraints and are, therefore, respected by ground loop contractors (who typically do not hold engineers in high regard).
- Because ENERGY STAR rating (unlike LEED) is based on measured energy performance, requires minimal paperwork, uses information routinely provided by the utilities, is relatively simple and inexpensive, the engineering firm maintains a listing of ratings for completed projects.
- The engineering firm tracks, maintains, and openly shares records of mechanical and ground loop costs. Contractors and subcontractors are encouraged (or possibly required) to submit itemized bids to identify components or designs that are not good value.
- They allow occupant and maintenance satisfaction surveys to be conducted and review results and comments to improve quality.
- The engineering firm oversees their design through construction and performs system commissioning as an included service rather than a separate line item in their fee proposals, which might be eliminated by a client.

pumps at conditions experienced in the field would demonstrate the actual economic value of "40 EER" heat pumps rated using current standards.

Standard 210/240

To not put water source heat pumps at a marketing disadvantage, the standard for air-source SEER/HSPF (ANSI/AHRI/ASHRAE 210/240) should simultaneously be revised since it also includes ratings conditions that provide unreasonably optimistic efficiencies.[6]

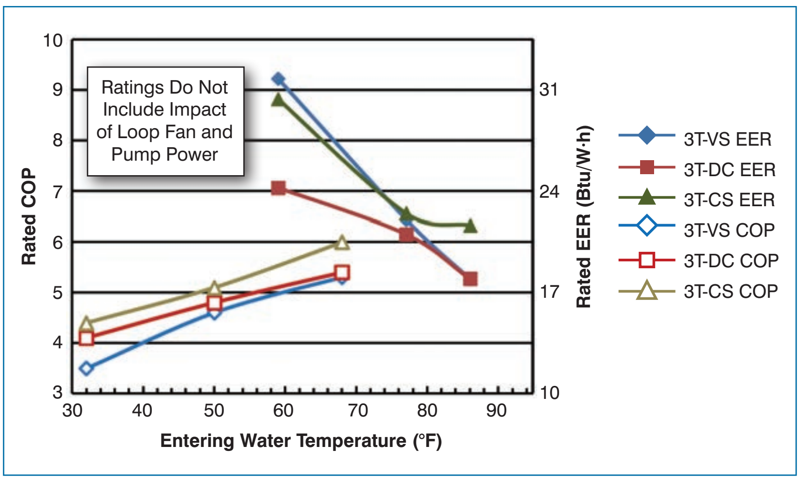

Figure 2: COP and EER comparison of high efficiency, 3 ton (10.6 kW) variable speed, dual capacity, and constant speed water-to-air heat pumps.[9]

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