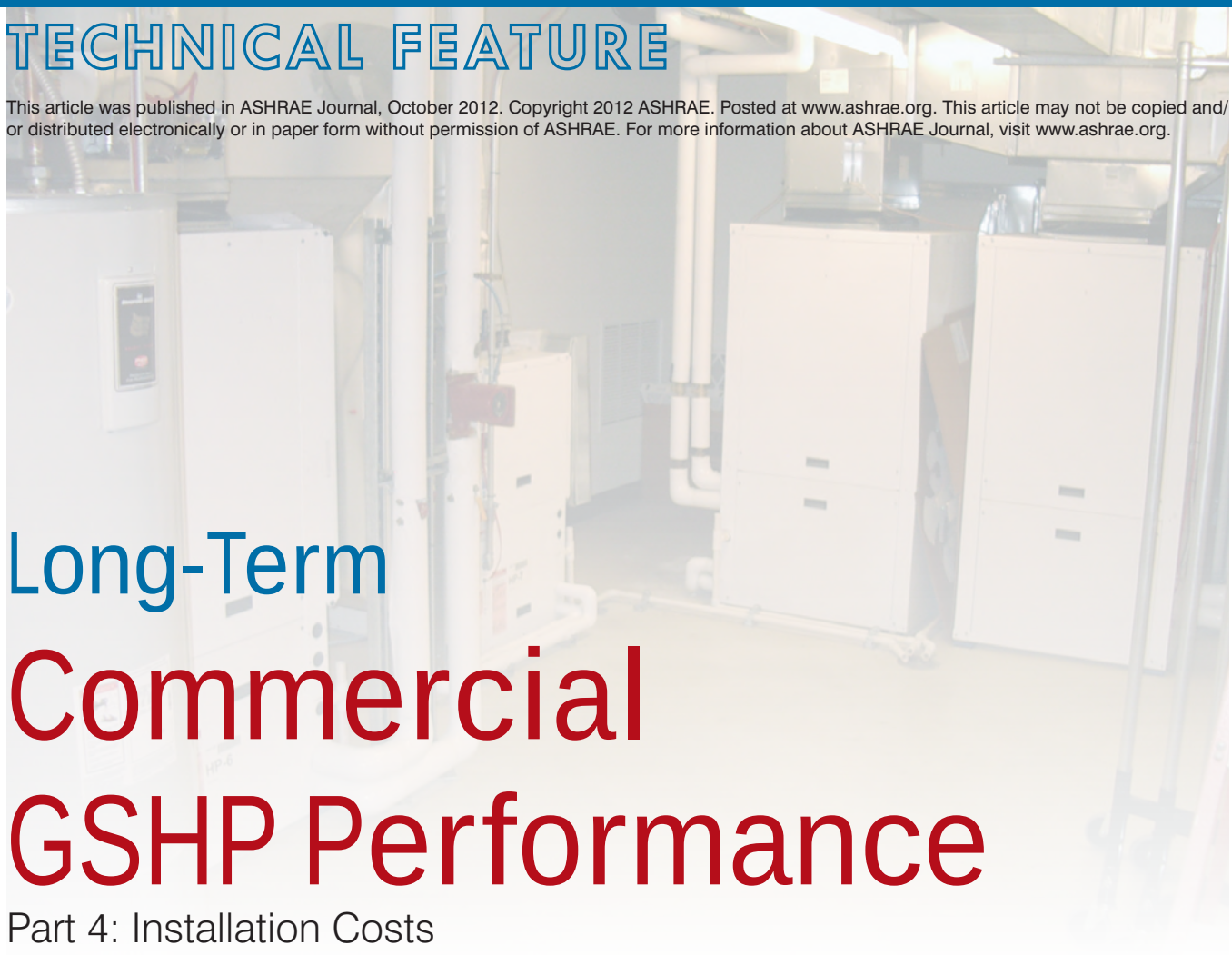

Long-Term Commercial GSHP Performance

Part 4: Installation Costs

By Steve Kavanaugh, Ph.D., Fellow ASHRAE; **Mike Green, P.E.,** Member ASHRAE; and **Kirk Mescher, P.E.,** Member ASHRAE

This article is the fourth installment in a series of articles that summarize a data collection and analysis project to identify common characteristics of successful ground source heat pump (GSHP) systems.[1] This article presents installation cost information that was provided for several of the newer projects.

Performance and cost surveys were collected and site visits were performed at 40 locations. This included 23 building owners, but only four building owners or engineers completed the installation cost portion of the surveys. Fortunately, they provided cost data for multiple buildings, some of which were monitored and several that were too new for performance rating or were under construction. The results are heavily weighted toward the two system types that achieved the highest ENERGY STAR ratings. Costs were available for seven systems with a one-pipe central loop in the building with small pumps that circulate liquid from a common supply and return pipe through the heat pumps. Data for seven unitary loop GSHPs in which each heat pump is connected to an individual loop and circulation is provided by a small on-off pump. Data for three central loop systems were also included along with results from a previous Electric Power Research Institute/Tennessee Valley Authority (EPRI/TVA) project[2] and an ASHRAE research project.[3]

The increase in the HVAC component costs of GSHP systems since the 1995 study has been 177% while the increase in ground loop portion was only 52%. In this recent study, the ground loop portion of GSHP systems accounted for 26% of the total while the HVAC component comprised 74% of the total. Thus, attempts to optimize GSHP cost by focusing primarily on the ground loop seemed illogical. The lack of responses to the cost component of the surveys is disappointing given commercial GSHPs are often avoided because of high cost. Emphasis should be placed on gathering additional detailed cost information to expand the results and further develop the conclusions of this article.

About the Authors

Steve Kavanaugh, Ph.D., is a professor emeritus of mechanical engineering at the University of Alabama, Tuscaloosa, Ala. **Mike Green, P.E.,** is a principal at MEP Engineering in Austin, Texas. **Kirk Mescher, P.E.,** is a principal at CM Engineering in Columbia, Mo.

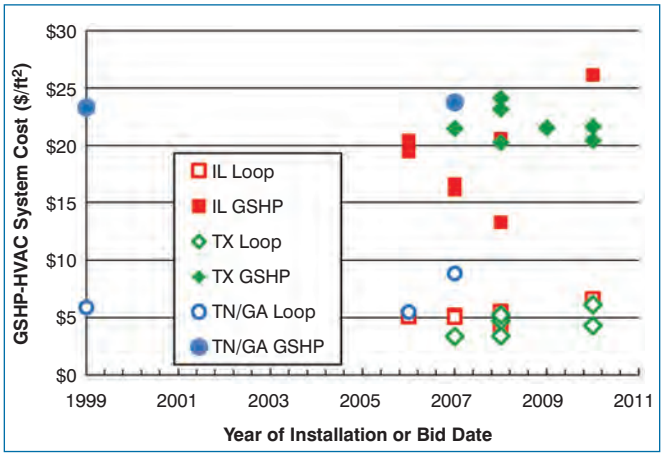

Figure 1: Ground source heat pump system and ground loop cost based on building floor area.

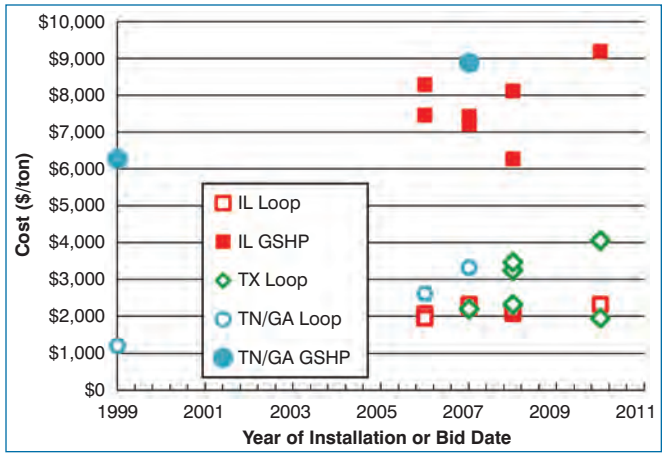

Figure 2: Ground source heat pump system and ground loop cost based on cooling capacity.

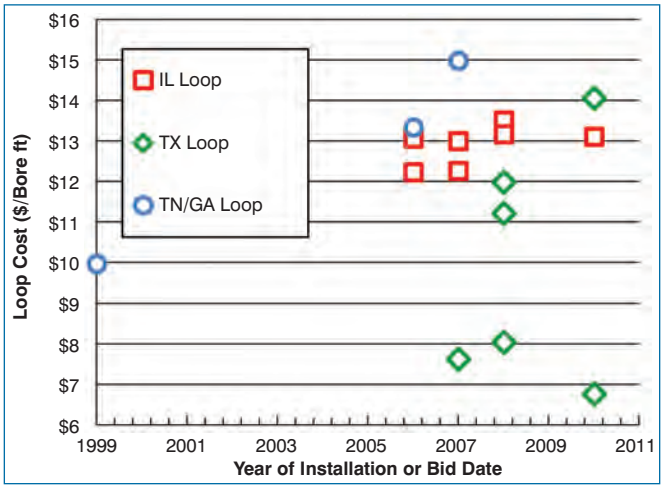

Figure 3: Ground loop cost based on vertical bore length.

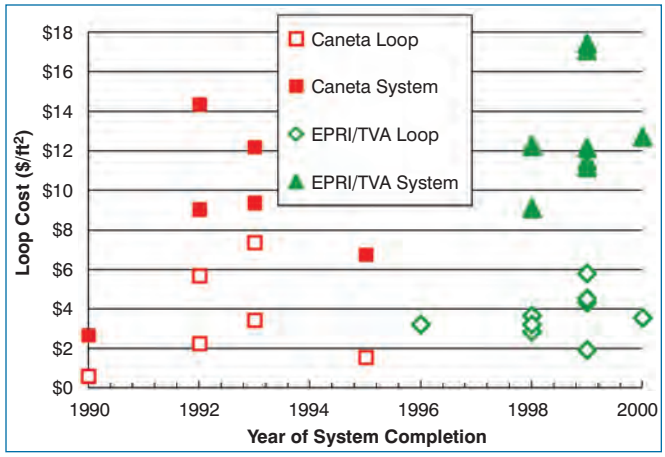

Figure 4: Ground source heat pump system and loop cost from previous studies.[2,3]

Summary Results

Figure 1 shows the costs for the complete GSHP system and the ground loop portion based on floor area. The Illinois (IL) systems are one-pipe loops, the Texas (TX) systems are unitary loops, and the Tennessee and Georgia (TN/GA) systems are central loops. The ground loop costs for the IL and TN/GA loops include the vertical bore and exterior header costs while the TX systems also include the interior building piping and pump costs.

The average system cost including the ground loop was $20.75/ft^2 ($223/m^2) with a high of $26.10/ft^2 ($281/m^2) and a low of $13.34/ft^2 ($144/m^2). The average ground loop cost was $5.29/ft^2 ($57/m^2) with a high of $8.89/ft^2 ($96/m^2) and a low of $3.35/ft^2 ($36/m^2). The average cost of the ground loop was 25.5% of the total GSHP system cost based on floor area. Costs for the TX systems include non-GSHP equipment.

Figure 2 shows the costs for the total GSHP system and the ground loop cost based on the rated capacity of the heat pumps. Again, the ground loop costs for the IL and TN/GA loops include the vertical bore and exterior header costs while the TX systems also include the interior building piping and pump costs. The system cost for the TX systems based on equipment capacity are not included because the common areas were heated and cooled by non-GSHP equipment.

The average GSHP system cost was $7,694/ton ($2,190/kW) with a high of $9,206/ton ($2,620/kW) and a low of $6,291/ton ($1,790/kW). These values include the cost of the ground loop. The average ground loop cost was $2,483/ton ($706/kW) with a high of $4,076/ton ($1,160/kW) and a low of $1,209/ton ($344/kW). As shown in *Figure 2*, the low value was for the system installed in 1999, which also had a relatively short loop length for the rated capacity of the installed equipment. The average cost of the ground loop was 32.3% of the total GSHP system cost based on rated equipment capacity.

Figure 3 provides the costs for the ground loop based on the length of the vertical bore. The average ground loop cost was $11.77/ft ($38.62/m) with a high of $15/ft ($49.20/m) and a low of $6.76/ft ($22.18/m). These values include the cost of exterior headers for the IL and TN/GA systems and the TX systems also include interior piping and pumps.

Figure 4 shows the costs for the total GSHP system and the ground loop cost based on floor area from two earlier studies. A condensed publication[4] of a large survey from an ASHRAE-

Building Type	Elementary School	Elementary School	Elementary School	Elementary School	Elementary School	Elementary School	Elementary School
Installation Type	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	New
GSHP Installation Date	2006	2006	2007	2007	2008	2008	2010
Building Construction Date	1954	1954	1957	1954	1938	1956	2010
Building size (ft^2)	23,700	43,200	37,400	31,000	19,000	55,150	76,900
Equipment Capacity (tons)	59	115	86	67	48	117	218
GSHP System ($)	$490,000	$859,000	$621,000	$499,000	$390,000	$736,000	$2,007,000
GSHP System ($/ton)	$8,305	$7,470	$7,221	$7,448	$8,125	$6,291	$9,206
GSHP System ($/$ft^2$)	$20.68	$19.88	$16.60	$16.10	$20.53	$13.35	$26.10
Ground Loop ($)	$123,000	$225,000	$195,000	$156,000	$105,000	$243,000	$511,000
Ground Loop ($/ton)	$2,085	$1,957	$2,267	$2,328	$2,188	$2,077	$2,344
Ground Loop ($/$ft^2$)	$5.19	$5.21	$5.21	$5.03	$5.53	$4.41	$6.64
Ground Loop ($/ft)	$12.30	$12.23	$13.00	$13.00	$13.13	$13.50	$13.10
Vertical Bore Length (ft)	10,000	18,400	15,000	12,000	8,000	18,000	39,000
Vertical Bore (ft/ton)	169	160	174	179	167	154	179
Vert. Bore ($)	$82,000	n/a	$129,000	$98,000	$72,000	$144,000	n/a
Vert. Bore ($/$ft^2$)	$3.46	n/a	$3.45	$3.16	$3.79	$2.61	n/a
Vert. Bore ($/ft)	$8.20	n/a	$8.60	$8.17	$9.00	$8.00	n/a
Exterior Header & Purge ($)	$40,000	n/a	$66,000	$59,000	$33,000	$99,000	n/a
Header & Purge ($/$ft^2$)	$1.69	n/a	$1.76	$1.90	$1.74	$1.80	n/a
HVAC System ($)	$367,000	$634,000	$426,000	$342,000	$289,000	$492,000	$1,496,000
HVAC System ($/$ft^2$)	$15.49	$14.68	$11.39	$11.03	$15.21	$8.92	$19.45
Heat Pumps ($)	n/a	n/a	n/a	n/a	n/a	$159,000	$303,000
Heat Pumps ($/$ft^2$)	n/a	n/a	n/a	n/a	n/a	$2.88	$3.94
Heat Pumps ($/ton)	n/a	n/a	n/a	n/a	n/a	$1,359	$1,390

Table 1: Specification and cost details for Illinois one-pipe loop ground source heat pumps.

sponsored research project[3] studied systems located in colder climates including Canadian buildings. The system installed in 1990 is a unitary loop while the other five sites have central loops. Horizontal closed-loop and open-loop groundwater systems were surveyed but only the vertical closed-loop systems are shown in *Figure 4*. An Electric Power Research Institute cost and maintenance survey in the Tennessee Valley was conducted on several GSHP schools.[2] All systems are vertical central loop GSHPs.

The average GSHP system cost for the 1995 survey was $9.07/ft^2 ($98/m^2) with a very high variation in cost between the maximum of $14.34/ft^2 ($154/m^2) and minimum of $2.67/ft^2 ($29/m^2). The average ground loop cost was $3.49/ft^2 ($38/m^2) with an even more pronounced variation between the maximum of $7.38/ft^2 ($79/m^2) and minimum of $0.60/ft^2 ($6.46/m^2). The average cost of the ground loop was 38.5% of the total GSHP system cost based on floor area, which is notably higher than the value for the more recent survey (25.5%).

The average GSHP system cost for the 2000 survey was $13.08/ft^2 ($138/m^2) with a maximum of $17.41/ft^2 ($187/m^2) and minimum of 9.10/ft^2 ($98/m^2). The average ground loop cost was $3.76/ft^2 ($40/m^2) with a maximum of $5.80/ft^2 ($62/m^2) and minimum of $1.93/ft^2 ($21/m^2). The average cost of the ground loop was 30.1% of the total GSHP system cost based on floor area, which is greater than the value for the more recent survey (25.5%). It may be of interest that results were not influenced by LEED-related costs since no buildings were rated.

Detailed Costs

Table 1 provides a more detailed listing of system cost for seven elementary schools in central Illinois. Six installations are retrofits of older schools and their ENERGY STAR ratings were shown in *Figure 5*, in Part 1 of this series of articles.[5] Ground loop costs are fairly consistent based on bore length (±5%) and equipment capacity (±9%).

Costs range between $1,956 to $2,330 per ton ($556 to $662/kW) and $12.26 to $13.51 per bore foot ($40.22 to $44.32/m). However, costs based on floor area vary more (±21%) ranging from a low of $13.51 to $20.55 per ft^2 ($144 to $221/m^2). This can be explained, to some extent, by observing that the buildings with lower costs have smaller heat pump capacities per unit floor area. The HVAC cost per unit area for lowest cost building was $8.93/ft^2 ($96/m^2). The highest cost school at

$26.10/ft^2 ($281/m^2) was a new building, which unexpectedly had a low floor area per unit cooling capacity at 353 ft^2/ton (9.33 m^2/kW), a low ENERGY STAR rating (75) and a high HVAC cost at $19.46/ft^2 ($209/m^2).

More detail is provided in *Table 2* for the lowest cost system listed in *Table 1*. The ground loop cost represents 33% of the total GSHP system cost at $13.34/ft^2 ($144/m^2). The most significant interior HVAC items were piping (18.9%), heat pump equipment (21.6%), and controls (8%). Itemized costs for the ground loop were not provided.

Table 3 summarizes the HVAC and ground loop costs for seven schools in central Texas. The common areas in these schools are conditioned with conventional HVAC, and GSHPs serve primarily the classrooms. The rated capacity of the GSHP equipment is considerably less than the conventional equipment, although the percentage of area served by GSHPs is typically larger. For example, the 61.8% of schools built in 2007 are served by GSHPs but the GSHP capacity is only 36% of the total system capacity.

Retrofit System Cost: 55,150 ft² Illinois Elementary School				
117 Ton One-Pipe Ground Source Heat Pump (90 Bores at 200 ft)				
Item	$/ft²	$/ton	Total	%
One-Pipe Loop	$2.52	$1,188	$138,951	18.9%
Insulation	$0.44	$207	$24,258	3.3%
Equipment	$2.50	$1,180	$138,075	18.8%
Equipment Markup	$0.38	$177	$20,700	2.8%
Pumps	$0.16	$74	$8,600	1.2%
Expansion Tank	$0.05	$26	$3,000	0.4%
Air Venting	$0.01	$4	$450	0.1%
Equipment Installation	$0.25	$118	$13,800	1.9%
Electric/Controls	$1.07	$506	$59,189	8.0%
Sheet Metal	$0.46	$216	$25,305	3.4%
General Work	$0.72	$340	$39,780	5.4%
Condensate Drainage	$0.11	$51	$6,000	0.8%
Balance	$0.09	$43	$5,040	0.7%
Chemical	$0.02	$12	$1,375	0.2%
Glycol	$0.14	$68	$7,900	1.1%
HVAC Total	$8.93	$4,209	$492,423	66.9%
Ground Loop Total	$4.41	$2,078	$243,117	33.1%
GSHP Total	$13.34	$6,287	$735,540	

Table 2: Itemized component costs for Illinois one-pipe ground source heat pump.

The average total system costs were $5,190/ton ($1,475/kW) and $21.75/ft^2 ($234/m^2). The average ground loop length was 282 ft/ton (24 m/kW) with a cost of $10.19/ft ($33.43/m) of bore and $2,924/ton ($831/kW). The variation in cost per unit length is significant, which may be a result of slow construction activity at this time that resulted in lower than normal ground loop costs.

School Building Type	Elementary	Elementary	Elementary	Middle	High	Middle	Elementary
Bid Date	2007	2008	2008	2008	2009	2010	2010
Building Size (ft²)	112,300	112,300	111,600	177,300	411,800	177,700	112,300
Percent GSHP Floor Area	61.8%	61.8%	61.4%	59.4%	37.1%	62.9%	61.4%
Heat Pump Capacity (tons)	163	163	163	262	345	308.5	163
Total System Capacity (tons)	459	463	459	804	1574	838	463
HVAC/GSHP System ($)	$2,407,000	$2,706,000	$2,582,000	$3,542,000	$8,862,000	$3,630,000	$2,429,000
HVAC/GSHP System ($/ton)	$5,244	$5,844	$5,625	$4,405	$5,630	$4,332	$5,246
HVAC/GSHP System ($/ft²)	$21.43	$24.10	$23.14	$19.98	$21.52	$20.43	$21.63
Vertical Bore Length (ft)	47,850	47,560	47,560	71,050	91,930	83,230	47,560
Vertical Bore (ft/ton)	294	292	292	271	266	270	292
Ground Loop ($)	$376,000	$591,000	$553,000	$606,000	n/a	$510,000	$693,000
Ground Loop ($/ton)	$2,307	$3,626	$3,393	$2,313	n/a	$1,653	$4,252
Ground Loop ($/ft)	$7.86	$12.43	$11.63	$8.53	n/a	$6.13	$14.57
Percent GSHP tons	35.5%	35.2%	35.5%	32.6%	21.9%	36.8%	35.2%

Table 3: Specification and cost details for central Texas unitary loop ground source heat pumps.

However, the average cost of the ground loop was 33% of the total, which is higher than the average for systems in this survey. This is expected since the loop lengths are significantly longer for this hot climate and high ground temperature.

Table 4 provides details of the GSHP system and ground loop cost at three central loop systems for schools in southeast Tennessee and northwest Georgia. The system installed in 1999 was one of the first installed in this region and uncertainty resulted in equipment with a relatively large capacity being installed. Therefore, the cost and ground loop length per unit capacity are not typical compared with the newer systems. There is significant scatter in the costs and design parameters with the exception of the ground loop cost per unit length.

Building Type	Primary School	Elementary School	Elementary School
Installation Type	New	Retrofit	New
GSHP Installation Date	1999	2006	2007
Building Construction Date	1999	1926	2007
Building size (ft^2)	87,000	69,750	84,000
Heat Pump Capacity (tons)	425	146	224
Area/Capacity (ft^2/ton)	205	478	375
GSHP System ($)	$2,027,000	n/a	$1,992,000
GSHP System ($/ton)	$4,769	n/a	$8,893
GSHP System ($/$ft^2$)	$23.30	n/a	$23.71
Ground Loop ($)	$514,000	$384,000	$747,000
Ground Loop ($/ton)	$1,209	$2,630	$3,335
Ground Loop ($/$ft^2$)	$5.91	$5.51	$8.89
Ground Loop ($/ft)	$9.98	$13.33	$15.00
Vertical Bore Length (ft)	51,500	28,800	49,800
Vertical Bore (ft/ton)	121	197	222
HVAC System ($)	$1,513,000	n/a	$1,246,000
HVAC System ($/$ft^2$)	$17.39	n/a	$14.83

Table 4: Specification and cost details for Tennessee-Georgia central loop GSHPs.

Detailed Cost—Previous GSHP Studies

Table 5 provides cost information for several GSHP systems installed between 1990 and 1995 and listed in the

Building Type	Golf Clubhouse	Secondary School	Elementary School	Office	Education Center	Hotel
Installation Date	1990	1992	1992	1993	1993	1995
Location	Pennsylvania	Ontario	Minnesota	Virginia	New York	Pennsylvania
Building size (ft^2)	15,000	181,000	78,000	26,700	8,000	39,900
Heat Pump Capacity (tons)	25.5	410	193	100	24	97
Area/Capacity (ft^2/tons)	588	441	404	267	333	411
GSHP System ($)	$40,000	$2,595,000	$706,100	$325,800	$75,000	$269,380
GSHP System ($/ton)	$1,569	$6,329	$3,659	$3,258	$3,125	$2,777
GSHP System ($/$ft^2$)	$2.67	$14.34	$9.05	$12.20	$9.38	$6.75
Ground Loop ($)	$9,000	$1,030,200	$176,500	$92,030	$59,040	$61,950
Ground Loop ($/ton)	$353	$2,513	$915	$920	$2,460	$639
Ground Loop ($/$ft^2$)	$0.60	$5.69	$2.26	$3.45	$7.38	$1.55
Ground Loop ($/ft)	$3.00	$14.31	$6.30	$5.81	$14.76	$6.88
Vertical Bore Length (ft)	3,000	72,000	28,000	15,840	4,000	9,000
Vertical Bore (ft/ton)	118	176	145	158	167	93

Table 5: Cost details for 1995 ASHRAE TRP-863 study.[3]

ASHRAE-sponsored research project.[3] The average GSHP system cost was \$9.06/ft^2 (\$98/m^2) with a wide variation between \$2.67/ft^2 to \$14.34/ft^2 (\$29/m^2 to \$154/m^2). Average ground loop was \$3.49/ft^2 (\$38/m^2) and ranged from \$0.60/ft^2 to \$7.38/ft^2 (\$6.50/m^2 to \$79/m^2). Average cost per unit capacity was \$3,453/ton (\$982/kW) and varied from \$1,569/ton to \$6,329/ton (\$446/kW to \$1,800/kW) and the average cost based on vertical bore length was \$8.51/ft. (\$28/m) with

a $3/ft to $14.76/ft ($10/m to $48/m) range. The average bore length was 143 ft/ton (12.4 m/kW) and variation was also notable from a low of 93 ft/ton (8.1 m/kW) to a high of 176 ft/ton (15.3 m/kW).

Table 6 lists costs for the three GSHP systems in the EPRI/TVA study[2] that contained the most complete detail. The GSHP system cost for the three buildings were $11.47/ft^2, $14.92/ft^2, and $17.06/ft^2 ($123/m^2, $161/m^2, and $184/m^2). Costs for the ground loop were $4.31/ft^2, $4.63/ft^2 and $5.79/ft^2 ($46/m^2, $50/m^2, and $62/m^2). The average GSHP system cost for all the buildings in the survey with complete data (nine) was $13.08/ft^2 ($141/m^2) and $4,190/ton ($1,190/kW). The average bore length was 148 ft/ton (12.8 m/kW) and the typical floor area per unit of cooling capacity was 330 ft^2/ton (8.7 m^2/kW). This study also contained building energy consumption, operating costs, and maintenance information.

Caution is advised in applying the results of this survey directly when estimating costs for GSHP projects. Reasons for uncertainty include the items listed below.

- This is a limited data set and should be considered a step toward greater transparency in publishing HVAC and GSHP system costs.
- There was a high degree of reluctance to share itemized costs, which would be expected for higher cost GSHPs. Therefore, it is suspected the averages in the recent survey may be lower than the actual national average.
- As discussed in the second article in this series,[6] optimum vertical bore lengths in colder climates tend to be shorter than lengths required in hot climates.
- Drilling conditions, local code requirements, and labor rates vary considerably from region to region and have a dramatic effect on costs.
- Very large projects can create a variation in costs due to a "feast or famine" effect for the ground loop contractor industry. Contractors who dedicate their entire capacity for months or years to a single project at a distant location endanger losing their local steady clientele.
- The Texas systems benefit from an infrastructure that has developed over 25 years. Consistent opportunities for loop contractors are available; travel distances are shorter; equipment has been optimized for local conditions; the local geology is less uncertain; and engineers have adjusted designs to optimize installation efficiency. Therefore, it is not uncommon for a single rig to install in excess of 1,500 vertical feet (460 m) of heat exchanger per day.

Component Cost from 2000 EPRI/TVA Project			
	Low	**Mid**	**High**
Total GSHP System Cost	$11.47	$14.92	$17.06
Major Equipment	$2.51	$2.59	$3.11
Piping/Valves	$1.91	$1.46	$2.99
Pumps/Controls	$0.24	$0.24	$0.12
Ductwork	$2.01	$2.39	$3.16
HVAC Controls	$0.08	$1.89	$1.33
Other	$0.41	$1.72	$0.56
Total Interior Cost	$7.16	$10.29	$11.27
Drilling (and Casing)	$1.90	$2.30	$3.39
Pipe and U-Tubes	$0.32	$1.00	$0.28
Grouting	$0.31	$0.42	$0.23
Trenching/Headers	$0.88	$0.74	$1.18
Compaction	$0.66		$0.43
Other	$0.24	$0.17	$0.28
Total Exterior Cost	$4.31	$4.63	$5.79
Exterior Cost Percent of Total	37.6%	31.0%	33.9%

Table 6: Itemized cost per unit floor area ($/ft^2) for EPRI/TVA study.[2]

Summary and Conclusions

- The average costs in the recently completed study were $20.75/ft^2 ($223/m^2) for the GSHP system, which included $15.46 ($166/m^2) for the HVAC and $5.29/ft^2 the ground loop ($57/m^2).
- The average costs in the 2000 study were $13.08/ft^2 ($141/m^2) for the system, $9.32 ($100/m^2) for the HVAC, and $3.76/ft^2 ($40/m^2) for the ground loop.
- The average costs in the 1995 study were $9.07/ft^2 ($98/m^2) for the system, $5.58 ($60/m^2) for the HVAC and $3.49/ft^2 ($40/m^2) for the ground loop.
- In the sixteen years since the 1995 study the cost of the interior portion of GSHP systems has increased by 177% while the cost of the ground loop portion has increased only 52%.
- The percentage of ground loop costs to total GSHP system cost have declined from 38.5% in 1995 to 30.1% in 2000 to 25.5% in 2011.
- Clearly the focus of future cost containment efforts in commercial GSHPs should concentrate on the HVAC systems while not neglecting efforts to improve efficiency and expand opportunities for ground loop installations.
- Greater emphasis should be placed on gathering detailed cost information to expand and improve the results and conclusions of the three studies discussed in this article.
- Building owners should request portfolios from recent projects when selecting GSHP engineers, architects, and contractors that include itemized installation costs and energy performance information such as ENERGY STAR rating.
- GSHP case studies being featured in publications and presentations should include owner verified itemized installation costs and energy performance information.

Acknowledgments

The project was made possible with a tailored collaboration through the Electric Power Research Institute (EPRI), with the Southern Company (SoCo) and the Tennessee Valley Authority (TVA) providing the funding. Project direction and collaboration were provided by Ron Domitrovic (EPRI), David Dinse (TVA), and Chris Gray (SoCo).

GSHP Series Overview

The Long-Term Commercial GSHP Performance series summarizes the results of a project that collected data from buildings heated and cooled by ground source heat pump systems. The buildings were primarily commercial or institutional and the ground heat exchangers were almost all closed-loop vertical designs. The age of the systems ranged from three to 23 years of operation and installation cost information for the newer buildings was included.

Part 1: Project Overview and Loop Circuit Type: This article (June 2012) provided a description of the project and present a summary of energy performance of all buildings and the function of different types of loop circuits.

Part 2: Ground Loops, Pumps, Ventilation Air, and Controls: This article (July 2012) provided a summary of energy and demand performance of GSHPs as a function of several important characteristics. These include vertical ground heat exchanger dimensions, relative building and ground loop pump size, specified flow rate of the ventilation air system, and the general type of building control system.

Part 3: Ground Loop Temperatures: This article (Sept. 2012) provided a summary of energy and demand performance of GSHPs as a function of ground loop temperatures.

Part 5: Comfort and Satisfaction: This article will provide a summary of satisfaction levels of building occupants and the personnel that maintain and operate the systems.

Part 6: Maintenance and Controls: This article will present results from maintenance personnel assessments of GSHP systems including the controls.

Part 7: Characteristics of Quality GSHPs: This article will summarize the results of the project and highlight characteristics that tend to optimize energy use, installation cost, and occupant/operator satisfaction.

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