A Simple Approach To Affordable GSHPs

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Conventional wisdom is that ground source heat pumps (GSHPs) for commercial and institutional buildings have an added premium for the ground heat exchanger that eliminates their consideration for many projects. One avenue to overcome this barrier that has been considered, and in a few cases applied, is "loop leasing." The approach is for an investor or utility to install the ground heat exchanger and lease its use to the building owner for a monthly fee. An electric utility established a team to investigate the economics of this arrangement by first comparing the installation and preventative maintenance costs of a typical GSHP.

However, the utility requested the GSHP cost be compared to other premium HVAC systems for offices, schools, and low-rise hotels. The systems specified for the evaluation were four-pipe chilled water (CW) systems with an electric boiler, both constant air volume (CAV) and variable air volume (VAV). Additionally, the approach of connecting a ground heat exchanger to a conventional chilled-water system was averted in favor of unitary heat pump systems connected to "non-central" ground and interior piping networks. This article condenses the results of the comparisons for a 72,000 ft^2 (6700 m^2) school located Birmingham, Ala., with a 150-ton (530 kW) cooling requirement.

This approach to comparison yielded results that indicate the installation cost of the GSHP system was actually 11.7% lower than the CW-CAV system and 31.9% less than the CW-VAV system. The annual preventative maintenance (PM) of the GSHP was 1.2% higher than the CW-CAV system but 39% lower than the CW-VAV system. The design load system demand of the GSHP was 133 kW, the CW-CAV was 157 kW, and the CW-VAV was 177 kW. Installation costs were based on 2014 data,[1] PM costs based on 2015 information,[2] and demand calculations follow procedures in the newly revised ASHRAE GSHP text.[3] Costs include controls for the components (thermostats, VAV actuators, sensors, etc.), but not building automation systems

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(BAS) or energy recovery units (ERUs).

Common Loop GSHP System

The "non-central" GSHP design approach has been demonstrated in a long-term field study as being effective in both terms of actual energy consumption and installation costs. A series of articles in the *ASHRAE Journal* (June 2012 through February 2013) presented the results of the study. Three types of systems discussed in the ASHRAE GSHP text are the unitary system, the common loop system, and the one-pipe system. This comparison considers the common loop GSHP using five common loops each connected to eight to 10 heat pumps with a total of 46 units serving the building. *Figure 1* provides an example of an office building with two common loops.

The number of five common loops at 30-tons (106 kW) each is not entirely arbitrary since many systems have been successful with both larger and smaller loops. In this case the logic is to limit the liquid flow rate to approximately 90 gpm (5.7 L/s) at 3 gpm/ton (0.054 L/s per kW) so that the largest diameter pipe is nominal 3-in. (75 mm), DR 13.5 high density polyethylene (HDPE). This will result in a modest system head loss so that 245 W pumps provide sufficient flow rate for each of the forty 3-ton (10.6 kW) classroom heat pumps. The six larger 5-ton (17.6 kW) units will each require two pumps or a single larger pump.

FIGURE 1 Common loop GSHP.[3]

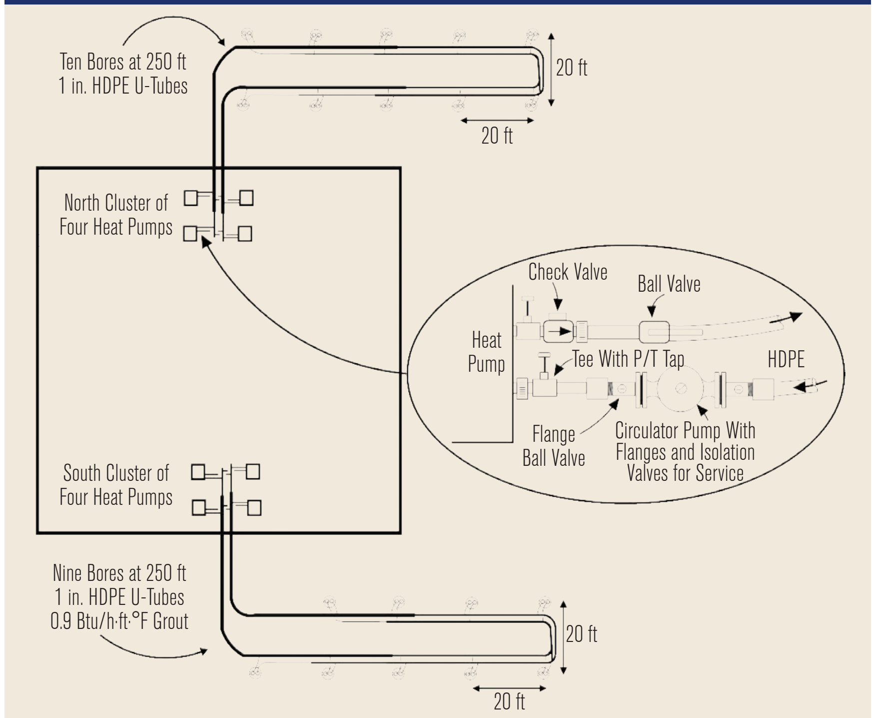

TABLE 1 GSHP installation cost, preventative maintenance cost, and cooling demand.

OPTION 1 – FIVE COMMON LOOP GSHPs[A] LOOP DETAIL: 150 TONS; 150 BORES; 225 FT/BORE				MAINTENANCE		COOLING DEMAND	
				UNIT	TOTAL	UNIT	TOTAL
QTY/UNIT	COMPONENT DESCRIPTION	UNIT COST	TOTAL COST		$/YR		KW
40 ea	3-ton Heat Pump With Duct And Thermostat, No Piping	$7,011	$280,440	$182	$7,280	2.4	96.0
6 ea	5-ton Heat Pump With Duct And Thermostat, No Piping	$8,411	$50,466	$184	$1,104	4.0	24.0
52 ea	1/6 hp (0.12 kW) In-Line Circulator Pumps[B]	$1,300	$67,600	–	–	0.3	13.0
33,750 ft	Vertical HDPE Ground Loops (150 at 225 ft)	$15	$506,250	–	–	–	–
7,920 ft	Interior Piping System (At $72/ft)	$72	$570,240	–	–	–	–
		Total	$1,474,996	Total	$8,384	Total	133
		Cost/ton	$9,833.31				
		Cost/ft²	$20.49				

[A] Includes unit controls costs but not BAS or energy recovery system costs

[B] Interpolated between 1/8 hp and 1/3 hp

The common loop GSHP costs and demand are shown in *Table 1* as Option 1. The cost to install a 3-ton (10.6 kW) heat pump is $7,011 with ductwork and a programmable thermostat. PM cost is $182 per year each. The rated energy efficiency ratio of the unit is 22.0 Btu/W·h (COP = 6.5) but when the design fan power, flow rates, air and water temperatures are applied the corrected EER is 15.4 Btu/W·h (COP = 4.5). This results in a cooling demand of 2.34 kW. Values for the 5-ton (17.6 kW) heat pumps are $8,411 for installation, $184 for PM, an EER of 14.4 Btu/W·h (COP = 4.2), and a cooling demand of 4.2 kW.

One of the articles in long-term performance study reported on a survey for the cost of GSHPs in the south and mid-west installed between 2006 and 2010.[4] The cost of the vertical ground heat exchangers including the horizontal headers ranged from a low of $7/ft ($23/m) to $15/ft ($49/m) with an average of $12/ft ($39/m) of vertical bore. A value of $15/ft ($49/m) is used for this comparison. The resulting cost of the 33,750 ft (10,300 m) bore field is $506,250. The ground loop layout is 150 bores at a depth of 225 ft (69 m). Each of the five circuits had 30 bores per common loop.

The mechanical cost data[1] provides an approximation for the cost of insulated steel chilled water pipe at $72/ft ($236/m). When this approximation is applied to a building for which the floor area per unit cooling load is 545 ft^2/ton (14.4 m^2/kW), the ratio of length of pipe per unit of floor area is 0.13 ft/ft^2. The example building has a higher load density so the ratio is adjusted downward to 0.11 ft/ft^2. The result is in an interior piping cost of of $570,240, which is 11% more than the ground loop cost. While the recommended material for "non-central" GSHPs is HDPE or fiber-core polypropylene, steel pipe will be considered for consistency with the chilled water system options.

TABLE 2 CW-CAV installation cost, preventative maintenance cost, and cooling demand.

Option 2 - Chilled Water Four-Pipe CAV With Electric Boiler[A]				Maintenance		Cooling Demand	
				Unit	Total	Unit	Total
Qty/ Unit	Component Description	Unit Cost	Total Cost		$/yr		kWe
2 ea	80-ton Packaged Rotary-Screw Chiller[C]	$68,000	$136,000	$199	$398	54.4	108.8
40 ea	3-ton CAV Fan Coil Units 4-Pipe With Ductwork	$7,375	$295,000	$145	$5,800	0.46	18.2
6 ea	5-ton CAV Fan Coil Units 4-Pipe With Ductwork[D]	$11,400	$68,400	$145	$870	0.76	4.6
2 ea	210 kW Boilers With Pumps and Connections	$30,400	$60,800	$411	$822	–	–
1 ea	150-ton Cooling Tower Draw Through, Fiberglass	$55,100	$55,100	$125	$125	8.3	8.3
7,920 ft	Chilled Water Piping System (at $72/ft)	$72	$570,240	–	–	–	–
7,920 ft	Hot Water Piping System (at $50/ft)	$50	$396,000	–	–	–	–
400 ft	Condenser Water Piping System (at $72/ft)	$72	$28,800	–	–	–	–
2 ea	7½ hp (5.6 kW) Chilled Water Pumps[E]	$12,800	$25,600	$66	–	6.0	6.0
2 ea	10 hp (7.5 kW) Condenser Water Pumps[E]	$16,800	$33,600	$66	$132	7.5	7.5
		Total	$1,669,540	Total	$8,147	Total	153.5
		Cost/ton	$11,130				
		Cost/ft²	$23.19				
	GSHP Cost Premium		–11.6%				

[A] Includes unit controls costs but not BAS or energy recovery system costs
[C] Gross tons (deduct 5% for net tons with fan coil units)
[D] Extrapolated
[E] Demand of back-up pump not included

Water-Cooled Chilled-Water Constant Air Volume System

As shown in *Table 2*, the primary cooling devices for the chilled-water constant air volume (CW-CAV) system are two 80-ton (280 kW) water cooled rotary screw chillers with a 0.68 kW/ton (COP = 5.2) rating. This is a 10% enhancement compared to the minimum required value.[5] The installation costs are $68,000 each, the PM cost is $199 per year each, and the demand is 54.4 kW each. The installation cost for the single 150-ton/450 gpm (520 kW/28.4 L/s) fiberglass draw-through cooling tower is $55,100, the annual PM is $125, and the fan demand is 8.3 kW based on a value of 45 gpm/hp (3.81 L/s per kW) with a 90% efficient motor.

The air-distribution system consists of 40 nominal 3-ton (10.6 kW) four-pipe fan coil units (FCUs) and six nominal 5-ton (17.6 kW) four-pipe FCUs. The installation costs are $7,375 for the smaller FCUs and $11,400 each for the larger units, and the PM cost is $145 per year each. To estimate the power demand, a value of 400 cfm/ton (54 L/s per kW) is assumed. The fans are driven by electronically commutated motors (ECMs) and recent ASHRAE research indicates the demand for the 1200 cfm (2040 m^3/h) FCUs is 460 W and 760 W for the larger 2000 cfm (3400 m^3/h) FCUs.[6]

Hot water is provided by two 210 kW electric boilers with an installation cost of $30,400 each, a PM cost of $411 per year each, and these pumps, of course, do not contribute to the cooling demand. The chilled water piping system cost is also $570,240, but the hot water piping is smaller in pipe diameter and the cost is lowered to $50/ft ($164/m) or $396,000 for a heating system of equivalent size. The condenser water piping is assumed to be 400 ft (120 m) total to the cooling tower for a total cost of $28,800 at $72/ft ($236/m). The chilled water pump and back-up are 7.5 hp (5.6 kW) with an installation cost of $12,800 each, a PM cost of $66/year each, and only one pump contributes to the cooling demand at 6.0 kW with a 90% efficient motor. The values for the 10 hp (7.5 kW) condenser pumps are $16,800 each for

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TABLE 3 CW-VAV installation cost, preventative maintenance cost, and cooling demand.

	OPTION 3 - CHILLED WATER FOUR-PIPE VAV WITH ELECTRIC BOILER[A]			MAINTENANCE		COOLING DEMAND	
				UNIT	TOTAL	UNIT	TOTAL
QTY/UNIT	COMPONENTS	UNIT COST	TOTAL COST		$/YR		KW[E]
1 ea	Chilled Water System: (2) 80-ton Chillers, CW Pumps (10 hp), CHW Pumps (7.5 hp), Piping, Cooling Tower[F]	$1,100,400	$1,100,400	$456	$456	130.7	130.7
4 ea	Upgrade FCUs to VAV AHUs (15,000 cfm, 3.0 in. w.g.)	$8,300	$33,200	$271	$1,084	7.3	29.4
2 ea	210 kW Boilers With Pumps (5 hp/3.7 kW) and Piping	$30,400	$60,800	$411	$822	–	–
7,920 ft	Hot Water Piping System (at $50/ft)	$50	$396,000	–	–	–	–
40 ea	1,250 cfm (2100 m³/h) FPVAV Reheat Terminals and Duct	$11,750	$470,000	$199	$7,960	0.48	19.0
6 ea	2,000 cfm (3400 m³/h) FPVAV Reheat Terminals and Duct	$17,625	$105,750	$199	$1,194	0.76	4.6
		Total	$2,166,150	Total	$11,516	Total	183.6
		Cost/ton	$14,441				
		Cost/ft²	$30.09				
	GSHP Cost Premium		–31.9%				

[A] Includes unit controls costs but not BAS or energy recovery system costs
[E] Demand of back-up pumps not included
[F] Gross tons (deduct 10% for AHUs), reciprocating chiller cost adjusted for less expensive screw chillers

installation, $66/year each for PM, and 7.5 kW demand with a 90% efficient motor. Note that the piping system costs are $995,040 of the total $1,669,540 total CW-CAV system cost, which is 11.7% higher than the GSHP system.

Total system demand is 153.5 kW, which is 20.5% higher than for the GSHP.

Water-Cooled Chilled-Water Variable-Air Volume System

The estimation of the cooling portion of the chilled-water variable-air volume (CW-VAV) system is simplified since the reference[1] contains the system costs for a similar application. The cost summary includes the chillers, chilled and condenser water piping and pumps, air-handling units (AHUs) and the cooling tower (*Table 3*). Since the reference cost is for CAV-AHUs an adjustment is made by adding the price difference ($8,300 each) for the four VAV-AHUs. However, cost savings ($68,000 each) are claimed for the two 80-ton (280 kW) rotary screw chillers with a 0.68 kW/ton (COP = 5.2) which are substituted for the more expensive reciprocating chillers ($74,000 each). The installation cost for the chillers, pumps, cooling tower, and piping systems is $1,100,400, the annual PM is $456, and the demand is 130.7 kW. The PM cost for the VAV-AHUs is $1,084 and AHU fan demand is 29.4 kW based on a pressure of 3.0 in.es of water (750 Pa), 75% efficient fans, and 90% efficient motors.

The air-distribution system consists of forty 1,250 cfm (2100 m³/h) fan-powered VAV (FPVAV) terminals and six 2,000 cfm (3400 m³/h) FPVAV terminals. The unit installation costs are $11,750 and $17,625, respectively, and the PM cost is $199 per year each. The fans are driven by electronically commutated motors (ECMs) and the demand for the smaller FPVAV terminals is 460 W each and 760 W for the larger terminals.

The electric boilers cost are $30,400 each with a PM cost of $411 per year each, and the pumps of course do not contribute to the cooling demand. The hot water piping cost is $396,000 more. Note that the piping system costs are $995,040 of the total $2,166,150 total CW-VAV system cost, which is 31.9% higher than the GSHP system. Total system demand is 183.6 kW, which is 38% higher than for the GSHP.

Enlightening Conventional Wisdom with Data

Piping

Conventional wisdom holds that the ground heat exchanger cost must be reduced in order for GSHPs to have a larger market penetration. Note that the interior piping cost of $570,240 is the largest component of the total GSHP system cost of $1,474,996 in *Table 1*. An important consideration is that the GSHP has one interior piping loop while the CW systems require two.

Table 4 has been assembled from the cost reference[1] in a summary format to assist the process of further reducing cost. The GSHP system interior piping cost in *Table 1* is based on steel pipe. *Table 4* indicates HDPE pipe and fitting costs are significantly lower than steel. Furthermore, HDPE does not require corrosion protection, which is an important benefit for building owners that have modest maintenance budgets and limited personnel (i.e., school districts). The downsides to HDPE are that it has a significant thermal expansion, fire code constraints (i.e., no return plenum location), and lower rated pressure, especially at higher water temperatures. The use of fiber-core polypropylene (FCPP) can to a great degree offset the thermal expansion, corrosion inhibitor, and pressure rating issues. However, note that FCPP cost is nearly equivalent to steel pipe. The constraints of HDPE pipe are countered in low-rise buildings by:

TABLE 4 Interior pipe, fitting, and tool costs.[3]

	NOM. DIA	STRAIGHT RUN		90° ELBOW	45° ELBOW	COUPLING	TEE	REDUCER
PIPE MATERIAL	IN (MM)	$/FT	$/M	$/FITTING	$/FITTING	$/FITTING	$/FITTING	$/FITTING
Steel - Black (Sch. 40)	1 (32)	15.9	52	47	47	32.5	72.5	
	1.25 (40)	18.3	60	50.5	50.5	32.5	77.5	
	1.5 (50)	21	69	54	54	36	83	
Grooved Joint Hangers at 10 ft (3 m) Centers	2 (60)	26	85	61	61	46.5	92.5	67.5
	3 (80)	43	141	96.5	96.5	61.5	127	82.5
	4 (100)	53	174	114	114	85	181	99
	6 (150)	98.5	323	256	256	141	400	165
Piping 10 ft (3 m) Above Floor	8 (200)	137	449	465	465	208	770	315
	10 (250)	177	581	755	755	289	1,400	555
	12 (300)	200	656	1,150	1,150	320	1950	935
	DIA. (IN.)	STRAIGHT RUN		90° ELBOW	45° ELBOW	COUPLING	TEE	REDUCER
HDPE DR 11	1 (32)	1.9	6	13.5		13.5	17.7	
	1.5 (50)	2.4	8	17.0		21.0	24.8	
	2 (60)	4.0	13	17.0	13.5	28.7	21.2	20.3
Butt Fusion Fittings Hangers at 3 to 4 ft (1 to 1.2 m) Centers	3 (80)	4.9	16	34	34	36.9	39.0	20.3
	4 (100)	8	27	47	47	48	57	30
	6 (150)	20	66	109	109	73	142	71
	8 (200)	34	112	268	268	96	350	109
Piping 10 ft (3 m) Above Floor	10 (250)	53	174	1,000	1,000	115	1,044	187
	12 (300)	77	253	1,055	1,055	135	1,400	306
	DIA. (IN.)	STRAIGHT RUN		90° ELBOW	45° ELBOW	COUPLING	TEE	REDUCER
Polypropylene DR 11	3/4 (25)	15.85	52	19	19	21	32	21
	1 (32)	17.5	57	26	26	25.5	38	23
	1.25 (40)	20.5	67	29	29	27	42.5	27
	1.5 (50)	24.5	80	36.5	36.5	32.5	56	38.5
Hangers 3 per 10 ft 1 per m	2 (60)	30	98	42	41.5	38.5	66.5	62
	3 (80)	40.5	133	87.5	92	63.5	116	108
	4 (100)	54.5	179	153	163	99	189	148
Piping 10 ft (3 m) Above Floor	6 (150)	60.5	198	320	335		450	221
	8 (200)	90.5	297	630	550		705	286
	10 (250)	122	400	895	735		970	

HDPE Butt Fusion Tool Cost: 1 to 4 in. (32 to 100 mm) = $805, 6 to 12 in. (150 to 300 mm) = $27,900

- Limiting diameter so header pipe can be placed in trays to allow expansion/contraction;
- Using unitary heat pumps with small or non-existent return duct runs, and;
- Sizing ground heat exchangers so that loop temperatures remain well below critical values (this does not apply to high-rise buildings in which static pressures are greater).

Attention is called to the modest cost of fusion tools for smaller diameter HDPE shown in the lower row of *Table 4*. A butt fusion tool for pipe up to 4 in. (100 mm) diameter costs $805 compared to $27,900 for equivalent tools for 6 to 12 in. (150 to 300 mm) diameter HDPE. Note also the significant difference in pipe and fitting cost for 4 in. (100 mm) and smaller pipe compared to 6 in. (150 mm) and larger diameter.

Attention is also called to the modest cost of the heat pump equipment in *Table 1*. These values are for constant-speed equipment. The much higher efficiency of dual-capacity (DCHP) and variable speed heat pumps (VSHP) is based on part-load rated values with full-load airflow and assumes no power is required to circulate air through the distribution system. High efficiency single-speed heat pumps typically have higher full load efficiency than most dual-capacity and variable speed heat pumps.[3] When DCHPs and VSHPs are corrected for fan power at the part-load airflow necessary to provide dehumidification and comfortable heating mode air delivery temperatures, the improvement in efficiency is small or non-existent. Additionally, air-distribution systems must be enhanced (added duct, diffusers, and/or fans) to provide comfort at part-load airflow.

The reference did not include preventative maintenance costs for the piping system water treatment. H&CWSs are four-pipe systems with two separate building loops which require PM, one for cooling and one for heating. The third piping loop is the condenser water loop but the PM costs were included in the fluid cooler PM cost. The GSHP system has a single exterior piping loop which is thermally-fused high density polyethylene (HDPE) that has no PM costs. The interior piping loop can be metal (which has a PM cost), HDPE (no PM cost), or thermally-fused FCPP (which also has no PM cost). In southern climates the use of HDPE or FCPP in many cases can be done without insulation since the surface of the low conductivity pipe is warm during the high humidity cooling season and often above the air dew point during the heating season.

TABLE 5 Control costs.[1]

	BARE COST	WITH O&P
SENSORS AND TRANSDUCERS	$ PER SENSOR	
Duct Temperature Sensor (With 50 ft Run in EMT)	$360	$395
Space Temperature Sensor (With 50 ft Run in EMT)	$575	$635
Duct Humidity Sensor (With 50 ft Run in EMT)	$605	$665
Space Humidity Sensor (With 50 ft Run in EMT)	$925	$1,025
Duct Static Pressure Sensor (With 50 ft Run in EMT)	$490	$540
Airflow (cfm) Transducer (With 50 ft Run in EMT)	$660	$730
Water Temperature Sensor (With 50 ft Run in EMT, Not Including Pipe Tap)	$360	$395
Water Flow Transducer (With 50 ft Run in EMT, Not Including Pipe Tap)	$2,075	$2,300
Water Differential Sensor (With 50 ft Run in EMT, Not Including Pipe Taps)	$850	$935
Power (kW) Transducer (With 50 ft Run in EMT)	$1,175	$1,300
Energy (kWh) Totalizer (With 50 ft Run in EMT, Not Including Pulse Transmitter)	$545	$600
Space Static Pressure Sensor (With 50 ft Run in EMT)	$925	$1,025
CONTROLLERS	$ PER CONTROLLER	
Multiplexer Panel With Function Boards: 48 Point	$4,575	$5,050
Multiplexer Panel With Function Boards: 128 Point	$6,300	$6,925
DDC Controller: 16 Point in Mechanical Room	$1,925	$3,125
DDC Controller: 32 Point in Mechanical Room	$4,725	$5,200
VAV Terminal Box Controller With Space Temperature Sensor	$735	$805
FRONT END COSTS		
Computer With Software Program (Costs Vary With Complexity)	$5,675	$6,250
Color Graphics Software (Costs Vary With Complexity)	$3,400	$3,750
Color Graphics Slides (Costs Vary With Complexity)	$426	$470
Engineering, Calibration, and Start-Up Labor (Per Sensor)	$292/sensor	$320/sensor
Basic Maintenance Manager Software (Costs Vary With Complexity)	$1,700	$1,875

Controls

Tables 1, 2 and *3* do not include the cost of controls other than room thermostats. The advances in building automation systems are dramatic. Graphic displays of temperatures, airflows, and pressures with moving components are impressive. However, the cost and effectiveness of these improvements is typically not well documented. The data shown in *Table 5* and *Figures 2* and *3* raises serious concerns about the cost effectiveness of advanced building automation systems (BASs) for GSHP applications and other simple HVAC systems.

The surprisingly high installation and calibration cost of sensors shown in *Table 5* indicate the replacement of the forty-six $286 programmable thermostats with just a single space temperature sensor per zone with calibration would cost over $30,000. This is equivalent to over 2,000 ft (625 m) of ground heat exchanger at $15/ft ($49/m). This added cost does not include costs for associated multiplexer panels, controllers, computer, and necessary software. The values in *Table 5* can be verified by consulting pages 268–270 of Reference 1.

Figure 2 shows measured GSHP building Energy Star rating by control type. These field test results indicate the systems with room thermostats with an average Energy Star rating of 80 performed better than the building automation systems that had an average Energy Star rating of 61. All of the systems have unitary heat pumps except the two BAS controlled high school systems that had Energy Star ratings of 20 and 21, which are central chilled water GSHPs. It is also obvious that the use of room thermostats and unitary heat pumps does not guarantee outstanding GSHP performance as noted by the hotel that received an Energy Star rating of 1.

FIGURE 2 Energy Star Ratings for GSHP control type.[7]

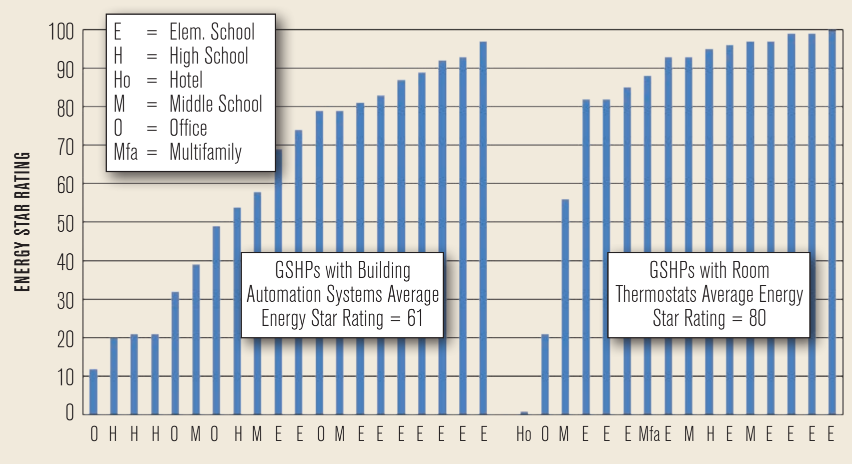

FIGURE 3 Commercial building energy consumption by cooling equipment type.[8]

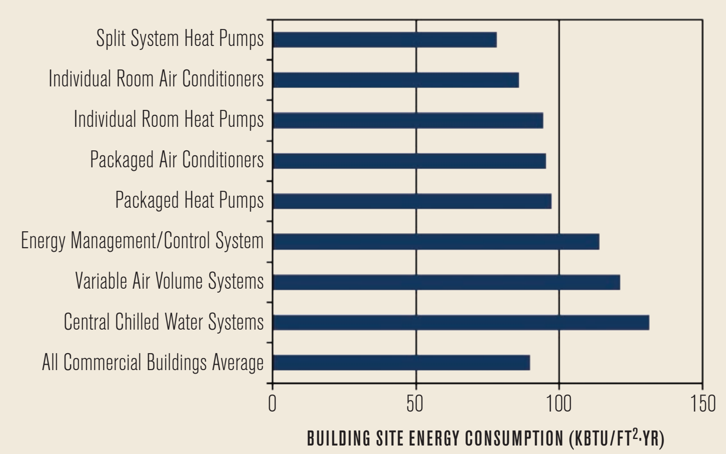

Figure 3 substantiates the tendency of buildings with BASs to consume more energy (~110 kBtu/ft^2) than average commercial buildings (~80 kBtu/ft^2). The figure also indicates buildings with unitary systems tend to consume less energy than those with VAV and chilled water systems. While the higher demand of the CW and VAV systems, as shown in *Tables 2* and *3*, have substantial influence on higher energy use. Also, these systems tend to be used in buildings with higher occupant densities and greater loads per unit floor area than those heated and cooled by unitary equipment.

Summary

While the cost of the ground heat exchanger is a substantial component of the total cost of a commercial building GSHP system, this should not be the sole reason to rule out GSHP as an option: a complete system-scale cost analysis should be used. The added ground loop cost is offset since GSHP equipment performs both cooling and heating compared to other HVAC options that have separate cooling and heating systems. The ground heat exchanger cost can be more than offset using simple designs that apply the following concepts.

1. Substitute the use of large diameter central piping systems with multiple common loops, multiple one-pipe loops, unitary loops, or combinations of each type.
2. Take advantage of the low head requirements of non-central loops and apply reliable on-off pump control.
3. Take advantage of lower cost of small diameter (1 to 4 in. [32 to 100 mm]) HDPE for interior piping for non-central GSHPs.

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4. Use primarily high-efficiency constant-speed water-to-air heat pumps that tend to have higher efficiency than dual-capacity and variable-speed heat pumps in actual operating conditions.

5. Minimize the use of sophisticated building automation systems in unitary GSHP applications until future independent field studies clearly indicate the significant added cost is economically justified for building owners with limited financial and personnel resources (i.e., k–12 schools).

This leads back to the concept of utility interest in leasing a ground heat exchanger: the ability of a GSHP system to provide superior efficiency over other system alternatives has been demonstrated time and again. However, perceptions still remain that GSHP system carry a cost premium. The findings of the aforementioned utility analysis revealed not only can a customer's energy consumption and demand be reduced, but the customer's overall operating costs and total construction costs can be reduced. Thus, if proper design and installation techniques such as those presented in this article are followed, an energy efficient, low-risk investment for a utility emerges and the customer receives a premium result at a lower cost.

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