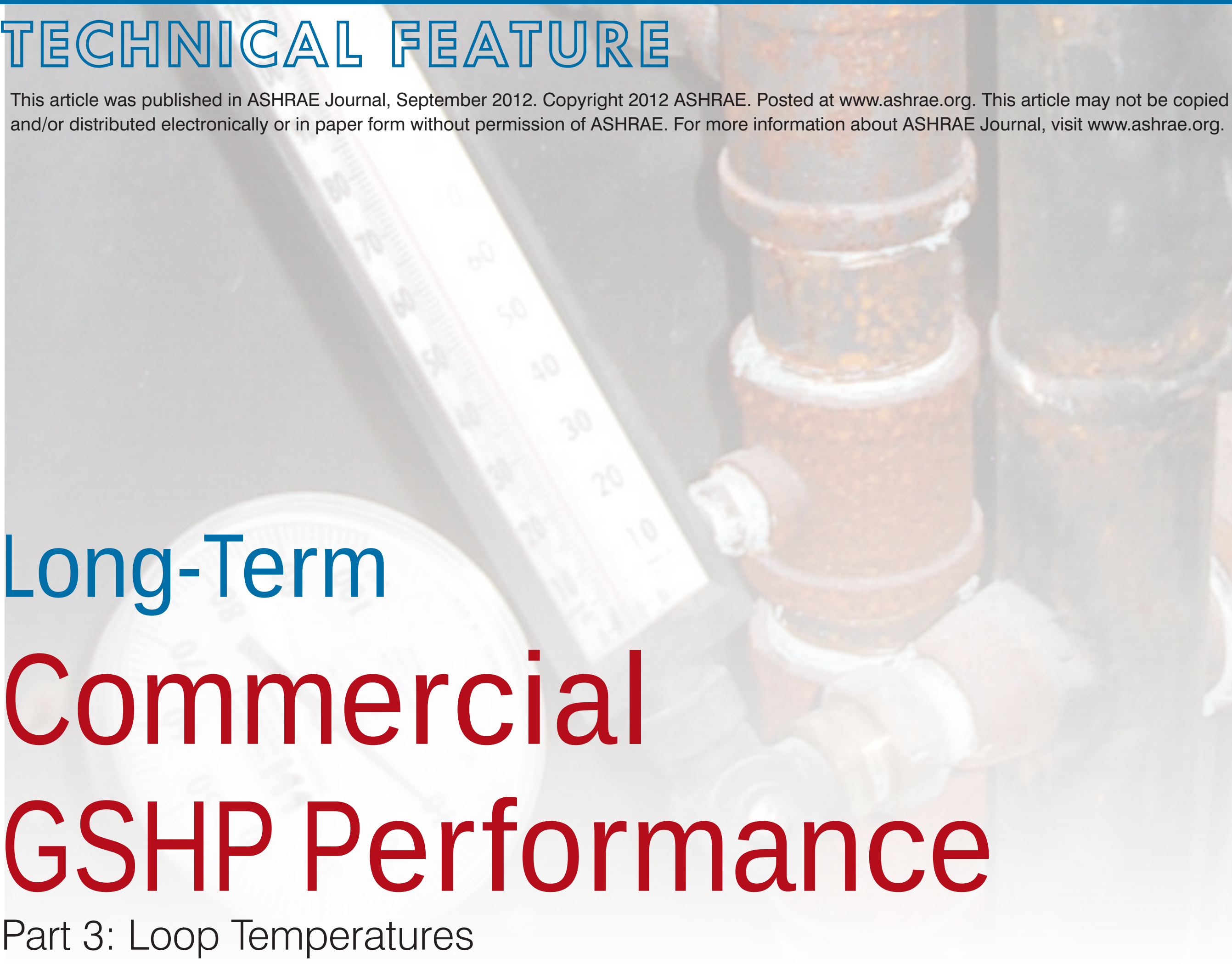

Long-Term Commercial GSHP Performance

Part 3: Loop Temperatures

By **Steve Kavanaugh, Ph.D.,** Fellow ASHRAE; and **Josh Kavanaugh,** Student Member ASHRAE

Ground loop temperatures have a significant impact on system performance. Systems with maximum average ground loop temperatures below 90°F (32°C) had an average ENERGY STAR rating of 92 while those with temperatures above 95°F (35°C) had an average rating of 53. This article is the third in a series that summarizes a data collection and analysis project to identify common characteristics of successful ground source heat pump (GSHP) systems.[1]

In addition to ground loop temperatures, other data include differential loop temperatures, ground loop size, undisturbed ground temperature (t_{grn}), thermal conductivity (k_{grn}), pump sizes and variable speed drive (VSD) operation. Several ground loop temperature plots will be presented that will be sorted by temperature range:

- Mild Loops: Maximum Leaving Water Temperature (LWT) < 85°F (29°C);
- Warm Loops: 85°F (29°C) > Maximum LWT < 95°F (35°C); and
- Hot Loops: Maximum LWT > 95°F (35°C).

Results of thermal property tests were rarely available, especially at the older sites. If no tests were performed, the undisturbed deep ground temperature (t_{grn}) values for tests performed at nearby sites or water well logs were used. Design loop calculations were not available at any of the sites and, in several cases no ground loop design details were included in the drawings. So, the comparison of loop performance results with design intent was not possible.

A few of the newer sites had functioning energy management systems that could provide monitored ground loop temperature data. Ground loop and air temperature measurements at most sites were made with multichannel data loggers. They were installed at each site for three to five week periods during the site visits when building and GSHP system information was collected.

Results indicate the primary reasons for elevated loop temperatures were insufficient heat exchanger bore length.

About the Authors

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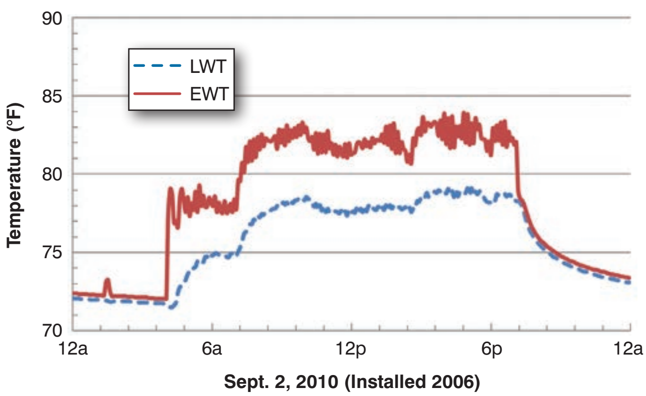
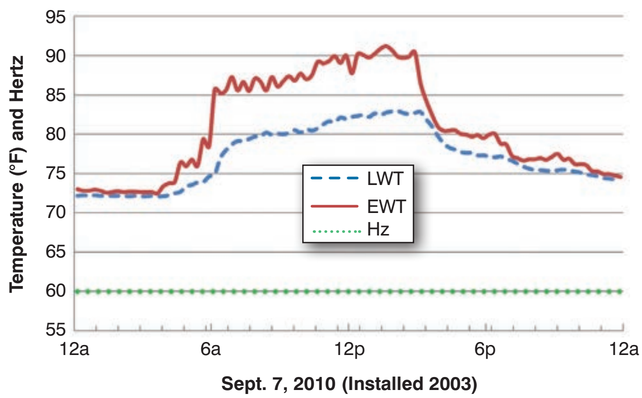


Ground loop entering and leaving water temperature; ENERGY STAR rating = 93; outdoor temperature high = 97°F; southeast Tennessee elementary school, L_{bore} = 197 ft/ton; t_{grn} = 61°F.

Figure 1: Hot day loop temperatures for 70,000 ft^2 (6500 m^2) Tennessee elementary school.



Entering and leaving water temperature, VSD frequency; ENERGY STAR rating = 83; outdoor air temperature high = 93°F; northwest Georgia elementary school, L_{bore} = 214 ft/ton; t_{grn} = 60°F.

Figure 2: Hot day loop temperatures and VSD speed for 85,000 ft^2 (7900 m^2) Georgia school.

Contributing factors included high capacity ventilation air equipment, low thermal conductivity bore grout, small vertical bore separation distance, and low indoor temperature set points. Although most of the sites had large cooling mode requirements compared to those in heating, no significant increases in long-term temperature rise were noted.

Mild Loops

A GSHP system retrofit was installed in 2006 in a three-story 70,000 ft^2 (6500 m^2) southeast Tennessee elementary school built in 1929. The ground loop consists of 96 vertical, 1 in. (25 mm) high density polyethylene (HDPE) U-tubes, 300 ft (91 m) in depth with a thermally enhanced cement grout placed in the bore annulus. The loop is connected to a 146 ton (510 kW) heat pump system that is supplemented with a 25 ton (88 kW) energy recovery unit (ERU). A 30 hp (22 kW) pump with a variable speed drive (VSD) provides circulation through the unitary heat pumps and loop field. A 30 hp (22 kW) backup pump is also available.

A ground loop previously installed in a nearby middle school experienced elevated ground loop temperatures. Therefore, the ground loop design length for this school was increased by 50%, the bore separation distance was increased from 15 ft to 20 ft (5 m to 6 m), and a fluid cooler was added.

Figure 1 indicates this ground loop design was successful since leaving water temperatures (LWTs) are below 80°F (27°C) and entering water temperatures (EWTs) are below 85°F (29°C) on a day that exceeded the design outdoor air temperature (OAT). The 4°F (2°C) differential loop temperature at full load indicates the pump is delivering over twice the optimal flow rate and the pump motor VSD is not properly functioning as differential temperatures are small at part load. The addition of the fluid cooler appears to have been unnecessary since tubes ruptured during the first winter of operation and were only recently repaired.

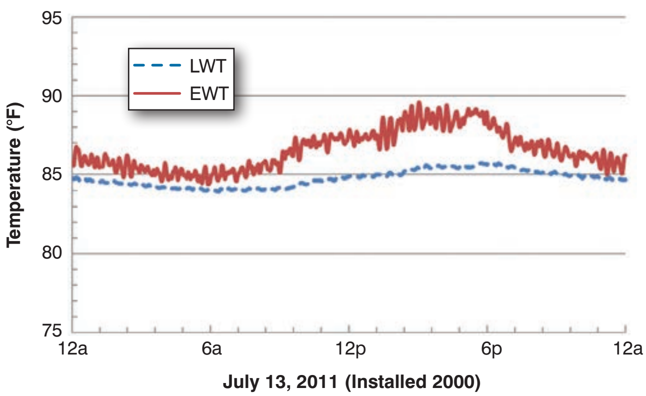
Loop temperatures were recorded for an 85,000 ft^2 (7900 m^2) elementary school constructed in 2003 with a 287 ton (1000 kW) heat pump system. Complete dimensions for the ground loop were not available but a nearby school built in 2002 with an identical footprint consisted of vertical 1¼ in. (30 mm) U-tubes installed at 214 ft/ton (18.5 m/kW) using an unknown grout. Classrooms are served by heat pumps connected to individual loops while a central loop with two 10 hp (7.5 kW) pumps with VSDs serve other areas of the school. Ventilation air is provided by multiple energy recovery units (ERUs) with a total rated flow of 15,850 cfm (7500 L/s). The ERUs are supplemented by water-to-water heat pumps connected to the central ground loop.

Figure 2 indicates the core building ground loop is operating as intended with the leaving temperatures remaining below 83°F (28°C) on a day when the high OAT was 93°F (34°C). The differential temperatures during this near peak load day indicate the pump is near correct size but part-load values suggest the VSD is not operating as intended. This is substantiated by the constant drive speed of 60 Hz shown in *Figure 2*.

Warm Loops

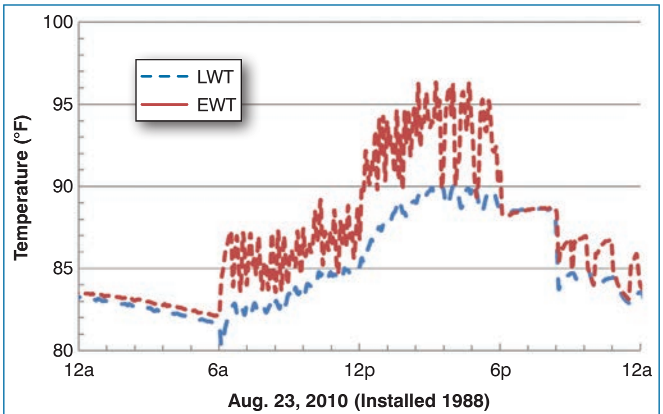
Ground loop temperatures were recorded in a four-story 78,000 ft^2 (7200 m^2) senior apartment building. A 125 ton (440 kW) ground source heat pump system is connected to a 130 bore ground loop with 1 in. (25 mm) diameter HDPE U-tubes 320 ft (97 m) in depth. A total of 50 two-bedroom apartments are served by heat pumps located in interior closets placed on platforms above the water heaters. Additional heat pumps serve common areas and two constant speed 25 hp (19 kW) pumps are alternated to provide continuous, constant flow circulation.

Figure 3 indicates the 11-year-old system is performing well with 83.5°F to 85.5°F (29°C to 30°C) ground loop LWTs during a day when the high OAT was 96°F (36°C). The low differential loop temperature of 4°F (2.2°C) at full load indicates the pump is delivering over twice optimal flow rate. The local ground temperature is relatively high but extended loop lengths resulted in good loop temperatures and ENERGY STAR rating.



Ground loop entering and leaving water temperature; ENERGY STAR rating = 88; outdoor temperature high = 96°F; northwest Florida multifamily, L_{bore} = 330 ft/ton; t_{grn} = 72°F.

Figure 3: Hot day loop temperatures for 78,000 ft^2 (7200 m^2) Florida apartment complex.



Ground loop entering and leaving water temperature; ENERGY STAR rating = 84/79; outdoor temperature high = 95°F; central Mississippi office, L_{bore} = 309 ft/ton; t_{grn} = 67°F.

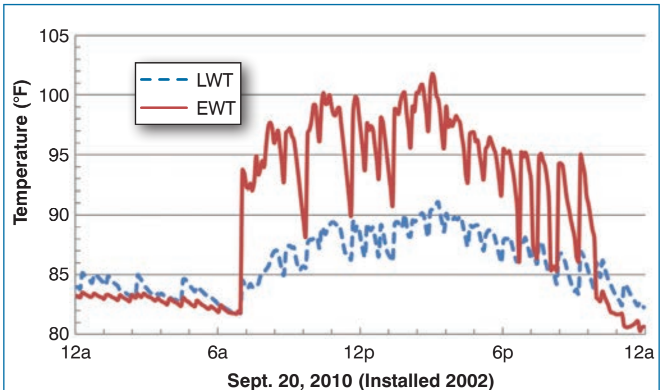
Figure 4: Hot day loop temperatures for 5,000 ft^2 (460 m^2) central Mississippi office.

Data was gathered at a 5,000 ft^2 (460 m^2) office building in central Mississippi that was completed in 1988. The structure was one of the first office buildings in the southeast with vertical HDPE U-tube ground heat exchangers. The building has four water-to-air heat pumps totaling 17 tons (60 kW) of capacity. A 5 hp (3.7 kW) pump runs continuously when the building is occupied. A portion of the building (with an unused 4 ton [14 kW] unit) remains unfinished, so performance data is based on 13 tons (46 kW).

The exact dimensions of the ground loop are unknown. One design detail indicates 13 vertical loops 350 ft (107 m) for a total of 4,550 ft (1390 m) installed on 15 ft (4.6 m) centers. The ground loop contractor bid submittal indicates 12 bores at 333 ft (101 m) for a total of 4,000 ft (1220 m) on 12 ft (3.7 m) centers. The U-tubes are ¾ in. (20 mm) HDPE. Standard practice at the time was to fill the bore annulus with cuttings and sand.

The building has operated well for 23 years with only minor replacements of leaking hose connections and the failure of a pump. However, during the summer of 2010 after several weeks with high OATs and minimal rainfall, high loop temperatures resulted in units shutting off due to high pressure. Thermostat settings were raised and the area experienced significant rainfall between August 5 and 17 and high OATs returned to the mid-90°Fs (local design = 96°F). Ground loop LWTs then returned to a range of 80 to 90°F (27 to 32°C) as shown in *Figure 4.*

A south Alabama elementary school campus consists of five single-story buildings totaling approximately 55,400 ft^2 (5150 m^2). A 102 ton (360 kW) GSHP system was installed during a 2002 renovation in Buildings I, IV and V, which comprise 38,400 ft^2 (3570 m^2) or 69% of the total school floor area. Each building has its own common ground loop to which all heat pumps in the building are connected. Vertical 200 ft (60 m), ¾ in. (20 mm) HDPE U-tubes are backfilled with sand/pea gravel and a bentonite surface seal. There are 100 vertical bores total in the three loop fields each separated from the adjacent bores by 20 ft (6 m). Circulation for each heat pump



Ground loop entering and leaving water temperature; ENERGY STAR rating = 85; outdoor temperature high = 98°F; south Alabama Elementary School, L_{bore} = 196 ft/ton; t_{grn} = 69°F.

Figure 5: Hot day loop temperatures for 38,400 ft^2 (3600 m^2) Alabama elementary school.

is provided by a single 1/6 hp (125 W) pump with on-off control. Check valves are placed in the pump outlets to prevent backflow through idle heat pumps.

Figure 5 indicates the ground loop is operating as intended after nine years of operation since LWTs are near 90°F (32°C) and EWTs are near 100°F (38°C) on a day near with a high OAT above the local 95°F (35°C) design condition. Local deep ground temperature at the site is 69°F (21°C). The pump and piping system appear to also be operating near optimal flow rates as indicated by the 10°F (6°C) differential loop temperature at full load. Off-peak differential of approximately 4°F (2°C) are lower but expected given the reduced loop field flow resistance when only a few of the individual pumps are operating.

A five-story 59,000 ft^2 (5500 m^2) office building in northwest Florida has a 165 ton (580 kW) GSHP system with 60 tons (210 kW) of the total dedicated to conditioning the ventilation air. The building was constructed in two phases in

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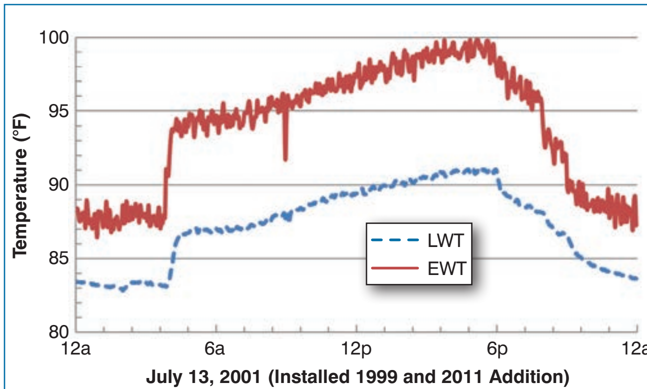
1999 and 2001. Floors 1 to 3 are served by 22 heat pumps with a total capacity of 105 tons (370 kW) and connected to 120 vertical bores with ¾ in. (20 mm) HDPE U-tubes each 250 ft (76 m) in length. Floors 4 and 5 are served by 14 heat pumps with a total capacity of 60 tons (210 kW), which are connected to 51 vertical bores. The bores were reported to be backfilled with cuttings and a 20 ft (6 m) bentonite surface seal.

Figure 6 shows the ground loop LWT and EWT during a day when the OAT exceeded the local design. LWTs remained between 83°F and 91°F (28°C and 33°C) for the entire 24-hour period. The differential loop temperature during the occupied period was between 7°F and 8°F (3.9°C and 4.4°C) and near 4°F (2.2°C) during the unoccupied period. This indicates the variable speed pump drive is functioning, although not ramping down enough at part load for full energy savings benefit. Although the ground loop is performing adequately, the building ENERGY STAR rating was only 32. The ventilation air equipment capacity of 75 cfm (35 L/s) per person may be a factor.



Ground loop entering and leaving water temperatures; ENERGY STAR rating = 32, outdoor temperature high = 96°F; northwest Florida office, L_{bore} = 270 ft/ton, t_{grn} = 72°F.

Figure 6. Hot day loop temperatures for 59,000 ft^2 (5500 m^2) northwest Florida office.

A central Texas 108,000 ft^2 (10 000 m^2) elementary school was built in 2001 with a 230 ton (809 kW) geothermal heat pump system that serves 70% of the building load with the common areas being served by air-cooled equipment. Classrooms are served by console heat pumps with individual energy recovery units and circulator pumps with on-off control. Ventilation air is provided to the non-classroom areas by 15,600 cfm (7400 L/s) energy recovery units.

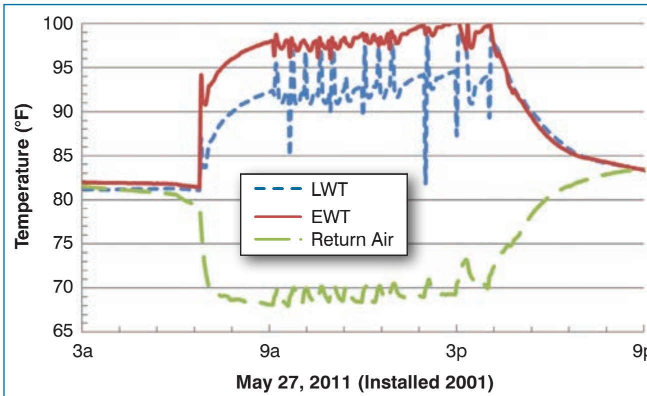
The ground loop consists of 230, 1 in. (25 mm) HDPE U-bend vertical heat exchangers 290 ft (88 m) in length separated by 20 ft (6 m). Each heat pump is connected to individual supply and return headers connected to individual ground loops. The vertical bores are grouted with limestone slurry with a bentonite surface plug. The local ground temperature is 71°F (22°C).

Figure 7 indicates that the ground loop leaving water temperature approached 95°F (35°C) in the library near the end of the school year. The water returning from the ground loop is about 6°F (3°C) cooler when the units are operating. This would indicate the two pumps are somewhat oversized. It should be noted the return air temperature is quite low (69°F [21°C]) and the unit cycles off, which indicates the system operates with more than sufficient capacity on a hot day.

Hot (and Short) Loops

A 135,000 ft² (12 500 m²) northwest Georgia middle school was built in 2004 with a 447 ton (1572 kW) geothermal heat pump system. The ground loop consists of 200 vertical 1 in. (25 mm) HDPE U-tubes, 260 ft (79 m) in length arranged in a 10 × 20 grid and backfilled with thermally enhanced grout. A total of 103 heat pumps are connected to a central loop served by two 20 hp (15 kW) pumps with variable speed drives. Ventilation air is provided by a 29,300 cfm (13 800 L/s) energy recovery unit (ERU) supplemented by 84 ton (300 kW) water-to-water heat pumps.

The building received a low ENERGY STAR rating of 39, which may be a result of the elevated ground loop temperatures. *Figure 8* indicates the ground loop LWT was 99°F (37°C) during a day when the outdoor air high temperature was 97°F (36°C). The low differential loop temperature of less than 5°F (3°C) at full load indicates the pumps are delivering more than adequate flow rate. The owner prefers to operate both pumps continuously to prevent ground loop EWT above 105°F (41°C), a condition when heat pumps begin tripping out.



Ground loop water and indoor air temperatures; ENERGY STAR rating = 100; outdoor temperature high = 100°F; central Texas elementary school (library), L_{bore} = 290 ft/ton, t_{grn} = 71°F.

Figure 7 Hot day loop and air temperatures for "cold" central Texas school library.

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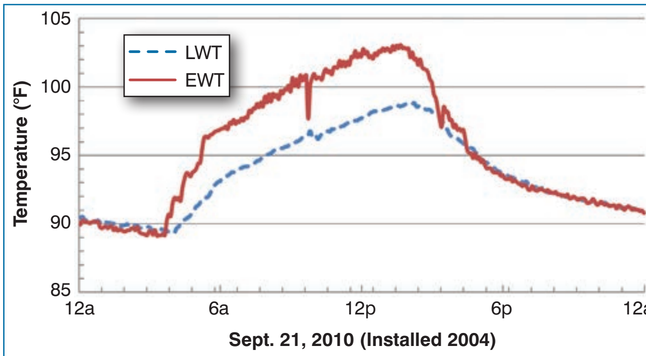
The obviously insufficient ground heat exchanger length of 116 ft/ton (10 m/kW) is the primary reason for the elevated loop temperatures and poor ENERGY STAR rating. As shown in *Figure 2*, the LWT at a nearby school was 83°F (28°C) for a loop installed at 214 ft/ton (18.5 m/kW) in 2003. The ventilation air system capacity of 25 cfm (12 L/s) per person may also affect energy use.

A 400 ton (1407 kW) geothermal heat pump system was installed in a 161,600 ft^2 (15 000 m^2) northeast Tennessee high school in 1995, which was originally built in 1971. One hundred eighteen water-to-air heat pumps serve the main building. Two 40 hp (30 kW) dual-speed pumps with programmable logic controllers (PLCs) provide circulation through the heat pumps and loop field. Eight circulator pumps were added to high head loss units to prevent nuisance trip outs. Unconditioned ventilation air is introduced when conditions are mild but outside air dampers are closed when outdoor temperatures are high or low. Electric heaters are used as backup.

The ground loop is 320, ¾ in. (20 mm) HDPE U-tube vertical heat exchangers 150 ft (46 m) in length separated by 15 ft (5 m). The bores were grouted with a flowable fill mixture of sand and cement. The grid was arranged in 16 circuits with 20 U-tubes each. One circuit has been disabled because of a leak. In 2008 air-to-air heat pumps in the office area were replaced with water-to-air heat pumps and six heat pumps were added with no additions to the ground loop.



Ground loop entering and leaving water temperature; ENERGY STAR Rating = 39; outdoor temperature high = 97°F; northwest Georgia middle school, L_{bore} = 116 ft/ton, t_{grn} = 60°F.

Figure 8: Hot day loop temperatures for 135,000 ft^2 (12 500 m^2) northwest Georgia middle school.

As noted previously, the insufficient ground heat exchanger length of 113 ft/ton (10 m/kW) is the primary reason for elevated loop temperatures and low ENERGY STAR rating. *Figure 9* indicates LWTs approaching 101°F (38°C). EWTs were between 101°F and 110°F (38°C and 43°C) on a day

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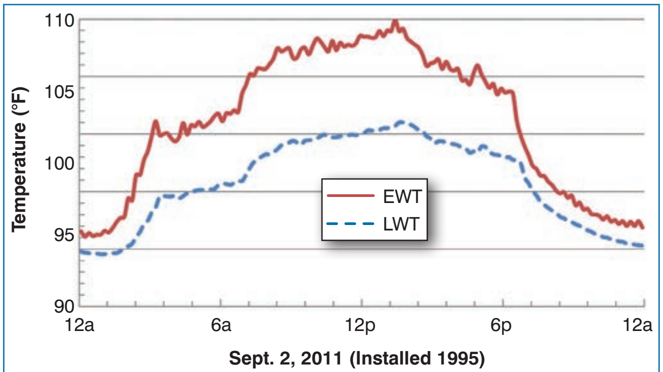
with an outdoor high temperature of 97°F (36°C). The differential temperature indicates the pump(s) were delivering near optimal flow at full load but excessive flows at part load.

A 162,700 ft^2 (15 500 m^2) middle school in central Texas was built in 1996 with a 344 ton (1210 kW) geothermal heat pump system. The balance of the estimated 494 ton (1740 kW) building cooling load is satisfied with air-cooled equipment. The HVAC system includes 141 water-to-air heat pumps that are a combination of console units and vertical units in equipment rooms. Each heat pump is connected to individual supply and return headers. Individual pumps totaling 33.6 hp (25 kW) with on-off control provide water flow to each heat pump. Ventilation air is provided by energy recovery units with a total capacity of 67,500 cfm (32 000 L/s) and are supplemented by direct-expansion (DX) air-cooled units.

The ground loop consists of 405, 1 in. (25 mm) HDPE U-bend vertical heat exchangers. The bores range in length from 260 to 320 ft (79 to 98 m) for a total length of 100,000 ft (30 500 m). Bores are separated by 15 ft (4.6 m) and are grouted with a bentonite clay product with relatively poor thermal properties. The local ground temperature is approximately 71°F (22°C).

Figure 10 shows the ground loop EWTs and LWTs for the system on three very hot days. The pronounced and almost immediate rise in loop temperatures at morning start-up compared to the other hot loop sites indicates a poor thermal connection between the tubing and ground. The differential temperature remained near 10°F (6°C) indicating the pump(s) are near optimal size. The local area experienced a severe drought and record high temperatures from March to September with a rainfall total of 0.06 in. (1.5 mm) during July, August and September. Even under these adverse conditions the school received an ENERGY STAR rating of 93.



Ground loop entering and leaving water temperatures; ENERGY STAR Rating = 21; outdoor temperature high = 95°F; northeast Tennessee high school, L_{bore} = 113 ft/ton, t_{grn} = 59°F.

Figure 9: Hot day loop temperatures for 161,000 ft^2 (15 000 m^2) northeast Tennessee high school.

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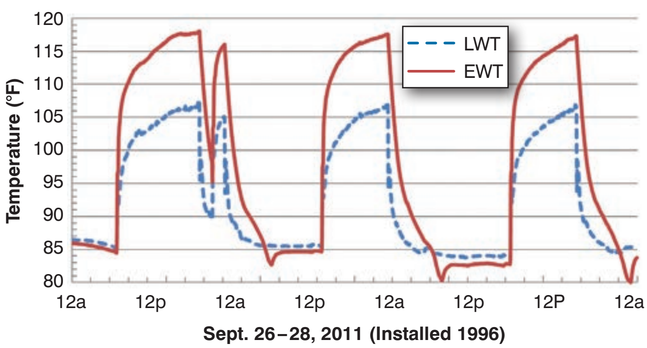
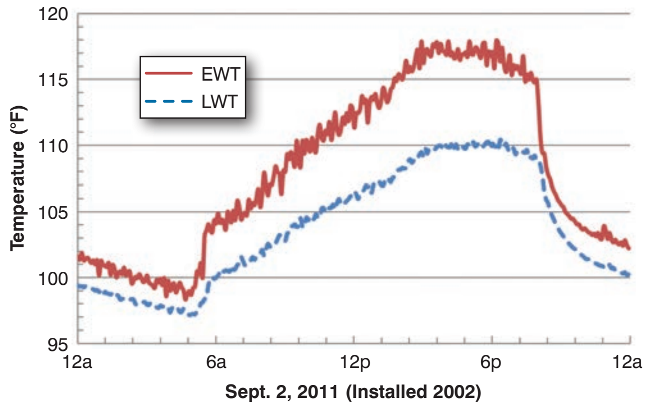


Ground loop entering and leaving water temperatures; ENERGY STAR rating = 93; outdoor high temperatures = 104°F, 100°F, 103°F; central Texas middle school, L_{bore} = 290 ft/ton, t_{grn} = 7°F; bore separation = 15 ft, k_{grout} = 0.38 Btu/h·ft·°F

Figure 10: Hot day loop temperatures for 163,000 ft^2 (15 000 m^2) Texas middle school.



Ground loop water temperatures; ENERGY STAR rating = 11, outdoor temperature high = 95°F; northwest Tennessee office, L_{bore} = 119 ft/ton, t_{grn} = 59°F.

Figure 11: Hot day loop temperatures for 37,000 ft^2 (3400 m^2) northwest Tennessee office.

A two-story 37,000 ft^2 (3400 m^2) office building in northwest Tennessee was constructed in 2002 with a GSHP system. Thirty–seven water-to-air heat pumps with a total nominal capacity of 106 tons (373 kW) heat and cool the building. The units are located in a first floor equipment room. Two 10 hp (7.5 kW) pumps with VSDs provide circulation through the interior piping, heat pumps and loop field. Six exhaust fans with a total capacity of 3450 cfm (1630 L/s) provide fresh air, which are capable of delivering approximately 65 cfm/person (31 L/s per person). A 550 lb/day (250 kg/day) dehumidifier has been added to assist in maintaining comfort.

The ground loop is beneath the building parking lot and consists of 42, 1¼ in. HDPE U-bend vertical heat exchangers 300 ft (91 m) in length arranged in a 6 × 7 grid and separated by 20 ft (6 m). Design specifications called for 93 U-tubes at 300 ft (91 m) each to be filled with "pea-gravel" and grouted with bentonite plugs at intervals of 40 ft (12 m). This design would have been 263 ft/ton (23 m/kW) of bore rather than the installed length of 119 ft/ton (10 m/kW). The ground thermal conductivity at the site is 1.3 Btu/h·ft·°F (2.3 W/m·°C).

Again, the obviously insufficient ground heat exchanger length of 119 ft/ton (10 m/kW), resulting from the reduction from 93 to 42 bores, is the primary reason for elevated loop temperatures and poor ENERGY STAR rating. *Figure 11* indicates peak leaving water temperatures are 110°F (43°C) and return temperatures are 117°F (47°C) on days that exceeded the local 90°F (32°C) design outdoor air temperature. The 7°F (4°C) differential loop temperature at near full load indicates the pump is delivering slightly more than optimal flow. The variable speed pump drive does not appear to be properly functioning since part-load differential temperatures are low at 2°F (1°C).

Heating Mode Temperatures

The majority of the systems in this survey are cooling mode dominant applications where low winter ground loop temperatures are not an issue. Five schools are located in a heating mode dominate climate, but design ground loop lengths are nearly the same for both heating and cooling. One of these schools is a single-story 37,400 ft^2 (3450 m^2) building constructed in 1957. An 86 ton (300 kW) one-pipe geothermal heat pump system was installed in 2007. Thirty-two vertical water-to-air heat pumps replaced the unit ventilators in the classrooms. Console units condition the offices and ducted horizontal units serve the gymnasium, cafeteria, and kitchen. Ventilation air is provided via dampers in the heat pumps that are controlled by CO_2 sensors. After two years of GSHP operation a lighting and envelope energy upgrade were conducted.

The ground loop consists of 60, 1 in. (25 mm) HDPE 250 ft (76 m) vertical U-bend heat exchangers installed in 5 × 12 grid and separated by 20 ft (6 m). Bore holes were grouted with thermally enhanced bentonite. A thermal property test indicates the local ground temperature is 55°F (13°C) and thermal conductivity is 1.30 Btu/h·ft·°F (2.3 W/m·°C).

Figure 12 indicates the ground loop leaving liquid temperature remains between 48°F and 50°F (9°C and 10°C) on a very cold day in late January. The temperature entering the ground loop (leaving the heat pumps) reached a minimum of 41°F (5°C) when the outdoor temperature was near –6°F (–21°C). The differential loop temperature is 7°F (4°C) when the loads are larger during morning start-up. However, the low differential temperatures [$\Delta t \approx 2$°F (1°C)] indicates excess flow is being delivered at low part–loads.

Long-Term Temperature Change

The maximum approach temperatures between the ground loop average water temperatures [(EWT+LWT)/2] and the undisturbed deep ground temperature (t_{grn}) is used as a measure of success in providing acceptable loop performance. *Figure 13* provides a plot of maximum approach temperature as a function of years of operation. A trend of higher approach temperatures with increased years of operation would

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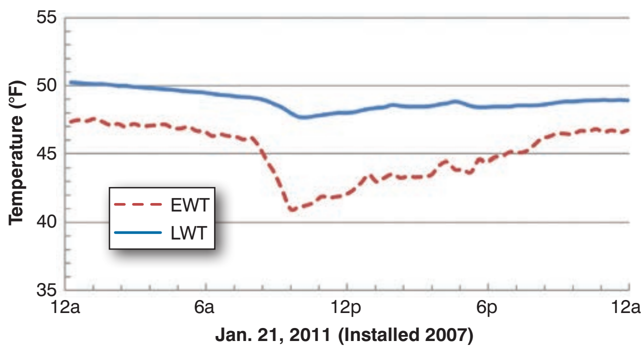
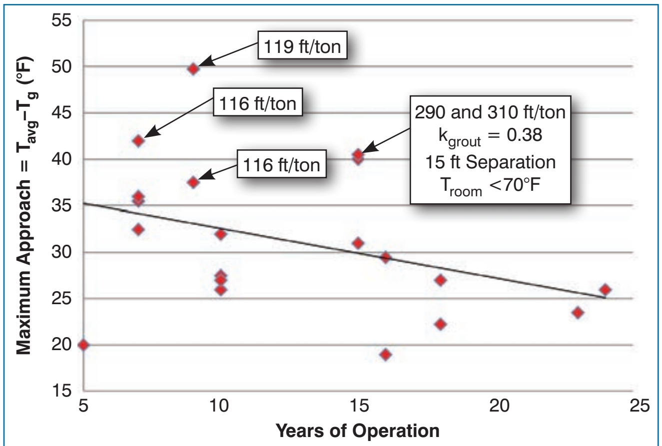


Winter ground loop water temperatures; ENERGY STAR rating = 97; outdoor temperatures: High 6°F, Low –6°F; central Illinois elementary school, L_{bore} = 174 ft/ton, t_{grn} = 55°F.

Figure 12: Cold day loop temperatures for 37,400 ft^2 (3450 m^2) central Illinois elementary school.



Maximum approach temperature vs. GSHP age; maximum average applied temperature = [(EWT+LWT)/2] – T_{ground}.

Figure 13: Maximum average ground loop-to-ground approach temperatures vs. GSHP age.

raise concern about the expected life of ground loops with imbalanced cooling loads compared to heating loads.

Older GSHP systems appear to have lower approach temperatures. Results are not adjusted for many important factors such as vertical bore length, ground thermal properties, and vertical bore separation distance. Newer systems tend to have slightly shorter ground loops but this is offset somewhat since older systems tend to have smaller vertical bore separation distances and lower conductivity grout and fill. *Figure 13* does provide some factors that likely influence the loops with the largest approach factors. Three of the newer systems with high approach temperatures have vertical bore lengths less than 120 ft/ton (10.4 m/kW_T). Two systems with long loops but large approach temperatures have low thermal conductivity grout (0.38 Btu/h·ft·°F

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 appeared in the June 2012 issue and 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 appeared in the July 2012 issue and 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 4: GSHP System Installation Costs: This article will provide a list of the installation costs for newer systems.

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

Part 6: 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. A suggested portfolio format will be presented that is intended for engineering firms to follow that can demonstrate the quality and success of previous projects.

[0.66 W/m·°C]), 15 ft (4.6 m) bore separation, and indoor air temperatures below 70°F (21°C).

It is recognized this data set is small and the presence of significant long-term temperature change cannot be excluded at this point. Although much more field data is highly desirable, the absence of any significant trend of increased ground temperature (noted by elevated maximum approach temperature) with increased years of GSHP operation would indicate that long-term ground temperature change is not prevalent. Elevated temperatures in vertical ground loops are primarily a result of inadequate heat exchanger length. Inadequate bore separation distance, low conductivity grout, and improper completion methods may also contribute to increases.

Results from this project cannot be applied to long-term temperature decline in which the amount of heat removed from the

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ground in heating far exceeds the heat rejected. In cooling dominant applications, the long-term temperature rise is mitigated by the evaporative cooling effect from reductions in moisture content when ground temperature rises in the loop field. The heat rejection required to affect a 1% reduction in ground moisture is approximately the same amount needed to raise the ground temperature 30°F (17°C).[2] The moisture content is likely to be restored to its natural condition via groundwater movement and rainwater percolation. However, in cold climates the latent heat available from freezing of soil moisture is significantly less than from evaporation, moisture migration is obviously minimal, and little is known regarding the thermal and physical properties of conventional grouts at low temperatures. Therefore, no projections of long-term temperature decline can be offered.

Summary

- GSHP Systems with maximum average ground loop temperatures below 90°F (32°C) had an average ENERGY STAR rating of 92 and systems with maximum average ground loop temperatures above 95°F (35°C) had an average ENERGY STAR rating of 53.
- The three sites with the largest increases in loop temperature have been operating for less than 10 years and have bore lengths of less than 120 ft/ton (10.4 m/kW).
- Sites with large ground loop temperature increases, but with long bore lengths, have low conductivity grout, small bore separation, and low indoor temperatures.
- Trend lines indicate systems that have been operating for a greater number of years actually have lower ground loop temperature increases. These systems also tend to have longer ground loops but smaller vertical bore separation and lower thermal conductivity backfill/grout.
- The limited data set indicates bore separation distances near 15 ft (5 m) experienced high ground loop temperatures during extended periods of drought and high outdoor air temperatures.
- Measured differential loop temperatures indicate most central loop pumps were significantly oversized and variable speed drives did not reduce flow at part load.
- Although several of the sites in this study were in climates with annual heating loads greater than cooling loads, the vertical ground loop design lengths were determined by the maximum hourly cooling load.

Conclusions

- Ground heat exchanger size is the dominant influence on maximum loop-to-ground approach temperatures and undersized loops are the primary cause of hot loops.
- The thermal conductivity of the ground and bore grout/backfill were not available for many older sites, but low conductivity and bore separation may also contribute to hot loops.
- Variable speed pump drives were largely inoperable and likely saved little energy.
- This data set does not reveal any significant increases in long-term ground loop temperature rise.
- Additional GSHP system data collection and analysis efforts are needed to more thoroughly access the prevalence of long-term temperature change. This is needed in both cooling dominant and heating dominant climates.
- The thermal performance of ground and ground moisture is complex and models that do not address phase change phenomena are likely to over-predict ground temperature changes.

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