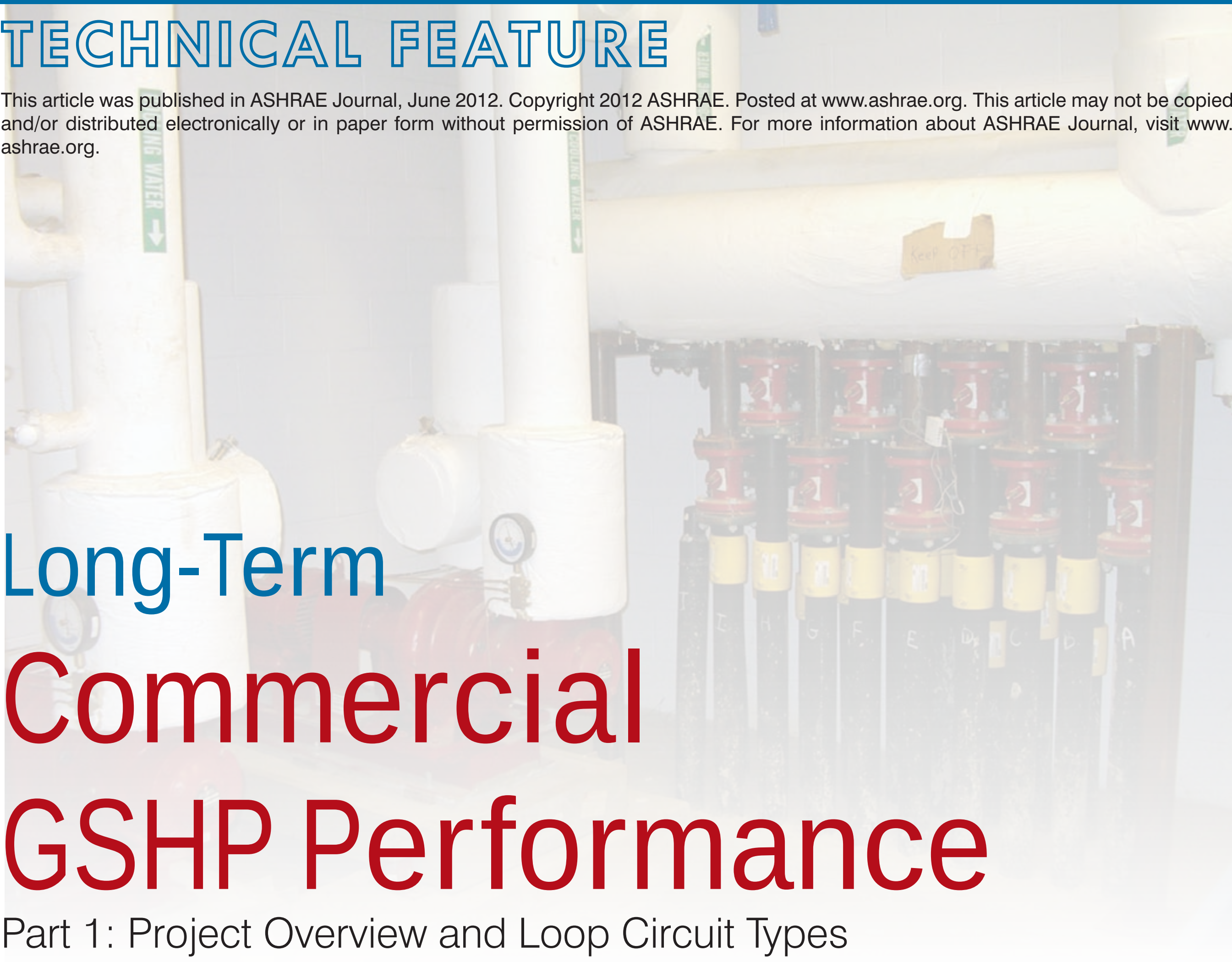

Long-Term Commercial GSHP Performance

Part 1: Project Overview and Loop Circuit Types

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

Many ground source heat pump (GSHP) systems, also known as geothermal heat pumps (GHPs), have been successfully installed and operated for many years throughout the United States. However, other installations have experienced poor reliability, high energy costs, and undesirable ground loop temperatures. Some have had significant equipment replacements, have added supplemental heating, or installed fluid coolers. A few GSHPs have been abandoned. It has been suggested that a reason for abandonment may be the overheating or freezing of ground formations or groundwater due to imbalances in the amount of heat stored and removed.

An 18-month data collection and analysis project has been completed to identify common characteristics of successful GSHP systems and the prevalence of unacceptable long-term temperature change.[1] The goal of the project is to enhance the ability of GSHPs to minimize energy consumption, electrical demand, and maintenance requirements while being cost effective and environmentally responsible.

Gathering critical information from the entire building and GSHP system enables an improved determination of the extent unacceptable GSHP performance is attributable to poor design and installation and what is a result of fundamental thermodynamic limitations. The data collection efforts were structured to gather a limited amount of the critical information for a large number of systems. This article is the first of a series (see sidebar, Page 50) that will discuss the measured results and identify the variety of applications and design options that tend to result in quality, and economically attractive GSHP systems.

About the Authors

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Procedure

This project studied the long-term performance and temperature variations in systems operating in the service territories of the Southern Company and Tennessee Valley Authority (TVA). This includes sites from southern Kentucky to the Florida panhandle. To find sites with a wider variety of GSHP system types with successful long-term operation, the project was expanded to include south-central Texas and central Illinois. The approach included:

1. Identify monitoring sites for the following:
   - Length of operation; multiple years of operation;
   - Accessibility of data;
   - Proximity to nearby sites to minimize travel;
   - 30 to 60 sites at various geographic locations with a variety of system types; and
   - New buildings with installation cost data near long-term sites.
2. Conduct surveys (forms completed with assistance from owners, utilities, designers):
   - Building and GSHP system description performance;
   - Energy and demand from utility bills;
   - Installation costs for newer sites;
   - Comfort/IAQ/satisfaction; and
   - Maintenance personnel evaluation.
3. Collect data including the following:
   - Temperatures: ground loop, initial ground, change with time and load;
   - Loop field description: number of bores, depth, separation, U-tube size, bore grout/fill, header arrangement and sizes, thermal property test and well logs;
   - Building details: type, size, loads, occupancy, schedules, ventilation air method;
   - Equipment description: heat pump type, capacity, pump system, interior piping, air distribution system, heat pump control method, pump control method;
   - Sufficient information to determine ENERGY STAR rating (energy consumption, number of occupants, occupancy hours, important internal loads, etc.); and
   - Installation costs for newer buildings.
4. Provide a summary of results for each site.
5. Summarize and compare results.

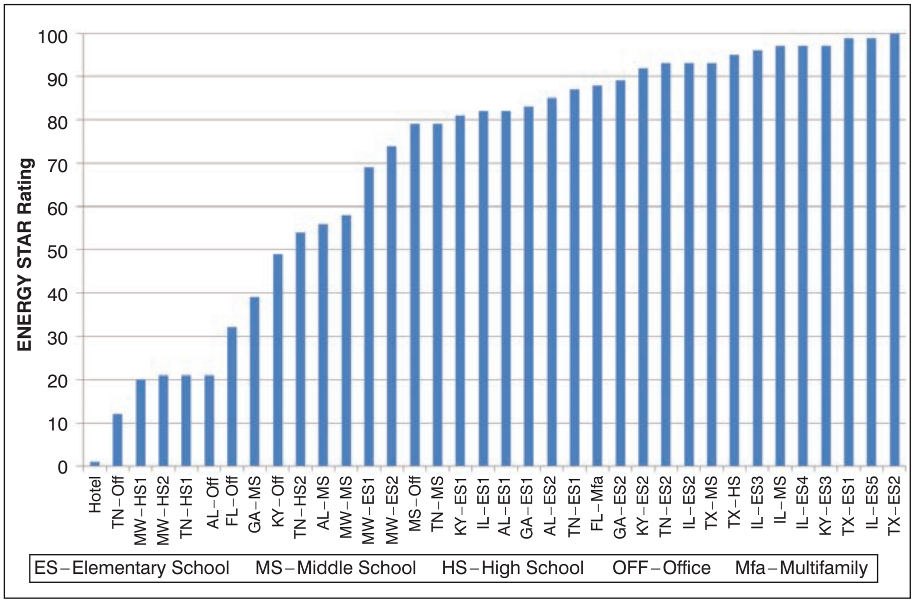

Figure 1: ENERGY STAR ratings of commercial buildings with sufficient data. (Three engineering firms designed 92% of the 90+ rated buildings.)

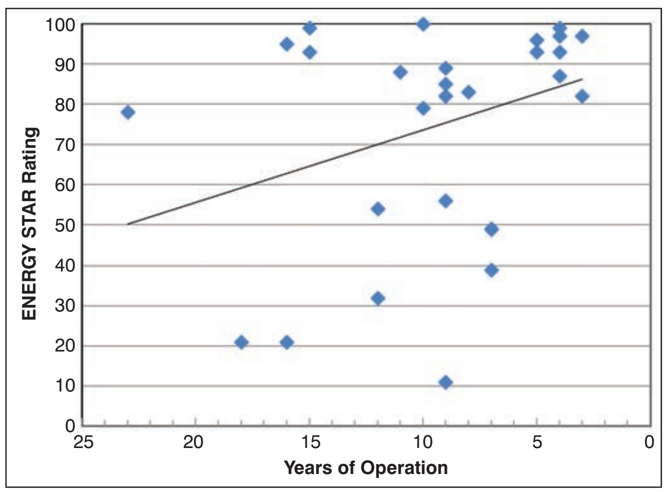

Figure 2: ENERGY STAR rating versus years of GSHP operation.

Results

Figure 1 is a graph of the surveyed commercial buildings with GSHP systems where sufficient information was available to obtain an ENERGY STAR rating.[2] Buildings with ratings below 75 are not official since the EPA ENERGY STAR Buildings program does not list buildings with scores below 75. Unlike many widely used rating systems that rely on predictions of building performance, ENERGY STAR is based on actual building energy use. A simple and inexpensive procedure sums the measured annual energy input from all sources and corrects the rating for building size, type, location, occupancy, schedules, and critical internal loads. A rating of 75 qualifies for ENERGY STAR designation and indicates the normalized building source energy use is lower than 75% of equivalent buildings as determined from the Energy Information Administration Commercial Building Energy Consumption Survey (CBECS).[3]

Twenty-two of the 35 buildings with sufficient information attained an ENERGY STAR designation. The variation in ENERGY STAR rating ranged from a low of one to a high of 100. While most of these systems performed well, this variation

GSHP Series Overview

The Long-Term Commercial GSHP Performance series will summarize 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.

Project Overview and Loop Circuit Type: This article will provide a description of the project and present a summary of energy performance of all buildings and the function of different types of loop circuits. Loop circuits are categorized by 1) central building loops, ground loops and pumps, 2) central one-pipe building loops, ground loops and pumps with individual pumps on each heat pump, 3) individual loops and pumps for each heat pump, and 4) common building and ground loops with individual pumps for each heat pump. The ENERGY STAR rating is used as the primary indicator of performance since it is based on measured source energy use and is normalized for building type, climate, primary loads, occupancy, schedules and other appropriate characteristics.

Ground Loops, Pumps, Ventilation Air, and Controls: This article will present 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.

Ground Loop Temperatures: This article will provide a summary of energy and demand performance of GSHPs as a function of ground loop temperatures. The trends of temperatures to ground loop dimensions and differential temperature as a function of pump size will be shown. Data will be presented to address the issue of long-term ground loop temperature changes in applications with imbalanced cooling and heating loads.

GSHP System Installation Costs: This article will provide a list of the installation costs for newer systems. Costs will be itemized by interior HVAC costs (74% of the total) and ground loop cost (26% of the total). The sampling is weighted toward one-pipe and individual loops since little information was made available for central and common loops.

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. Occupants were provided rating surveys for their satisfaction levels with indoor temperature, air quality, acoustics, lighting, access to controls, and maintenance. Some of the many comments will be listed. Maintenance personnel were provided surveys and the opportunity to provide comments and recommendations. The rating results are insightful and comments were abundant.

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.

indicates GSHPs, in some cases, have been poorly designed and installed.

Figure 2 (Page 49) indicates a general trend of improved ENERGY STAR ratings for newer GSHP systems. All of the surveyed sites installed in the last six years have ratings above 80 and most of them are above 90. However, the highest rated building has been operating for 10 years and three buildings with 15 years of operation have ENERGY STAR ratings above 90. The longest operating system (23 years) obtained an ENERGY STAR rating of 78 in spite of the fact that it has operated in a southern climate with vertical bore spacing less than 15 ft. (5 m). The lowest rated buildings have GSHP systems that have operated nine, 16, 18 and 12 years.

ENERGY STAR Ratings by Loop Circuit Type

This article summarizes ENERGY STAR ratings categorized by loop circuit type. The most common type of ground loop is a central loop with central pumps as shown in the upper left portion of *Figure 3*. Almost all of the systems were connected inside the building to individual heat pumps and most had variable speed drives. Two of the central systems incorporated reversible central chillers and air-handling units with VAV (variable air volume) terminals rather than heat pumps.

Another central ground loop type is the one-pipe system shown in the lower left portion of *Figure 3*. A single central pipe loop inside the building is connected to a central ground loop. Central pumps provide continuous flow, which is typically regulated by ground loop return temperature. As each heat pump is activated, a secondary pump circulates water to the heat pump and returns the discharge downstream into the common one-pipe loop.

The third category is unitary single loops connected to individual heat pumps with low head, on-off circulator pumps as shown in the lower right section of *Figure 3*. These resemble residential systems and in some cases these individual loops serve the classrooms and offices while the common areas are served by air-cooled equipment or a central loop GSHP.

The fourth category is a common building with a ground loop with individual on-off circulator pumps on each heat pump as shown in the upper right section of *Figure 3*. Note that a check valve is installed on the pump discharge to prevent reverse circulation when the heat pump is not operating. These pumps typically only provide 25 to 30 ft of head (75 to 90 kPa). They are not able to circulate through large central loops unless the header diameters are increased above standard practice or two pumps are placed in series on each unit. One elementary school in the survey had a single common loop while the others had multiple common loops.

Figure 4 is a graph of ENERGY STAR ratings for the central GSHP systems. Eight of the 20 systems (40%) achieved

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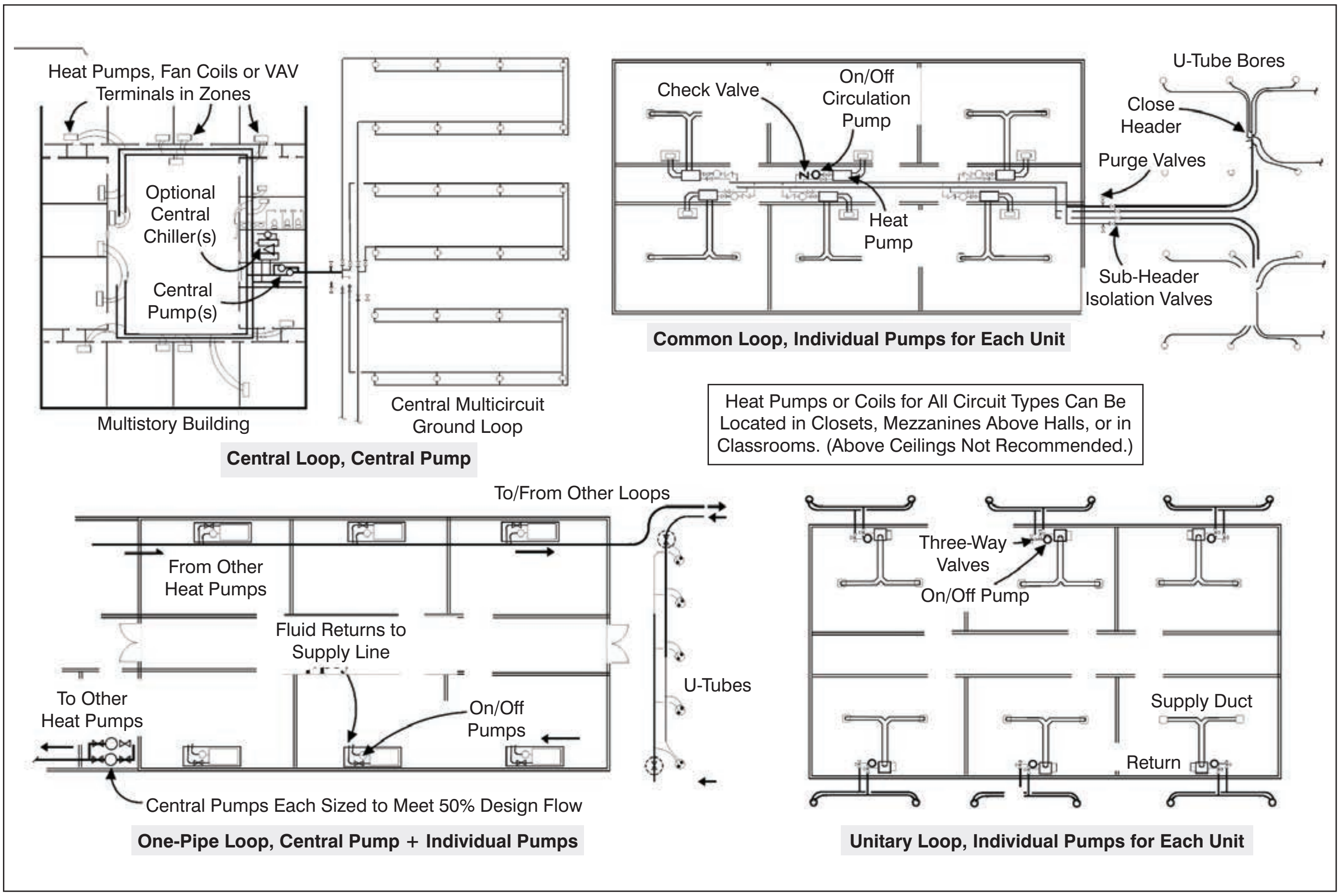

Figure 3: GSHP building and ground loop circuit types.

ENERGY STAR designation with two exceeding a rating of 90. There appears to be little difference in the performance of those with variable speed drive pumps (six of 16 achieving ENERGY STAR) and those with constant speed motors (two of four achieving ENERGY STAR).

While most of the central systems were connected to unitary heat pumps in the building, two were connected to central chilled water loops with VAV air-distribution systems. As shown in *Figure 4*, these systems received a below average ENERGY STAR rating. Four of the central loops had constant speed pumps that operated continuously. One of these systems had a variable speed drive but it was operated at full speed continuously by design.

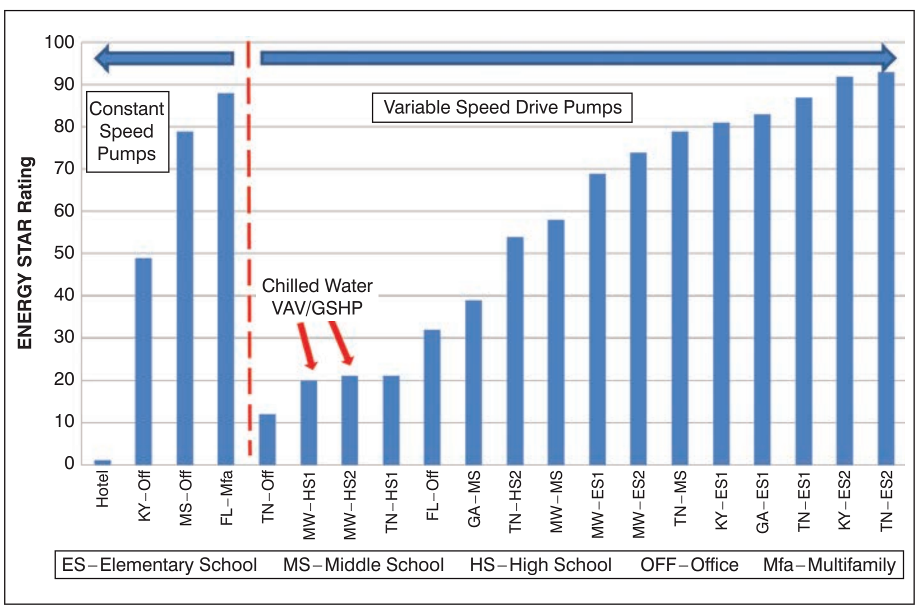

Figure 4: ENERGY STAR ratings of central loop GSHPs with central pumps.

Two buildings in the survey were served by a central loop in the common areas while the classrooms and offices were conditioned by unitary loops with individual units and ground loops.

Six systems in the survey were central one-pipe loops that were retrofits of existing schools. Five were built in the 1950s and one in 1938. As shown in *Figure 5* all of these GSHP buildings achieved the ENERGY STAR designation with four

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rating 95 or higher. The lone school with a rating below 90 was built in 1938. It should be noted that all of these schools are in the same district and the systems were designed by the same engineer.

Four systems in the survey were unitary loops connected to individual heat pumps with on-off circulator pumps. As indicated in *Figure 5* these buildings received an ENERGY STAR rating above 90, with one achieving a rating of 100 (TX-ES2). They are in the same district and the systems were designed by the same engineering firm. The two older schools (TX-MS, 1996 and TX-ES1, 1996) are served by GSHPs in all areas. The classrooms and offices in the two newer schools (TX-HS, 1998 and TX-ES2, 2001) are conditioned with GSHPs while the common areas such as cafeterias, gymnasium and kitchens are served by air-cooled equipment. Ventilation air energy recovery units are supplemented by non-GSHP equipment.

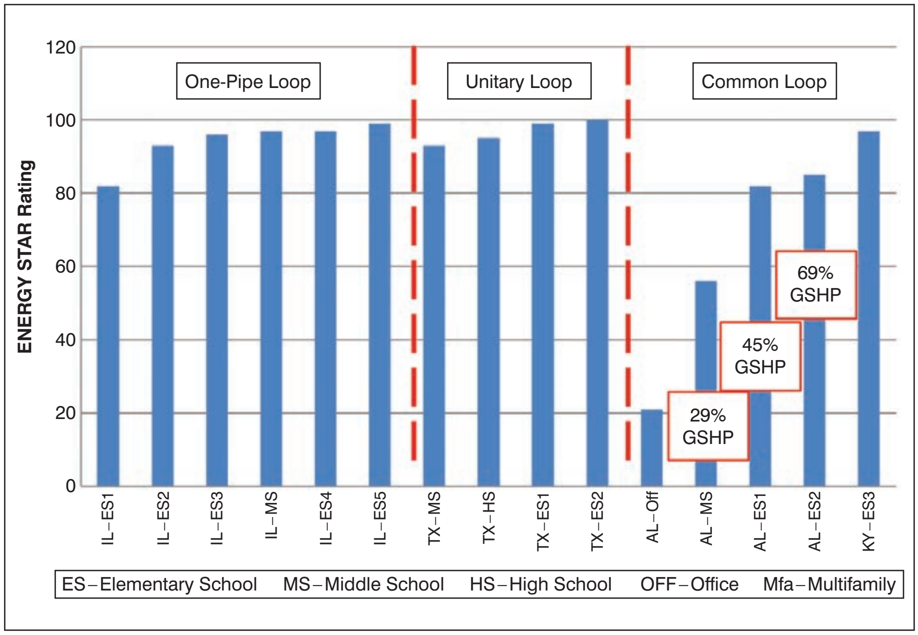

Figure 5: ENERGY STAR ratings of one-pipe central loop with central & individual pumps.

The school district has been installing GSHPs since 1994 and has 26 GSHP schools that achieved the ENERGY STAR designation, four of which received a rating of 100 in 2010 including TX-ES2.

Five systems in the survey were served by common loops connected to multiple heat pumps inside the building. Three of the systems were located in buildings that were also partially served by conventional unitary equipment as noted in *Figure 5*.

Four of the five systems appear to be operating effectively while one is operating well below the average ENERGY STAR rating of 50. One building received a rating slightly above 50 but only 29% of the floor space is conditioned by GSHPs. The other two buildings that are partially heated and cooled by GSHPs rated high enough to merit an ENERGY STAR designation. The school building with a single common ground loop received an ENERGY STAR rating of 97.

Summary and Conclusions

All Loop Circuit Types Energy Performance

• The GSHP systems in this survey, which varied in age from three to 23 years, performed well above average ENERGY STAR ratings with 33% (12/36) receiving a rating above 90 (top 10% of buildings) and 22% (8/36) receiving a rating above 95 (top 5% of buildings).

• The surveyed GSHP buildings also had a large percentage receiving the ENERGY STAR designation with 61% (22/36) having a rating of 75 or above (top 25% of buildings).

• However, 17% (6/36) of the GSHP buildings had ENERGY STAR ratings below 21.

• When properly applied, GSHPs offer significant energy performance advantages compared to buildings surveyed in the Energy Information Administration (EIA) Commercial Buildings Energy Consumption Survey[3] upon which the ENERGY STAR rating is based.

• The survey suggests that GSHP systems on the lower end of the performance scale do no better than average HVAC systems.

Central Loop GSHP Energy Performance

• Buildings with central loop GSHPs and pumps did not fare as well as overall GSHPs with 10% (2/20) receiving a rating above 90 (top 10% of buildings).

• The central loop GSHP buildings performed somewhat better based on the percentage achieving ENERGY STAR designation with 40% (8/20) receiving a rating of 75 or above.

• However, 25% (5/20) of the central loop GSHP buildings had ENERGY STAR ratings of 21 or below.

• Central loop GSHPs with central pumps appear to offer only a small advantage compared to the energy performance of buildings in the DOE/EIA CBECS database.

• Central loop GSHPs on the lower end of this energy performance scale actually functioned slightly worse than the CBECS buildings.

Central One-Pipe Loop GSHP Energy Performance

• Buildings with central one-pipe loop GSHPs performed well above average ENERGY STAR ratings with 83% (5/6) receiving a rating above 90 (top 10% of buildings) and 66% (4/6) receiving a rating above 95 (top 5% of buildings).

• The GSHP buildings with one-pipe central loops all achieved ENERGY STAR designation.

• Central One-Pipe Loop GSHP buildings offer significant energy performance advantages compared to buildings in the DOE/EIA CBECS database.

Unitary Loop GSHP Energy Performance

• Buildings with unitary loop GSHPs performed well above average ENERGY STAR ratings with 100% (4/4) receiving a rating above 90 (top 10% of buildings) and 75% (3/4) receiving a rating above 95 or above (top 5% of buildings).

• Unitary Loop GSHP buildings offer significant energy performance advantages compared to buildings in the DOE/EIA CBECS database.

Common Loop GSHP with Individual Pumps Energy Performance

• Buildings with common loop GSHPs and individual pumps received above average ENERGY STAR ratings with 20% (1/5) receiving a rating above 95 (top 5% of buildings).

• The GSHP buildings with common loop GSHPs also had a large percentage receiving an ENERGY STAR designation with 60% (3/5) with a rating of 75 or above.

• One building with common loop GSHP received an ENERGY STAR rating of 56 but only 29% of the building floor is conditioned with GSHPs. A fifth building received an unofficial ENERGY STAR rating of 21.

• Common loop GSHPs with individual pumps offer energy performance advantages compared to buildings in the DOE/EIA CBECS database.

References

1. EPRI. 2012. "Long-Term Performance of Commercial Ground Source Heat Pumps." Final Report Draft. EP-P40851/EP-P40852. Electric Power Research Institute. Palo Alto, Calif.

2. EPA. 2010. "How the Rating System Works." ENERGY STAR Portfolio Manager Overview. U.S. Environmental Protection Agency, Washington, D.C.

3. EIA. 2008. "Commercial Buildings Energy Consumption Survey." 2003 Detailed Tables. U.S. Energy Information Administration. Washington, D.C. http://www.energystar.gov/index.cfm?c=evaluate_performance.pt_neprs_learn.

Acknowledgments

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