A CAPITAL COST COMPARISON OF COMMERCIAL GROUND-SOURCE HEAT PUMP SYSTEMS

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ABSTRACT

The ground-source heat pump industry is focusing a great deal of effort on reducing system first cost. For the most part, this effort has been directed at ground-coupled systems. This paper explores two other ground-source system types (hybrid and groundwater) and compares their costs to ground-coupled systems. Costs were developed for the three system types over a range of soil temperatures, well depths, building load characteristics and other parameters. Results show that reductions in capital cost of 20 to 80% can be achieved with hybrid and groundwater systems compared to ground-coupled systems.

GSHP DESIGN CONSIDERATIONS

Unitary ground-source heat pump systems for commercial buildings can be installed in a variety of configurations. The oldest and, until recently, most widely used approach was the groundwater system. In this design (Figure 1), groundwater from a well or wells is delivered to a heat exchanger installed in the heat pump loop. After passing through the heat exchanger (where it absorbs heat from or delivers heat to the loop), the groundwater is disposed of on the surface or in an injection well. The use of an injection well is desirable in order to conserve the groundwater resource.

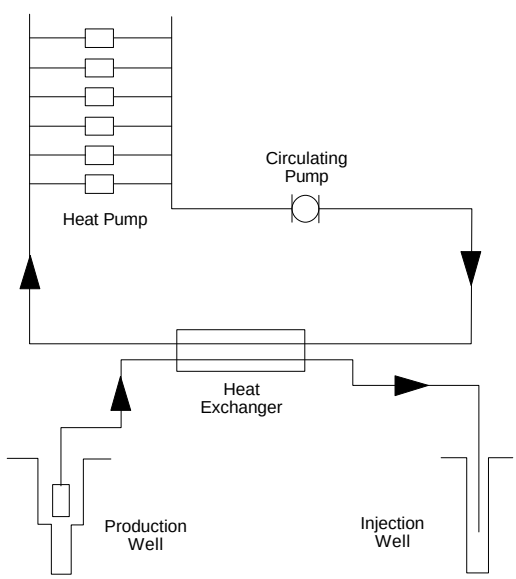

Figure 1. Groundwater heat pump system.

A second and increasingly popular design is the ground-coupled heat pump system. In this approach (Figure 2), a closed loop of buried piping is connected to the building loop. For most larger commercial applications, the buried piping is installed in a grid of vertical boreholes 100 to 300 ft deep. Heat pump loop water is circulated through the buried piping network absorbing heat from or delivering heat to the soil. The quantity of buried piping varies with climate, soil properties and building characteristics, but is generally in the range of 150 to 250 ft (of borehole) per ton of system capacity. Borehole length requirements are almost always dictated by heat rejection (cooling mode) duty for commercial buildings.

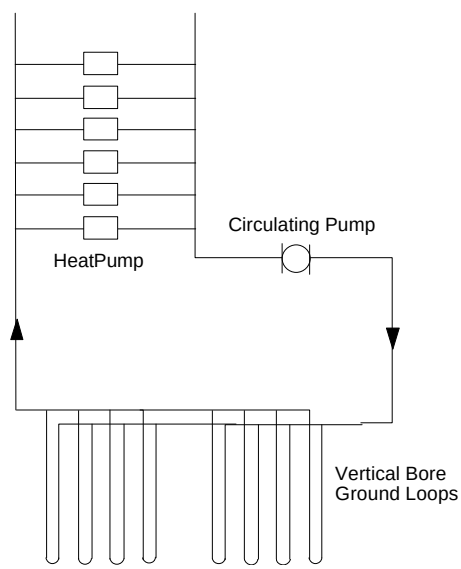

Figure 2. Ground-coupled heat pump system.

A third design for ground-source systems in commercial buildings is the "hybrid" system. This approach (Figure 3) may also be considered a variation of the ground-coupled design. Due to the high cost associated with installing a ground loop to meet the peak cooling load, the hybrid system includes a cooling tower. The use of the tower allows the designer to size the ground loop for the heating load and use it in combination with the tower to meet the peak cooling load. The tower preserves some of the energy efficiency of the system, but reduces the capital cost associated with the ground loop installation.

In addition to the three designs discussed above, ground source systems can also be installed using lake water, standing column wells and horizontal ground coupled approaches. This article focuses on the three former schemes due to their wider use and broad potential application.

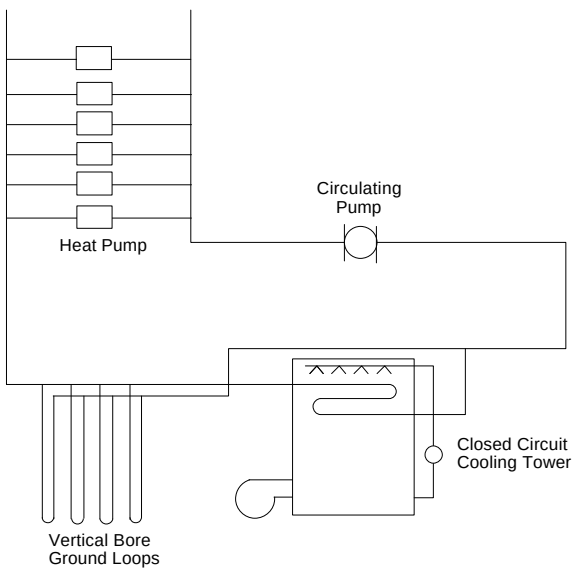

Figure 3. Hybrid ground-coupled heat pump system.

The purpose of this article is to compare capital costs associated with the three designs. Specifically, the costs considered are those associated with the heat source/heat sink or ground source portion of the system. In order to standardize the heat rejection over the three designs, it was assumed that the heat pump loop would operate at a temperature range of 85° (to the heat pumps) to 95° (from the heat pumps) under peak conditions. The assumption of constant loop temperature conditions for all three permits an apples-to-apples comparison of the alternatives.

The following items are included in the costs calculated in this article.

Groundwater system:
- Production well (or wells)
- Production well pump test
- Production well pump
- Well pump variable-speed drive
- Buried piping (wells to building)
- Heat exchanger
- Heat exchanger controls
- Injection well
- Injection well test
- 15% contingency factor

Ground-coupled system:
- Vertical borehole
- Loop installation
- Header piping and installation

Hybrid system:
- Vertical boreholes
- Loop installation
- Header piping and installation
- Closed circuit cooling tower
- Tower pad
- Tower piping
- 15% contingency (on tower and accessories)

Commercial building is a term which can cover a very broad spectrum of sizes from a few hundred square feet to several million square feet. The range selected for this article includes system sizes from 50 to 500 tons. Using an average value of 300 ft^2 per ton, this translates into a building area range of 15,000 to 150,000 ft^2. Buildings in this size range comprise the bulk of the commercial building stock in the United States.

In order for the results to be as broadly applicable as possible, cost calculations were made for a wide variety of soil (or groundwater) temperatures, well depths (groundwater), loop lengths (ground coupled) and tower/loop ratios (hybrid system).

It is common in the ground-source heat pump industry to refer to costs for the ground source portion of the system on a cost per ton basis. In keeping with this practice, most cost data presented for this article is expressed in terms of cost per ton. It is important to note, however, that the cost per ton refers to the actual load imposed on the ground source portion of the system. This is not the same as the installed capacity of the equipment. Due to load diversity, the peak load imposed upon the heat rejection equipment is always less than the total installed capacity. The load used for cost calculations in this article is frequently referred to by engineers as the block load.

RESULTS

Costs were developed for three groundwater/soil temperatures 50°, 60° and 70°F representing northern, central and southern climates. For brevity, only the results for the 60° cases are presented. These costs address only the ground-water portion of the system.

Figure 4 presents the results for the 60°F ground-water case assuming the use of a single production/injection well pair to serve the system. The four curves shown indicate costs (in $/ton) for four different groundwater well depths: 200, 400, 600 and 800 feet. In all cases, the values shown include costs for the production wells, well flow testing, production well pump, pump variable-speed drive, buried piping for transport

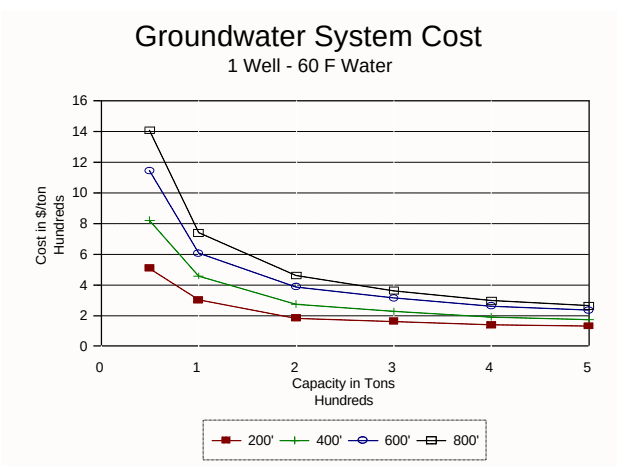

Figure 4.

of the groundwater to the building, heat exchanger to isolate the groundwater from the building loop, heat exchanger controls, injection well, injection well flow testing, and a 15% contingency factor. As indicated, the depth requirement for the wells has a substantial impact upon the installed cost. In addition, the unit cost for small systems (50 - 100 tons) is often higher by a factor of 3 compared to costs for larger systems (300 - 500 tons).

In many cases, a single production/injection well pair may not be capable of producing (or injecting) the required system flow rate. To address this situation, costs were calculated for systems using 2 production wells and 2 injection wells. In addition to the wells, adjustments were also made in well pump, piping, and testing costs to accommodate the installation of the additional wells. Figure 5 presents these costs for 200 and 600 foot well depths and system sizes of 100 to 500 tons.

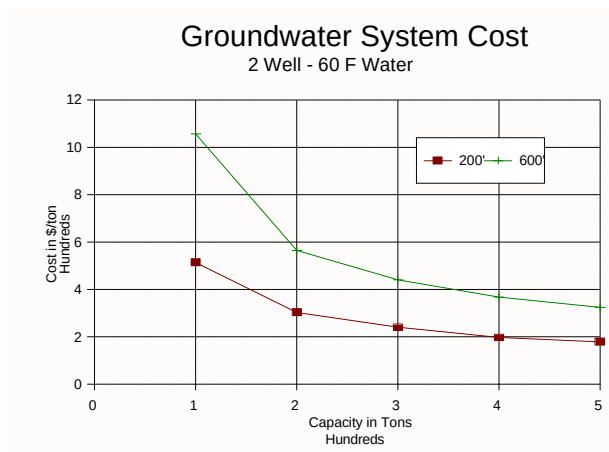

Figure 5.

For ground-coupled systems, actual project costs rather than calculations were used. Costs for these systems are a function of two values--the number of feet of borehole necessary per ton of heat rejection, and the cost per foot for com-pleting the vertical bore and installing the piping. For purposes of this article, the values of 150 feet per ton for 50°F soil, 200 feet per ton for 60°F soil, and 250 feet per ton for 70°F soil have been used. To arrive at a cost per ton, a value of $5 per foot of bore has been used. Although some recent projects have been the beneficiary of costs as low as $3.75

per foot and one as low as $3 per foot, many areas of the country are still reporting costs of as much as $15 per foot.

Hybrid systems include both a ground loop and a cooling tower. The ground loop is sized to meet the heating load and, it along with the tower, is used to meet the cooling heat rejection load. As a result, hybrid system costs are a combination of ground loop costs and cooling tower costs. Using the $5 per foot value for the hybrid ground loop portion and vendor quotes for the cooling tower, Figure 6 shows the cost per ton for the hybrid system based on 60ºF soil temperature. Hybrid system costs were also developed for 50º and 70ºF soil. The four curves shown for the hybrid system reflect costs for different ratios of heating loop length versus cooling loop length. As indicated, hybrid systems enjoy more favorable economics as the heating ground loop length decreases as percentage of the cooling ground loop length requirement. This is because the cost per ton of the cooling tower is less than the cost per ton of the ground loop.

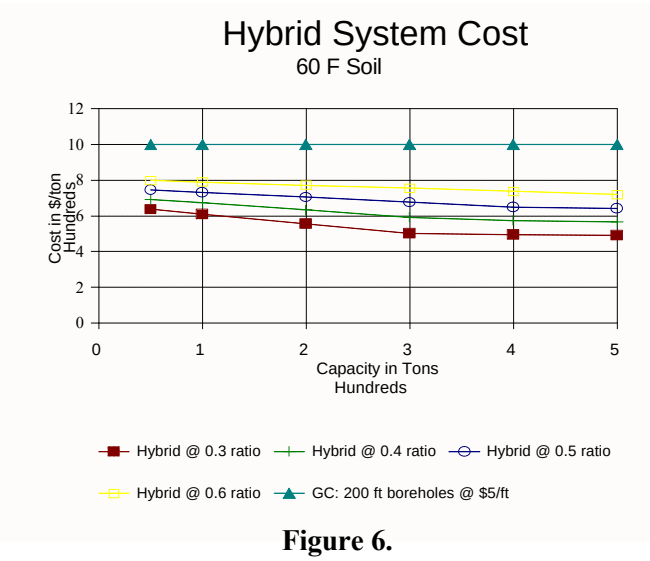

Figure 6.

Generally, the hybrid system is attractive in situations where ground loop costs per ton are high, and where the heating loop length requirement is low relative to the cooling loop length requirement.

Figure 7 presents a comparison of the three types of systems for 60ºF soil. The ground-coupled system cost line is based upon $5 per foot and 200 ft per ton ($1000 per ton). The two hybrid system curves are based upon loop length ratios (heating ÷ cooling) of 0.30 and 0.40 evaluated in this article. These are the most favorable conditions for hybrid systems. The two groundwater curves are based upon 200 ft wells and one production/injection well pair (lower curve) and two production/injection well pairs (upper curve). Again, these are the most favorable conditions calculated for groundwater systems in this article. It is clear that, based on these conditions, the groundwater system enjoys substantial capital cost advantage over the remaining two systems over the entire range of capacity covered.

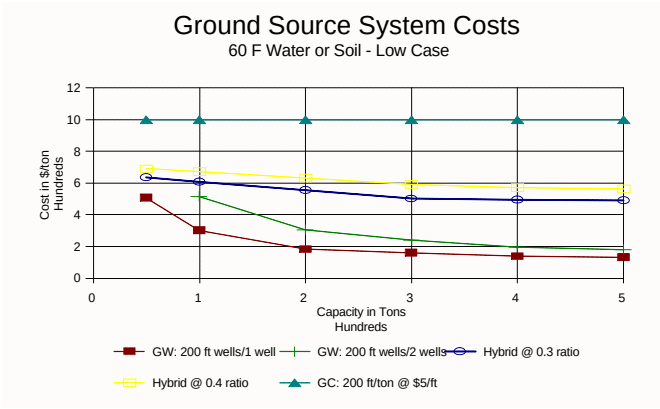

Figure 7.

Figure 8 presents additional data for the 60ºF soil case. Again, the ground-coupled line is based on 200 ft per ton and $5 per foot. The two hybrid system curves are based upon loop

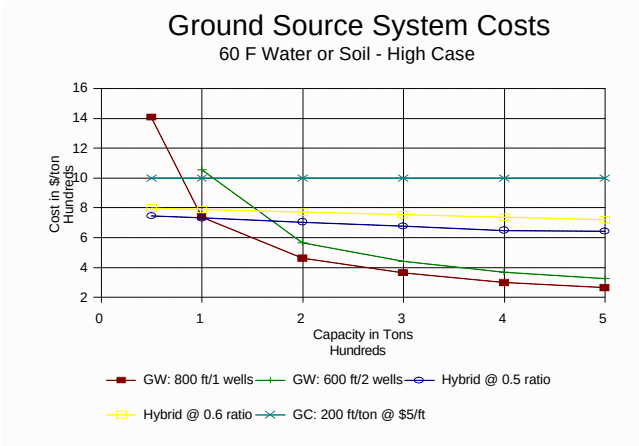

Figure 8.

length ratios of 0.50 (lower) and 0.60 (upper). These are the least favorable conditions for the hybrid systems covered in this article. The two curves for the groundwater system are based upon a single production/injection well pair at 800 foot depth (lower curve) and two production/injection well pairs at a 600 foot depth. These are the least favorable conditions for the groundwater system cover in this article.

As indicated at system capacities of 100 - 175 tons and above, the groundwater system has the capital cost advantage over hybrid and ground-coupled systems. Below this range, the hybrid system is the most attractive. It is only under conditions of less than 100 tons with well depths of 800 feet, that the groundwater system capital cost exceeds that of the ground-coupled system. To emphasize the cost advantage of the ground-water system for large heat pumps, Figures 9 and 10 portray the cost comparisons for the three systems in a bar graph format. The graphs are based on groundwater systems with 400 ft pro-duction and injection wells, hybrid system at a loop length ratio of .30, and ground-coupled system at 200 ft/ton and $5.00 per foot.

This article addresses only system capital cost. In the process of system selection, other issues should be considered as well. These would include operating costs such as electricity for pumps and fans, water treatment costs (tower) and regulatory issues with respect to groundwater. As a result, system capital cost provides only a portion of the information required for informed decision making.

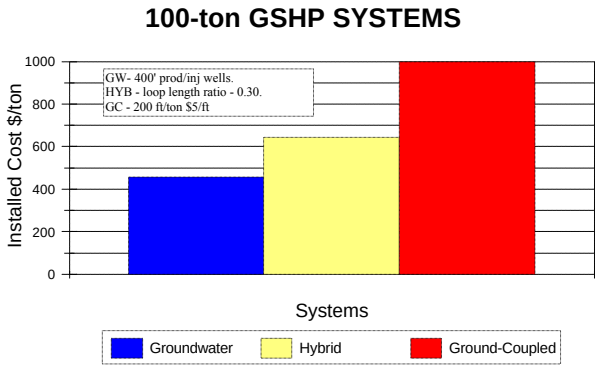

Figure 9.

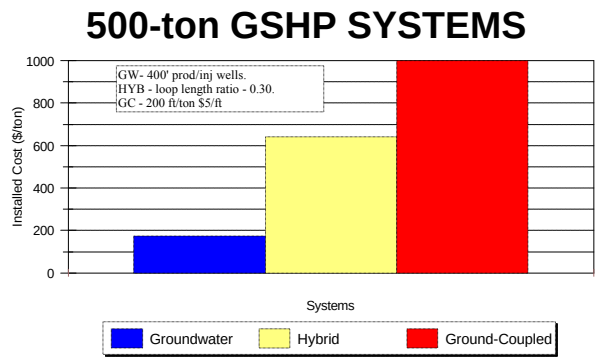

Figure 10.