# Well-Pumping Issues in Commercial Groundwater Heat Pump Systems

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## ABSTRACT

*Groundwater flow minimizes total system power (well pump, heat pumps, loop pump) and is based upon building peak block load. Optimum flow for water temperatures in the 50°F to 70°F range is 1.25 gpm to 2.5 gpm per ton of peak block load, depending upon total pump head. Submersible pumps are likely to be the type used in most systems. Contrary to popular belief, well pumping does not result in substantially lower groundwater system performance (system EER, system COP) compared to closed-loop systems. In fact, groundwater systems, due to more favorable operating temperatures, can offer performance superior to ground-coupled systems under certain circumstances. All systems evaluated in this report employ a plate heat exchanger to isolate the heat pump from the groundwater.*

## INTRODUCTION

Groundwater heat pump (GWHP) systems have been characterized as using excessive pumping energy. When poorly designed or controlled, this can be true; however, much of the perception is a carryover from experiences in residential systems. In large commercial GWHP systems, overall pump efficiency is much higher, flow requirements (gpm/ton) are generally lower, and in many applications, pump head is reduced relative to residential systems. These factors combined result in much lower unit pumping energy requirements than is commonly believed. In fact, under some conditions, groundwater systems can offer system performance superior to ground-coupled systems.

Key to efficient well-pumping design are three major power-consuming components of the system: well pump, heat pumps, and building loop pump. Careful consideration of the interaction between these components and their impact upon system performance is necessary in order to minimize costs for the building owner.

The strategies discussed in this paper are intended to address large (>50 tons) commercial GWHP systems. The basic system configuration is illustrated in Figure 1. The heat exchanger, separating the building loop from the groundwater, distinguishes large systems from smaller installations in which the groundwater may be supplied directly to the heat pumps.

This discussion of system performance focuses on the cooling mode since this is usually the dominant load in large buildings regardless of the climate.

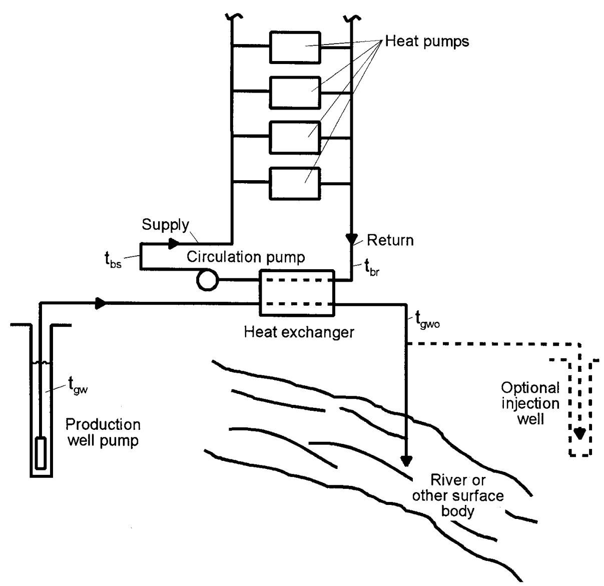


***Figure 1*** *Groundwater heat pump system.*

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## WELL PUMP HEAD

Well pump head in a GWHP application consists of three major components: lift, surface requirements, and injection head. A small friction loss also occurs in the pump column, and most designers include this in the well lift.

In water wells, the removal of water on a continuous basis results in a drop in water level from the static (nonpumping) level to the dynamic (pumping) level. This drop in water level is a manifestation of the drop in pressure necessary to cause water to flow from and through the aquifer into the well. The pumping level is a function of the pumping rate with higher flow resulting in lower (deeper) pumping levels. The vertical distance between the pumping level and the ground surface constitutes the "lift" portion of the well pump head. The lift varies with flow, but at far less than the second power relationship of frictional resistance. The total depth of the well and the distance the pump is submerged below the water surface have no bearing upon pump head.

For a system with an original static water level of 100 ft and a drawdown of 40 ft, the lift (and the pumping level) would be 140 ft.

Surface head loss includes the losses in the piping to and from the building, the isolation heat exchanger, and associated fittings, accessories, and controls. Table 1 presents a summary of losses from a 300 gpm system with 300 ft of piping from the production well and 400 ft of piping to the surface disposal point.

The largest single loss, in most cases, is the heat exchanger, and depending upon the design, the value will be in the range of 12 ft to 28 ft. The example case includes a pressure-sustaining valve (a device sometimes used in the absence of injection) to maintain a slight positive pressure on the disposal line.

**TABLE 1**
**Example Well Pump Head Summary**

| | | Loss @ 300 gpm (ft) |
|---|---|---|
| Well Head | Three 6-in. elbows | 0.24 |
| | One 6-in. butterfly valve | 0.05 |
| | One 6-in. check valve | 0.3 |
| Piping to Building | 300 ft, 6-in. PVC Class 160 | 2.4 |
| Mechanical Room | Twelve 6-in.elbows | 1.0 |
| | Heat exchanger @ 7 psi | 11.5 |
| | Two 6-in.butterfly valves | 0.1 |
| Piping to Disposal Point | 400 ft, 6-in. PVC Class 160 | 3.2 |
| | Four 6-in. elbows | 0.3 |
| | One pressure-sustaining valve @ 3 psi | 6.9 |
| | Total Surface Loss | 25.99 ft |

The use of injection for disposal does not necessarily involve additional pump head. Most regulatory agencies require that the water be injected into the same aquifer from which it was withdrawn. As a result, the production well's performance is a good indication of potential injection well performance. In theory, the rise in water level required to force the water back into the aquifer mirrors the drop in water level required to produce it. As a result, if a production well had a 100 ft static water level and a 140 ft pumping level @ 300 gpm, the injection well (assuming the same 100 ft static level) would have an injection water level of 100 ft – 40 ft or 60 ft below ground surface. Actual injection water levels are frequently higher than this theoretical relationship. With proper drilling practices and well design and moderate water quality, it is reasonable to expect that injection head (relative to the static level) will be approximately 20% greater than the production drawdown. For poor conditions, this value may be as much as 60% (Kavanaugh and Rafferty 1996).

Using the 300 gpm production well as a guide, the injection head can be calculated assuming average injection conditions (injection head 40% greater than production drawdown).

| | | |
|---|---|---|
| Production drawdown | = | 40 ft |
| Injection well water level rise | = | 40 ft × 1.4 = 56 ft |
| Injection well static level | = | 100 ft |
| Injection level | = | 100 ft – 56 ft = 44 ft (below ground surface) |

Since the water level in the injection well remains below ground level, there is no additional well pump head associated with injection in this case.

Summarizing the total pump head for the 300 gpm example:

| | | |
|---|---|---|
| *Production well lift | = | 142 ft |
| Surface requirements | = | 26 ft |
| Injection head | = | 0 ft |
| Total pump head | | 168 ft |

*Includes additional 2 ft column friction loss

## WELL PUMP POWER REQUIREMENTS

A well pump power requirement is a function of flow, head, and efficiency. Properly selected vertical turbine well pumps in the 100 gpm to 1000 gpm range have peak efficiencies of 70% to 80% (PP [undated]; L&B 1985). Submersible pump motor efficiency varies with size from approximately 75% (5 hp) to 85% (75 hp) (FE 1986). Combining average values from these ranges results in an overall efficiency of 65% for the well pump and motor. Using this average value, a plot can be made of well pump power requirements for a variety of water flows and pump heads appropriate to GWHP systems. These data appear in Figure 2.

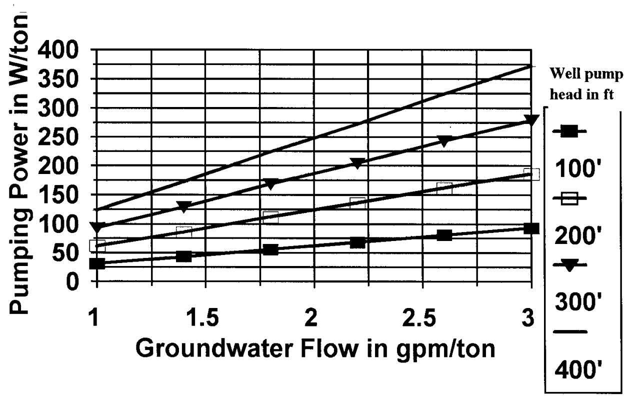


*Figure 2 Well pump power requirements. Submersible (75% pump, 80% motor).*

As indicated, in situations of high flow rate and high pump head, the well pump power consumption is substantial. This is particularly true when one considers that a water-source heat pump operating at a 15 EER requires 800 watts per ton. In a system with a water flow of 2.5 gpm per ton and a pump head of 400 ft, the well pump could consume 325 watts per ton or 40% of the heat pump power.

Avoiding this excessive level of well pump power can be done with a design procedure that rests upon total system performance rather than simply heat pump unit performance and the use of actual loads rather than installed capacity.

## OPTIMUM WATER FLOW REQUIREMENTS

Optimum system performance is obtained when the sum of the power consumption of the well pump, loop pump, and heat pumps is minimized through careful design. At a given loop flow rate, heat pump performance is largely a function of loop water temperature. Loop temperature, in turn, is governed by groundwater flow and temperature along with heat exchanger design. In most GWHP applications, the groundwater flow will be less than building loop flow for optimum designs. This results in the minimum temperature difference between the groundwater and the building loop occurring at the groundwater exit/building loop entrance side of the exchanger. Under these conditions, the heat exchanger can be selected economically for a 3°F "approach" between the entering building loop water (return from the heat pumps) and the leaving groundwater temperature.

Given a constant groundwater temperature and heat exchanger approach, increasing groundwater flow results in lower loop temperature and higher heat pump performance (in the cooling mode). For example, using heat pumps with an ARI 330 EER rating of 14.1, a 3°F heat exchanger approach, and 60°F groundwater, a heat pump unit of 15 EER would require a flow rate of 0.79 gpm/ton; 16 EER, a flow of 0.91 gpm/ton; 17 EER, a flow of 1.05 gpm/ton; and so on. At some point, the increasing heat pump performance will be compromised by rising well pump power consumption. As a result, for a given set of site conditions, there is an optimum groundwater flow with respect to system peak power consumption.

Power consumption of the building loop circulating pump must also be considered in the calculation of optimum flow. Loop pump energy consumption is a function of the loop flow rate and system head loss. A recently developed design guide for ground-source heat pump systems (Kavanaugh 1996) provides a range of values for acceptable design. According to this document, high-efficiency systems are characterized by loop pumping energy loads of 75 watts/ton or less, average systems 75 to 100 watts/ton, and poorly designed systems >100 watts/ton. These guidelines were developed for closed-loop (ground-coupled) commercial systems, but the values also provide useful input for groundwater systems. The major difference between the two designs is the presence of a plate-and-frame heat exchanger in place of the ground loop.

As mentioned above, heat exchanger head losses vary from 12 ft to 28 ft depending upon design. Ground loop losses vary from 10 ft to 40 ft. Since these losses constitute less than 50% of the total head in most systems, loop pumping power is comparable for groundwater and ground-coupled systems.

Using a loop pump power consumption of 75 watts/ton, an overall (pump and motor) well pump efficiency of 65%, and performance data for heat pumps of moderate efficiency (ARI 330 EER 14.1), Figures 3 through 8 provide information on total system performance (system COP and system EER) at various well pump heads, flows, and temperatures. All curves are based on peak block load.

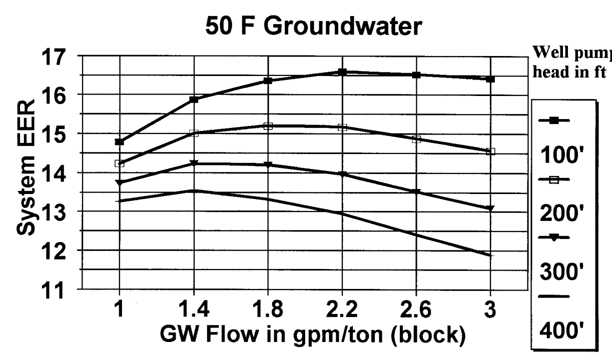


*Figure 3 System performance—cooling.*

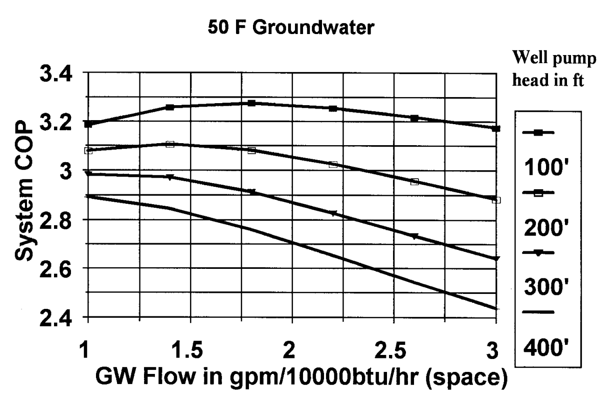


*Figure 4 System performance—heating.*

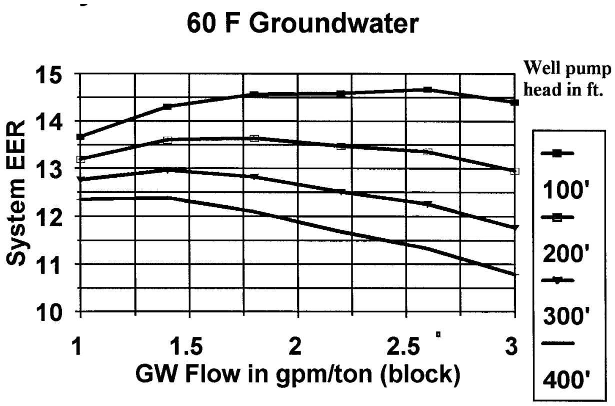


*Figure 5* *System performance—cooling.*

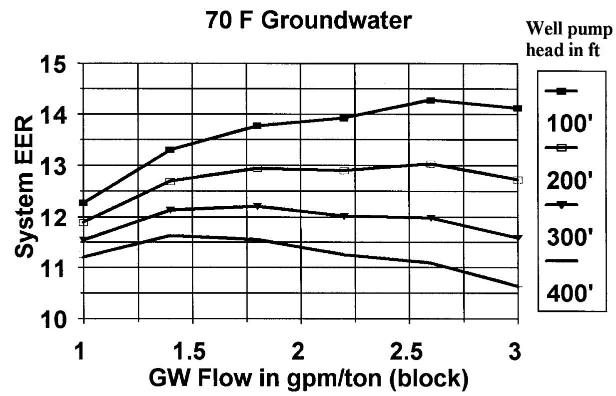


*Figure 7* *System performance—cooling.*

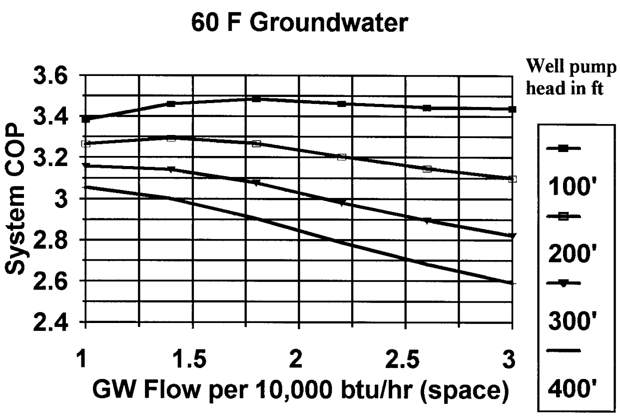


*Figure 6* *System performance—heating.*

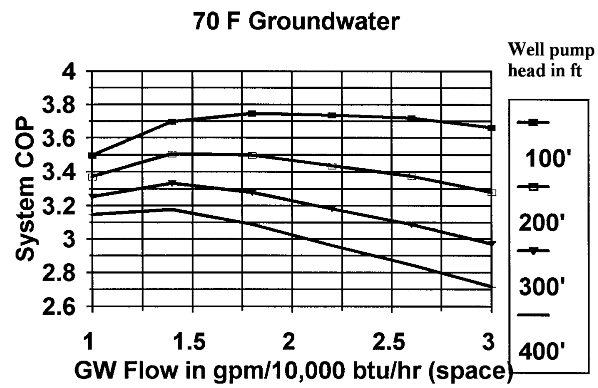


*Figure 8* *System performance—heating.*

In general, the higher the well pump head, the lower the optimum groundwater flow. Although there is a clear optimum point on each curve, in some cases it may be advisable to operate at flows much less than at the optimum. For example, consider a 300 ton (peak block) system with 60°F water in which cooling is the dominant load. Assuming a well pump head of 200 ft, the optimum flow would be about 1.8 gpm/ton or 540 gpm total, resulting in a system EER of 13.7. Reducing this flow 30% (to 1.25 gpm/ton or 375 gpm) would result in a system EER of approximately 13.5. Although this would increase system operating costs slightly ($273/yr @ 1000 h/yr and $0.07/kWh), the reduced flow would result in lower well pump capital costs. Lower groundwater flows also ease disposal, particularly in the case of injection. These considerations often are very site specific, but the nature of the curves does allow the designer some latitude in flow selection.

## COMPARISON TO GROUND-COUPLED SYSTEM PERFORMANCE

It is useful to compare the performance of the groundwater system to that of a ground-coupled (closed loop) system in a similar location. The performance of the closed-loop system is influenced by the length of the ground loop installed. When entering the heat pumps, current guidelines (Kavanaugh 1996) recommend a peak water temperature of 25°F (±5°F) above the local undisturbed soil temperature. Using the 25°F value, and assuming that the undisturbed soil temperature is equal to the local groundwater temperature, appropriate values for peak water temperatures upon entering the heat pump for ground-coupled systems would be 75°F for 50°F soil, 85°F for 60°F soil, and 95°F for 70°F soil. Based on the use of ARI 330 rated 14.1 EER equipment, heat pump performance (EER) at these temperatures would be 75°F - 16.8°F, 85°F - 14.9°F, and 95°F - 13.2°F. System performance for the closed-loop system is determined only by the heat pump and loop-pump power consumption since there is no well pump. As a result, assuming again the use of a well-designed system operating at 75 watts/ton loop pumping power, Table 2 summarizes the results for average ground-coupled systems at the three soil temperatures.

Based on these cooling EER values and the results for groundwater systems shown in Figures 3, 5, and 7, conclusions can be drawn with respect to the relative performance of ground-coupled and groundwater systems.

For water temperatures of 50°F and 60°F, ground-water systems can offer higher system EER than ground-coupled systems when total well pump head is less than approximately 200 ft. At 70°F, groundwater systems can offer better performance at well pump TDH (total dynamic head) up to 300 ft.

**TABLE 2**
**Summary of Ground-Coupled Peak System Power Requirements**

| Soil Temperature | H/P EWT (°F) | H/P EER | H/P watts | Loop Pump watts | System watts | System EER |
|---|---|---|---|---|---|---|
| 50 | 75 | 16.8 | 714 | 75 | 789 | 15.2 |
| 60 | 85 | 14.9 | 805 | 75 | 880 | 13.6 |
| 70 | 95 | 13.2 | 909 | 75 | 984 | 12.2 |

However, the difference between the two system types is small. At 60°F groundwater, for example, the performance of the GWHP system at 100 ft head is 8% better than the ground-coupled system and at 400 ft head, only 8% worse than the ground-coupled system. In addition, these figures are based on average design parameters in both cases. As a result, it seems apparent that the skill of the designer has at least as much impact on system performance as does the system type.

## CONCLUSIONS

Properly designed groundwater heat pump systems are characterized by peak load performance comparable to ground-coupled systems. To achieve this performance, it is necessary to select the groundwater flow with total system performance in mind. In addition, the flow should be based upon peak block load and not installed capacity.

The optimum groundwater flow requirement is a function of temperature, heat exchanger design, and total pump head, but in most applications, it will be in the range of 1.0 to 2.5 gpm per ton, which is far less than the typical building loop flow of 2.5 to 3.0 gpm/ton.

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