WELL PUMPING ISSUES IN COMMERCIAL GROUNDWATER HEAT PUMP SYSTEMS

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INTRODUCTION

Groundwater heat pump (GWHP) systems have historically been considered by many to be characterized by 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 (per ton) are generally lower and in many applications, pump head is reduced relative to residential systems. These factors combine to 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 is the consideration of the 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 operating costs for the building owner.

The strategies discussed in this article 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 is commonly supplied directly to the heat pumps.

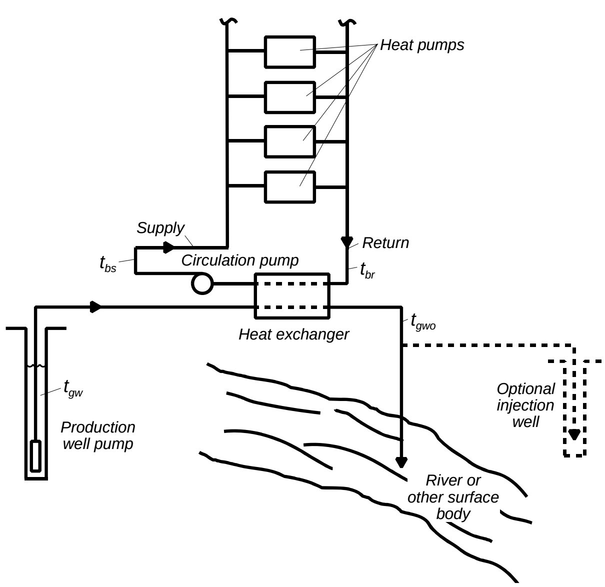

Figure 1. Groundwater heat pump system.

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

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 occurs in the pump column; however, this is minor in comparison to the other losses and is frequently neglected in head calculations.

In most water wells, the removal of water on a continuous basis results in a drop in water level from the static (non-pumping) 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 producing 300 gpm 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 and accessories. 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.

Table 1.

		Loss @ 300 gpm (ft)
Well head	3 - 6" elbows	0.24
	1 - 6" butterfly valve	0.05
	1 - 6" check valve	0.3
Piping to building	300 ft, 6-in. PVC Class 160	2.4
Mechanical room	12 - 6" elbows	1.0
	Heat exchanger @ 7 psi	11.5
	2 - 6" butterfly valves	0.1
Piping to disposal point		
	400 ft, 6-in. PVC Class 160	3.2
	4 - 6" elbows	0.3
	1 - Pressure sustaining valve @ 3 psi	6.9
	Total Surface Loss	25.99 ft

The largest single loss, in most cases, is the heat exchanger and depending upon the design, the value will vary from about 12 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.

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 injection water level of 100 - 40 ft or 60 ft below ground surface. Actual injection water level requirements frequently are higher than this theoretical relationship. With proper drilling practices, 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%.

Using the 300 gpm production well as a guide, the injection pressure 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 x 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	= 140 ft
Surface requirements	= 26 ft
Injection head	= 0 ft
Total pump head	166 ft

WELL PUMP POWER REQUIREMENTS

Well pump power requirement is a function of flow, head and efficiency. Properly selected vertical turbine well pumps in the 100 to 1000 gpm range have peak efficiencies of 77 to 80% (Peerless, undated; Layne and Bowler, 1991). Submersible pump motor efficiency varies with size from approximately 75% (5 hp) to 85% (75 hp) (Franklin Electric, 1996). Combining average values from these ranges results in an overall efficiency of 63% 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. This data appears in Figure 2.

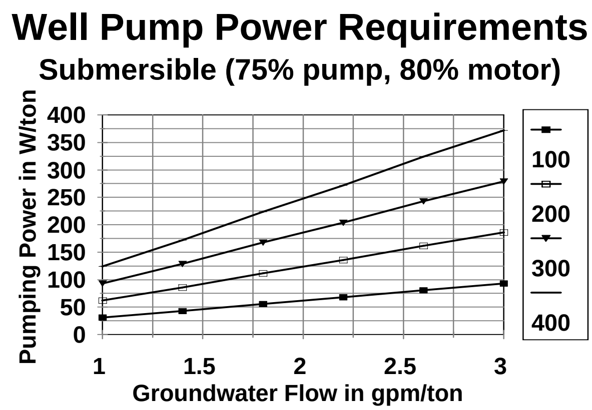

Figure 2. Well pump power requirements.

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/ton and a pump head of 400 ft, the well pump could consume 325 watts per ton or 40% or the heat pump power.

Avoidance of this excessive level of well pump power lies in a design procedure which rests upon total system performance rather than simply heat pump unit performance.

OPTIMUM WATER FLOW REQUIREMENTS

Optimum system performance is obtained when 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. Under these conditions, the heat exchangers can be designed economically for a 3°F approach between the entering 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 EER of 15 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. The values can also be used 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. On small systems (<75 tons), the ground loop friction losses are generally less than the plate heat exchanger. For larger systems, these losses are comparable. Since these losses constitute approximately 40% of the total system head loss, the resulting difference in loop pumping energy would amount to plus or minus 10% between groundwater and ground-coupled systems. This would translate into a difference of plus or minus 1% at a system EER of 13 and a loop pump rate of 75 watts/ton.

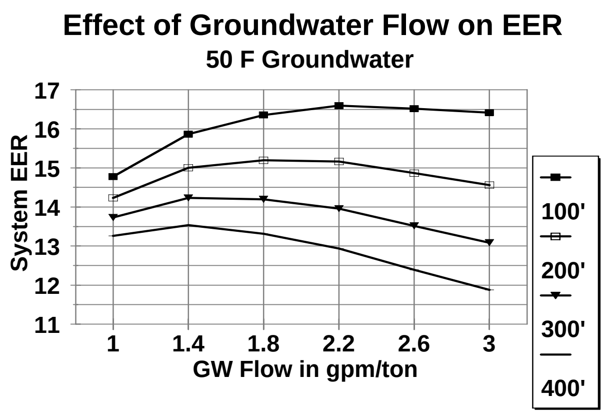

Figure 3. Effect of groundwater (50ºF) flow on EER.

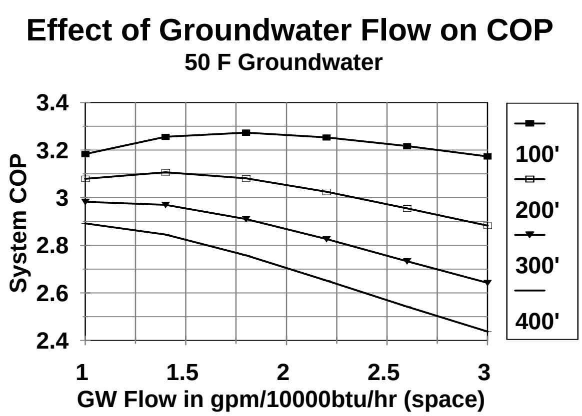

Figure 4. Effect of groundwater (50ºF) flow on COP.

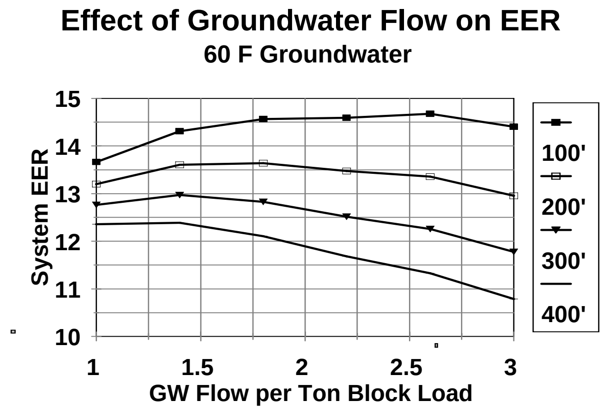

Figure 5. Effect of groundwater (60ºF) flow on EER

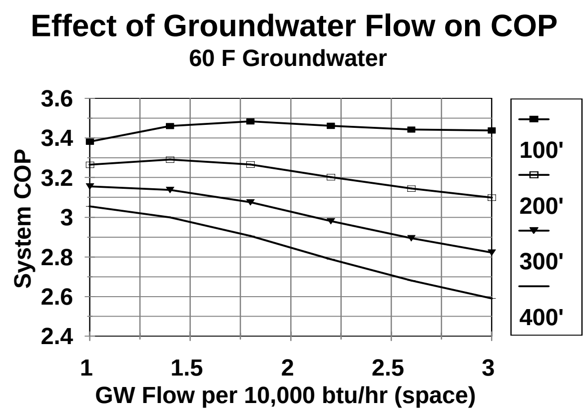

Figure 6. Effect of groundwater (60ºF) flow on COP.

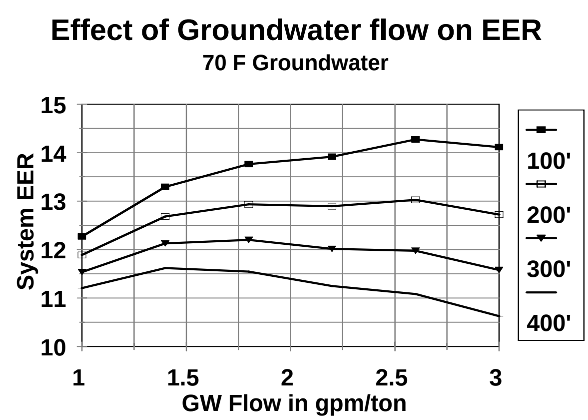

Figure 7. Effect of groundwater (70ºF) flow on EER.

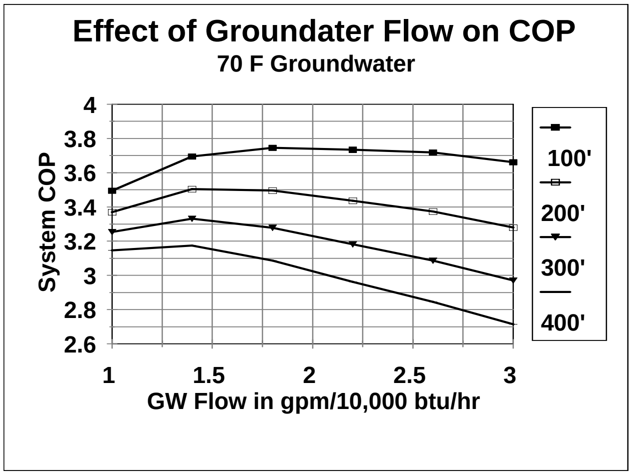

Figure 8. Effect of groundwater (70ºF) flow on COP.

Using a loop pump power consumption of 75 watts/ton, an overall (pump and motor) well pump efficiency of 63% and performance data for moderate efficiency heat pumps (ARI 330 EER 14.1), Figures 3 through 8 provide information on total system performance at various well pump heads and flows.

For low pump head, these curves are very flat, particularly in heating. Although there is a clear optimum point on each curve, in some cases, it may be advisable to operate at flows much less than optimum. For example, consider a 300-ton (peak block) system with 60ºF 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 ($273/yr @ 1000 hr/yr and $0.07/kWh) slightly, the reduced flow would result in much 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. Current guidelines recommend an entering water temperature to the heat pumps of 25ºF (plus or minus 5ºF) above the local undisturbed soil temperature. Using the 25ºF value, and assuming that the undisturbed soil temperature is equal to the local groundwater temperature, appropriate values for heat pump entering water temperatures for ground-coupled system would be 75ºF in the 50 ºF case, 85 ºF in the 60 ºF case and 95ºF in the 70 ºF case. Based on the use of a ARI 330 rated 14.1 EER equipment, heat pump performance (EER) at these temperatures would be 75ºF - 16.8, 85 ºF - 14.9, and 95 ºF - 13.2. System performance for the closed loop system is determined by only the heat pump and loop pump power consumption as 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 the ground-coupled system.

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

The differences between the two system types is small however. At 60ºF 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.

Table 2. Ground-Coupled System Power Requirements - Summary

Soil Temperature	H/P EWT (ºF)	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

CONCLUSIONS

Properly designed groundwater heat pump systems are characterized by peak load performance comparable to, or in some cases superior 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, will be in the range of 1.0 to 2.5 gpm per ton--far less than the typical building loop flow of 2.5 to 3.0 gpm/ton.

REFERENCES

Franklin Electric, 1986. Submersible Motors Application Manual, Franklin Electric.

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