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A Survey of Standing Column Well Installations in North America

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ABSTRACT

Groundwater heat pump systems using standing column wells as their ground heat exchanger can be used as a highly efficient source of heating and cooling in residential and commercial buildings. This paper describes design, installation, and operating practices used in the application of this technology. Attention is given in particular to application of "bleed" strategies—a key parameter in system design and operation. A survey of installations and details of some projects are given. Successful application of standing column wells is dependant on suitable hydrological and geological conditions. Accordingly, the geographical distribution of known systems is reported along with location and hydraulic properties of the different "groundwater regions" of North America.

INTRODUCTION

Groundwater heat pump systems that use groundwater drawn from wells in a semi-open loop arrangement are commonly known as "standing column well" (SCW) systems. The ground heat exchanger in such systems consists of a vertical borehole that is filled with groundwater up to the level of the water table. Water is circulated from the well through the heat pump in an open-loop pipe circuit. Standing column wells have been in use in growing numbers since the advent of geothermal heat pump systems and are recently receiving much more attention because of their improved overall performance in regions with suitable geological conditions.

Standing column well systems share the same advantages, in terms of energy efficiency, environmental benefits, low maintenance, etc., as other forms of geothermal heat pump systems. The heat exchange rate in a standing column well is enhanced by the pumping action, which promotes movement of groundwater to and from the borehole. The higher heat exchange rate and the fact that such systems are open loops means that the fluid flowing through the heat pump system is closer to the mean ground temperature compared to systems with closed-loop U-tube heat exchangers. Diagrams of typical residential and commercial systems are shown in Figure 1.

Historically, most applications of SCWs in North America (for geological and hydrological reasons) have been in the Northeast and Pacific Northwest of the United States and in adjacent parts of Canada. These regions have lower mean ground temperatures and higher heating loads than other areas. Consequently, the SCW design has been focused on heat extraction capacity. Bleeding of the well to induce in-flow of groundwater at more moderate temperatures into the well is a key feature of these well and system designs. Construction differences existing in the reported standing column wells relate in part to the depth of the well rather than any other influencing parameter.

The standing column well is best suited for regions where underground structure is competent rock so that well casing requirements are minimized. In regions where there are multiple aquifers that contain nonpotable water (by Primary Federal Drinking Quality Standards), the aquifers must be cased or grouted off or the well may be unsuitable for reinjection.

A survey of standing column well installations has been conducted by collecting well data from contractors via questionnaires. Data from the returned questionnaires (34 wells at 21 locations) includes the configuration of the wells and pump installation along with flow rates measured at the time of installation. These installations are believed to be representa-

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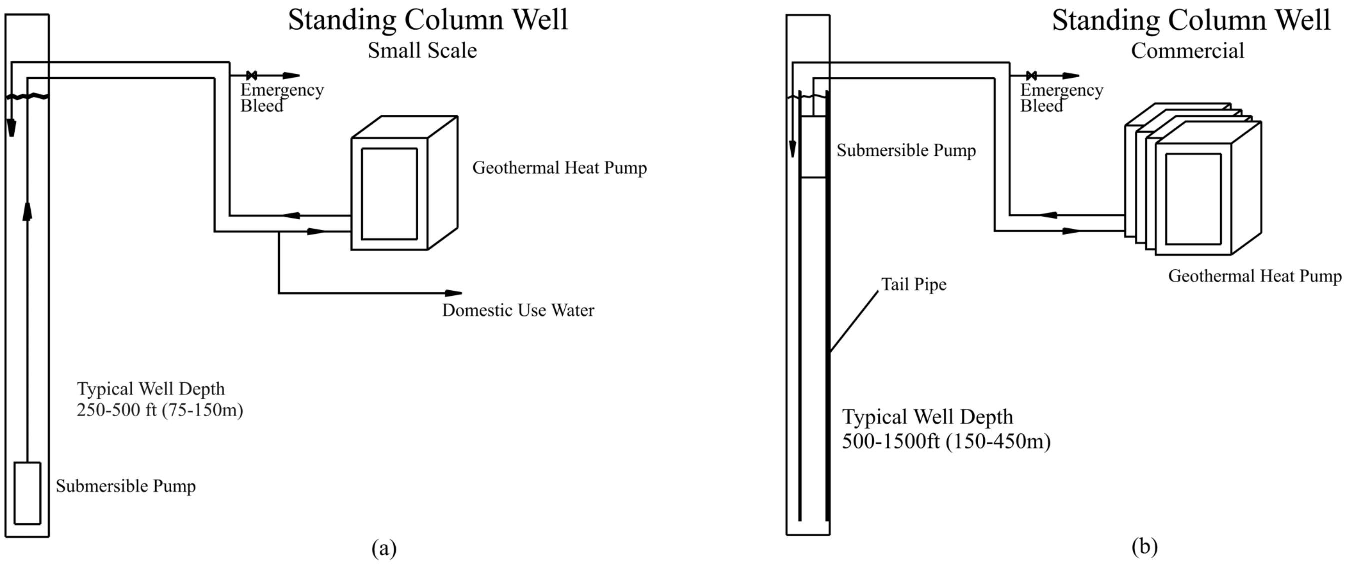

Figure 1 *Diagrams of (a) residential and (b) commercial standing column well systems (Orio 1999).*

tive of current installation practice and geographical distribution. Detailed information has been made available from a few installations in the Northeast of the US. Further details of these designs, operating practice, and measurements of performance are reported. As successful application of standing column well technology is dependant on suitable geology, a survey has been made of the general geological and hydrological characteristics of identifiable “groundwater regions” in North America. The conditions where SCW installations are known to exist are described in further detail.

SURVEY OF STANDING COLUMN WELL INSTALLATIONS

The objective of this study has been to catalog a representative group of SCW locations, designs, and operating practices. The geographical disposition and configuration of SCW installations has been surveyed by means of a questionnaire sent to contractors involved with SCW installation and well drilling. The following types of data have been collected:

- Standing column well construction
- Well depth and diameter
- Drilling conditions
- Pump and pipe arrangement
- Local climate and hydrological and geological conditions
- Operating strategies and characteristics
- Recorded operating data for model validation and case study
- Bleed strategy

All of the sites surveyed in this report are in New England and New York. In these installations, heating requirements generally dominate residential applications while some commercial office buildings might approach cooling-dominant conditions. As a result, the discussion that follows will assume heating load dominance in all cases with the realization that cooling is also a factor.

Well Data

Data from 34 wells at 21 locations have been collected from the questionnaires and are believed to be representative of current installation practice and geographical distribution. Eleven residences and ten commercial/school buildings are included in the study. Samples are located in New England and New York. Massachusetts leads the list with 10 sites. Table 1 is a summary of the collected data. The raw data collected are shown in Tables 2-6.

Standing Column Well Construction

Well diameters are generally 6 in. (150 mm) in bedrock with 8 in. (200 m) steel casing transitioning from the surface into the bedrock. Construction differences existing in the reported standing column wells relate in part to the depth of the well rather than any other influencing parameter. Shallower wells (i.e., depths less than 500 ft (150 m) as a rule have the pump placed near the bottom of the well with the return near the top). Deeper wells (depth greater than 500 ft (150 m) use dip tubes (Porter Shroud) constructed of 4 in. (100 mm) diameter PVC pipe to the bottom of the well). The dip tube has a minimum of 120 one-inch (25 mm) diameter perforations at 20-60 ft (6-18 m) from the bottom. The tube permits shorter

Table 1. Summary of Collected Well Data

		Residential[*]		Commercial	
	Units	Range	Median	Range	Median
Installed capacity	Tons (kW)	5-15 (17.6-52.8)	7.7 (27.1)	10-100 (35.2-352)	57 (200.6)
Well depth	Ft (m)	240-900 (73-274)	518 (158)	600-1500 (183-457)	1238 (377)
Depth/capacity	Ft/ton (m/kW)	32.2-85 (2.8-7.4)	59 (5.1)	30-65.5 (2.6-5.7)	49 (4.2)
Static water level.	Ft (m)	3-120 (1-37)	48 (15)	16-40 (5-12)	20 (6)

[*] Over 90% of the residential applications use the same well for domestic water and, hence, naturally provide supplemental bleed effects.

Table 2. Standing Column Well Field Data

Site	Units	New England Quilt Museum, Lowell, MA	Hastings School, Westborough, MA	Apartments, Saugus, MA	Halibut Point State Park, Rockport, MA
System capacity	Tons (kW)	60 (211)	200 (703.4)	63 (221.6)	6.5 (22.9)
Number of wells	–	2	6	4	1
Depth	Ft (m)	1040, 855 (317, 261)	1500 (457)	3@1100,650 (3@335, 198)	480 (146)
Location of pump	Ft (m)	50 (15.2)	110 (33.5)	50 (15.2)	100 (30.5)
Length/capacity	Ft/Ton (m/kW)	30 (2.6)	44 (3.8)	59.5 (5.2)	65.5 (5.7)
Diameter of wells	In. (mm)	6 (150)		6 (150)	6 (150)
Static water level	Ft (m)	20 (6.09)	6-10 (1.8-3.05)	20-25 (6.09-7.6)	29 (8.8)
Total yield@drawdown	GPM@Ft (L/s@m)	75 (4.7)	7@100 (0.44@30.4)	1.5@4 (0.09@1.2)	–
Depth to bedrock	Ft (m)	25-28 (7.6-8.5)	82-85 (24.9-25.9)	10-31 (3.05-9.4)	–
Type of overburden	–	–	–	–	–
Type of bedrock	–	–	–	Lt/Dk Grey	–
Well pump	HP (kW)	5 (3.7)	5 (3.73)	2 (1.49)	3/4 (0.56)
Pumping power/capacity	HP/ton (W/kW)	0.167 (17.7)	0.15 (5.3)	0.095 (6.7)	0.11 (24.5)
Well log?	–	Yes	Yes		Yes

Table 3. Standing Column Well Field Data

Site	Units	Maine Inn Main #2, Scarborough, ME	Haverhill Library, Haverhill, MA	Maine Audubon, Falmouth, ME	Hanscom AFB, Bedford, MA
System capacity	Tons (kW)	38.5 (135.4)	110 (386.9)	15 (52.8)	10 (35.2)
Number of wells	–	1	4	1	1
Depth	Ft (m)	1500	1500	600	650
Location of pump	Ft (m)	120 (36.6)		100 (30.5)	50 (15.2)
Length/capacity	Ft/Ton (m/kW)	37.9 (3.3)	53.3 (4.6)	36.7 (3.2)	59.5 (5.2)
Diameter of wells	In. (mm)	6 (150)	6 (150)	6 (150)	6 (150)
Static water level	Ft (m)	10 (3.05)	40 (12.2)	25 (7.6)	10 (3.05)
Total yield@drawdown	GPM@Ft (L/s@m)	15 (.94)	7@15 (.44@4.5)	–	30 (1.9)
Depth to bedrock	Ft (m)	11 (3.4)	22-23 (6.7-7.0)	–	30 (9.1)
Type of overburden	–	Clay, gravel	–	–	Clay
Type of bedrock	–	–	–	–	Med gray
Well pump	HP (kW)	0.6 (0.45)	5 (3.73)	2 (1.5)	1 (0.75)
Well pumping power/ HP capacity	HP/ton (W/kW)	0.08 (3.3)	0.18 (9.6)	0.13 (28.3)	0.1 (21.2)
Well log?	–	Yes	yes	no	yes

Table 4. Standing Column Well Field Data

Site	Units	Apartments, Cambridge, MA	Residence, Raymond, ME	Residence, Uxbridge, MA	Residence, Raymond, ME
System capacity	Tons (kW)	10 (35.2)	7 (24.6)	5 (17.6)	10 (35.2)
Number of wells	–	1	1	1	1
Depth	Ft (m)	650 (198)	750 (229)	240 (73)	520 (159)
Location of pump	Ft (m)	50 (15.2)	100 (30.5)	220 (67.1)	60 (18.3)
Length/capacity	Ft/Ton (m/kW)	59.5 (5.2)	85 (7.4)	39 (3.4)	50.5 (4.4)
Diameter of wells	In. (mm)	6 (150)	6 (150)	6 (150)	6 (150)
Static water level	Ft (m)	30 (9.1)		20 (6.09)	15 (4.6)
Total yield@drawdown	GPM@Ft (L/s@m)	6 (.37)	8 (.5)	5 (.31)	50 (3.2)
Depth to bedrock	Ft (m)	70 (21.3)	–	–	–
Type of overburden	–	–	–	–	–
Type of bedrock	–	Med gray	–	–	–
Well pump	HP (kW)	1 (0.75)	–	1 (0.75)	3 (2.24)
Well pumping power/ HP capacity	HP/ton (W/kW)	0.1 (21.2)	–	0.2 (42.4)	0.3 (63.6)
Well log?		Yes	–	No	Yes

Table 5. Standing Column Well Field Data

Site	Units	Residence, Carlisle, MA	Residence, Okimo Mt, VT	Residence, N. Easton, MA	Residence, Windham, NH
System capacity	Tons (kW)	6 (21.1)	15 (52.8)	5 (17.6)	7.5 (26.4)
No. of wells		1	1	1	1
Depth	Ft (m)	425 (130)	900 (274)	460 (140)	545 (166)
Location of pump	Ft (m)	75 (22.9)	75 (22.9)	420 (128.0)	525 (160)
Length/capacity	Ft/Ton (m/kW)	60.8 (5.3)	55 (4.8)	77 (6.7)	54.8 (4.8)
Diameter of wells	In. (mm)	6 (150)	6 (150)	6 (150)	6(150)
Static water level	Ft (m)	35 (10.7)	50 (15.2)	50 (15.2)	109 (33.2)
TTL yield@drawdown	GPM@Ft (L/s@m)	–	–	–	27@122 (1.7@37.2)
Depth to bedrock	Ft (m)	–	–	–	–
Type of overburden	–	–	–	–	–
Type of bedrock	–				–
Well pump	HP (kW)	2 (1.5)	2 (1.5)	3/4 (.56)	–
Well pumping power/ HP capacity	HP/ton (W/kW)	0.33 (70.7)	0.13 (28.3)	0.15 (31.8)	–
Well log?	–	No	No	Yes	–
Note	–	–	–	No Porter	No Porter

Table 6. Standing Column Well Field Data

Site	Units	Maine Cottages, Scarborough, ME	Maine Blackport Inn, Scarborough, ME	Residence, Rye, NH	Residence, Tapsham, ME
System capacity	Tons (kW)	26.5 (93.2)	200 (703.4)	10 (35.2)	5 (17.6)
No. of wells	–	1	4	1	1
Depth	Ft (m)	1500 (457)	1500 (457)	350 (107)	510 (155)
Location of pump	Ft (m)	220 (67.1)	120 (36.6)	25 (7.6)	490 (149.4)
Length/capacity	Ft/Ton (m/kW)	55.0 (4.8)	37.5 (3.3)	32.2 (2.8)	73 (6.3)
Diameter of wells	In. (mm)	6 (150)	6 (150)	6 (150)	6 (150)
Static water level	Ft (m)	15 (4.6)	15 (4.6)	3 (.91)	120 (36.6)
Total yield@drawdown	GPM@Ft (L/s@m)	12 (.76)	30 (1.9)	30@0 (1.9@0)	1@120 (0.06@36.6)
Depth to bedrock	Ft (m)	11 (3.4)	9 (2.7)	–	–
Type of overburden	–	Clay, gravel	Clay, gravel	–	–
Type of bedrock	–	–	–	–	–
Well pump	HP (kW)	1 (.75)	0.6 (0.45)	–	–
Well pumping power/ HP capacity	HP/ton (W/kW)	0.19 (8.0)	0.08 (0.6)	–	–
Well log?	–	Yes	Yes	No	–

riser pipes, shorter well pump power wiring, and more convenient access for well pump service. The pump and return pipe end are located near the top of the well, taking into account draw-down depths at bleed flow rates between 2% and 25% of the total heat pump flow. The return pipe end is positioned to be below the static level at all operating conditions. The pump is positioned to have the required net positive suction head at all operating conditions, including at higher temperatures in cooling.

Supply and return lines are sized to approximately 5 ft/s (1.5 m/s) to minimize flow noise and friction pressure drop. It is customary practice to thermally segregate the supply and return lines with a single layer of polystyrene foam between them before burying the pair in 5-6 in. (125-150 mm) of sand. A two pit-less adapter arrangement is employed to allow easy removal of the pump for periodic inspection. During the drilling process, the well contractor will be aware of "high," "medium," or "low" well yields. A decision is made with the owner's consent as to the amount of bleed to apply, accounting for identifying a responsible discharge location. The final well depth (recirculation length) is thus determined. A margin of design safety is used in this determination. When the well is completed, a 24- to 48-hour drawdown test is conducted at the bleed rate that conforms to the final well design and configuration.

A conventional submersible well pump of sufficient capacity to provide the water-source heat pumps 3 gpm/ton (132 L/s·W) at a head that encompasses the static head under operating conditions, pipe valve and fitting losses and the pressure provided to the heat pumps (usually 20 psig [135kPa]).

Many residential applications utilize the standing column well for domestic water supply purposes as well as source water for heat pump operation. This generally involves the management of a two-pressure system (higher pumping pressures are necessary for domestic water use) and is often equipped with a variable speed driven, submersible well pump. Typically annual running time is divided between heating and cooling full-load hours between 2800 and 3400 hours. Much of the above tabular data have full-load heating in the 1500-2300 hour range, the balance being the cooling hours.

Operating Strategies and Characteristics

If freezing of the system is a concern (e.g., entering water temperatures less than 38°F [3.8°C]), then "bleeding" the well can be used to moderate peak temperature swings. In the bleeding process, some fraction of the system flow is diverted to another well (or just disposed of) and the flow returning to the well is reduced. This has the effect of drawing more groundwater into the well from farther away to make up the flow. This always has the effect of moderating the well temperature. Bleed can similarly be used to lower the peak temperature in heat rejection mode if necessary. If the well is also used for domestic purposes (purely water extraction) this naturally bleeds the system.

The combination of relatively shallow water table and a deep well (some times greater than 1000 ft or 300 m) means that the well has a large water volume, about 150 gal per 100 ft (1800 L/100 m) for a 6 in. (150 mm) nominal diameter well (Sachs and Dinse 2000). Based on previous experience (Orio 1988, 1994, 1995), 50 to 60 feet of water column is needed per ton of building load (4.3 m/kW to 5.3 m/kW).

An open well design requires careful analysis and management of the water flow from the pump through the heat pump and back to the well. Pumping energy is minimized if water flow and pressure are managed to the lowest values required. Self-regulating flow control valves are recommended and used on all sites, minimizing the requirement for individually flow-balancing the equipment.

Bleed Flow

In colder climates, such as New England, where heating represents the dominant comfort conditioning load, and lower groundwater temperatures prevail, the use of a predetermined periodic small bleed flow rate to increase well water temperature on command by advective groundwater flow is often essential and can save the owner drilling costs. On design or near design days, the heat pumps can run at full capacity for as much as 20-24 hours continuously. To prevent extreme water temperature depression during space heating operation and consequent freezing of the heat pump heat exchanger, a bleed flow of well water can be called into function to restabilize the source water to a higher temperature. In southern climates or large commercial applications where the dominant load is cooling, the bleed is also employed to provide lower water column temperatures.

Specification of the correct bleed flow is essential for successful automatic operation of the system. If bleed at higher rates, e.g., approximately 30%, can be responsibly returned to the ground, it may allow the designer to reduce water recirculation lengths and consequent bore hole depths by as much as 65%. At higher bleed rates, a pressure-sustaining valve at the return to the well helps maintain adequate pressure for the bleed over a wider flow range. The safe amount of bleed flow to prevent equipment freeze-up can be estimated given assessment of the local geological characteristics. Measuring the well temperature drop while running continuously for an extended period of time, with a specific bleed rate, yields useful data for these purposes. Although application of these empirical methods has been shown to be effective, it is desirable that design methods based on validated models be introduced. It is hoped that the data collected in this work and detailed modeling studies (Spitler et al. 2004) may result in suitable models and optimum design methods.

Multiple Standing Column Well Systems

Some large systems, greater than 30-40 tons (100-140 kW), require more than one standing column well to achieve the required ground heat exchange. These larger systems typically will employ multiple heat pumps, zoned or staged in a diversified manner. The most efficient design of groundwater supply employs variable-speed well pump technology to control the pressure at the inlet of the heat pumps.

Single well systems return the water to the well at the same volume pumped out, thus maintaining the water level in the well constant. This is not so in multiple well systems. Even careful design and balancing will not return precisely the same volume as was removed. Most multiple well systems are now arranged so that the pumps are powered from individual variable frequency drives (VFD) in master/slave arrangement to drive all pumps with the same frequency and nearly the same flow. Returning equal flow volumes requires adjusting the return manifold pressure (by throttling a return balance valve) to a desired value while operating each well alone at a defined flow rate. When all wells are run at the set throttling valve positions, the wells will be nearly balanced. With automatic flow control valves on the heat pumps, their nameplate control settings can be used to estimate the flow. Most wells will absorb some overflow, so a minor mismatch will not be a problem.

INSTALLATIONS WITH DETAILED OPERATING DATA

Three sites with detailed installation and operating data were identified in the survey. Some of these sites have monitored data that may support validation of computer models. This information could also be used to aid in development of formal design procedures.

Maine Audubon Visitor's Center

Installed in 1996, this 5400 ft^2 (520 m^2) building has 15 tons (52.8 kW) of water-to-water heat pumps connected to radiant floors and fan coils throughout the building. The three heat pumps source from a single 600 ft (180 m) standing column well. At its inception the well pump was controlled by a pressure switch and fed a pair of large accumulator tanks to minimize cycling. A constant (with HPs running) bleed (of unknown quantity) to a duck pond was used.

In the winter of 1999-2000 the system was upgraded to incorporate a variable-speed drive on the well pump, building water temperature reset, and an automatic bleed system in an effort to increase efficiency. The automatic bleed system installed was found to be inadequate due to excessive resistance to flow caused by an overly restrictive solenoid valve and spring loaded flow meter. The constant bleed was restored and set at about 33% flow (13.5 gpm [0.85 L/s] under maximum load conditions). No problems have been reported relating to dangerously low well water temperatures. In mid-March 2001 after a full season, the well water temperature was 49°F-50°F (9.4-10°C) while in January readings of 43°F-46°F (6.1-7.8°C) were recorded, indicating the bleed could have been set somewhat lower, but at this site it is not a problem since water runoff promotes wildlife activity in the immediate area, a desirable side benefit.

Residence, Raymond, ME

This building is a 4000 ft^2 (370 m^2.) residence with seven tons of heat pump capacity (Logan 2001). The resident is on a time-of-day electric utility rate with a cost of \$0.26/KWh weekdays from 7 a.m. to noon and 4 p.m. to 8 p.m. and all other times at \$0.05/KWh. A switch to lower the control temperature locking out the heat pumps during peak rate times has been successfully employed. This is possible due to the higher thermal mass of the floor radiant heating system. A diagram of the system is shown in Figure 2.

The standing column well is 700 ft (213 m) deep with an effective length of 600 ft (180 m) or approximately 85 ft/ton (7.4 m/kW). The bleed is set to 4.8% (1.0 gpm [0.063 L/s]) and is operated by a thermostat with a setting of 42°F (5.6°C) open, 47°F (8.3°C) close. Figure 3 shows the well water temperature, outside air temperature, and bleed time expressed as a percentage of running time. Data were collected by the resident every Sunday at 7 a.m. and 8 p.m. and averaged. Total running time for the system annually in heating is 1800 hours and, compared to normal expected heating hours (2600), the system is about 25% oversized. As can be seen in Figure 3, the heaviest bleed occurs in the three months of January,

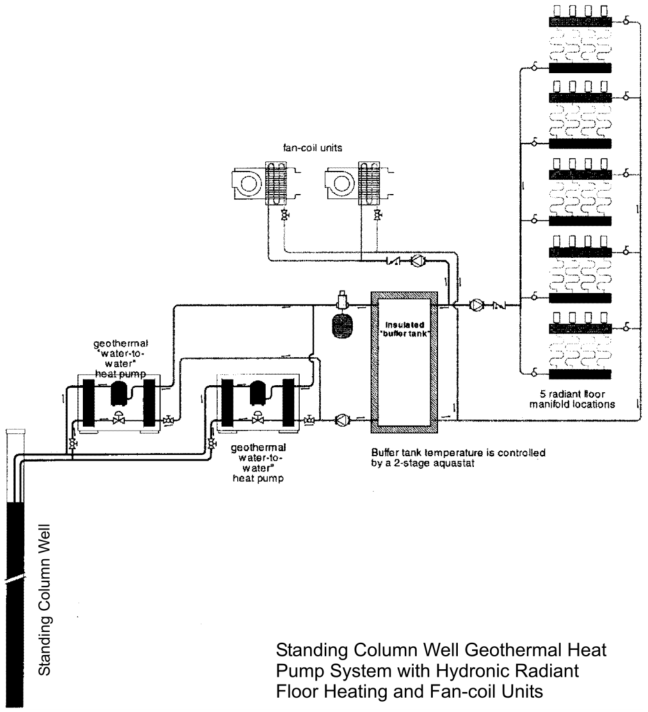

Figure 2 *A diagram of the standing column well and radiant floor heating system for the residential installation at Raymond, Maine. The radiant floors consist of 211 m^2 (2,300 ft^2) of 100 mm (4 in.) thick and165 m^2 (1800 ft^2) of 50 mm thick high-density concrete floor construction (Logan 2001).*

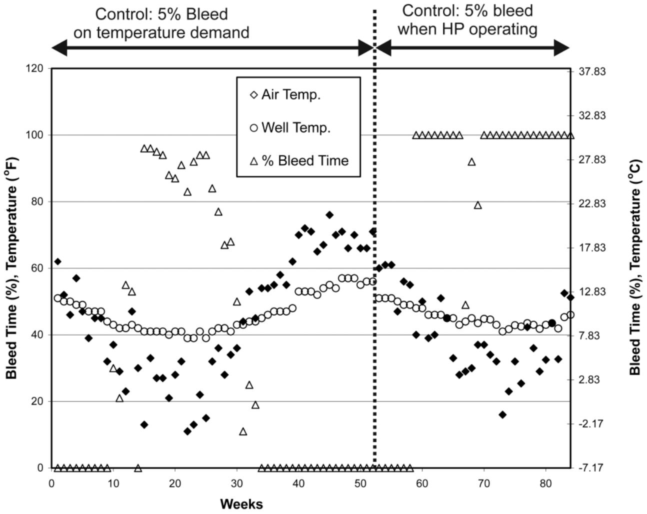

Figure 3 *Well and air temperatures plotted with percentage time bleed for the residential installation at Raymond, Maine. Control of the bleed was initially at 5% according to demand (temperature setpoint) and later at 5% whenever the heat pump was operating (Logan 2001).*

February, and March. Total annual bleed flow was calculated to be 63,500 gal (340 m^3) or about 12,500 gal (47 m^3) per year per load ton.

Hotel, Scarborough, ME

The hotel consists of three buildings containing 150 guest rooms, kitchen, dining rooms, and conference meeting rooms with a mixture console and unitary ground-source heat pumps. No central DDC control/monitoring system is installed, as each unit has its own thermostat and overall water flow is regulated on demand by variable-speed drives powering the well pumps under PID control at 20 psig pressure. When originally installed, the control method sequenced the wells on and off as demand varied. Difficulty was encountered managing the return flow to the proper well and some wells were getting more operating time than others. The owner asked to change the control strategy to master-slave—slave driving all wells at the same frequency and nearly the same flows. Once the return flows are balanced, they deliver nearly equal flows to each well.

GEOLOGICAL AND HYDRO-GEOLOGICAL CHARACTERISTICS OF SCW INSTALLATIONS

Heat transfer around SCWs takes place by both conductive and advective[1] processes. Conductive heat transfer is proportional to temperature gradient according to thermal conductivity. Advective heat transfer is driven by the flow of groundwater and is proportional to head gradient according to hydraulic conductivity. Pumping action primarily draws flow down the borehole in the annular space between the dip tube and borehole wall. Pumping action also induces recirculation of groundwater from higher to lower levels (given the discharge is at the top of the well) of the rock surrounding the borehole. In bleed conditions additional groundwater (at more moderate temperatures) is drawn into the bottom of the well from the surrounding rock. Buoyancy additionally promotes groundwater flow, even when the pump is not operating.

Both the thermal and hydrological properties of the geological formation are, therefore, important when considering the feasibility and design of SCW systems. It is, in addition, necessary to evaluate the quality of the water available, as poor quality may require additional equipment (e.g., plate frame heat exchangers) and can lead to maintenance difficulties. The Langelier Saturation Index (LSI, or saturation index, a measure of scaling) should be computed for all open well systems including SCW (see Rafferty 2004).

Groundwater Regions of North America

Recognizing the variability of hydraulic and thermal properties of various soils and rock types, it is important to know where they occur. The concept of "groundwater regions" is useful in summarizing the spatial variability of geologic and hydrogeological conditions. In the context of SCWs, this allows a general comparison between regions of known operating installations to those that have not yet been explored. Heath (1984) produced a classification scheme that is widely cited in the literature. Heath's scheme is based on the following items of groundwater systems:

- the components of the system and their arrangement,
- the nature of the water-bearing openings (porous or fractured),
- the mineral composition of the rock matrix,
- the hydraulic properties of the dominant aquifers, and
- the nature and location of recharge and discharge areas

Heath (1988) divided North America into 28 groundwater regions (Figure 4), which appears to be a useful means to generalize the hydrogeology of SCW installations. Discussion of soil and rock hydraulic and thermal properties, typical parametric values, and their importance in the determination of groundwater flow around ground heat exchangers can be found in Chiasson (2002). Material relating to groundwater regions, drilling methods, and state by state regulations are further referenced in Sachs (2000) and DenBraven (2001).

Standing column wells (SCW) have been categorized by the US Environmental Protection Agency (EPA) as diversion and reinjection wells. Geothermal heat pump groundwater use is identified as "non-contact cooling water, Class V UIC (Underground Injection Control), type 5A7 for geothermal heating and cooling."

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[1] Also termed "convection" in some contexts. We use the term *advection* to avoid confusion with convective heat transfer.

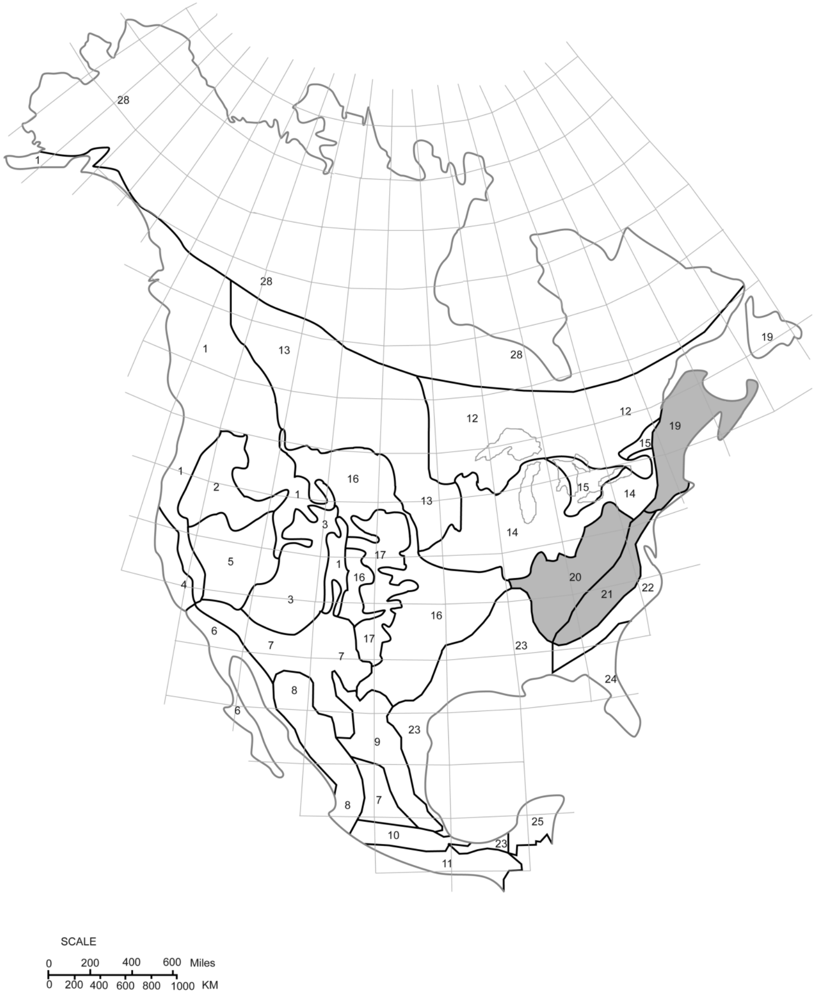

Figure 4 *Groundwater regions of North America. Source: Heath (1988). Regions with documented standing column wells are shown shaded. Key to regions on following pages.*

State and local codes vary and most require notification (what are you doing?) and permits (to allow). In the states listed in this report, notification or permits were not required for domestic home applications; diversion notification was required for small commercial applications, up to 60-80 tons (281.6). For larger systems, both a notification and a permit application may be required.

Class V reinjection waters must meet primary federal drinking water quality standards. These standards have relatively wide tolerances for dissolved solids and salts but allow no tolerance for fecal coliform bacteria. A properly cased well specifically separates surface water from deep groundwater. Surface water typically contains bacteria, volatile organic compounds (VOC), and various road runoff pollutants. Surface water or water not meeting the federal drinking quality cannot be allowed to mix with groundwater.

REGIONS WITH STANDING COLUMN WELL INSTALLATIONS

Northeastern Appalachians Region

The majority of currently known SCWs exist in the northeastern Appalachians region (Region 19, Figure 4). This region includes the states of Maine, Massachusetts, New Hampshire, New York, northwestern New Jersey, and also portions of southeastern Canada. Existing information implies that each of these is installed in igneous or metamorphic rock.

The northeastern Appalachians region is a hilly to mountainous region characterized by glacial deposits underlain by igneous and metamorphic rocks. The glacial deposits are typically 10 ft (3 m) to 30 ft (9 m) thick (Randall et al. 1988). The water table position commonly rises to within 6.5 ft (2 m) of the land surface each spring in the upland areas (Randall et al.

Key to Figure 4, Groundwater Regions of North America; Areas 19, 20, and 21 Have Known SCW Installations

Region	Hydrogeoloic Situation*	Common RAnges in Hydraulic Characteristics of the Dominant Aquifers							
		Transmissivity		Hydraulic Conductivity		Recharge Rate		Well Yield	
		(ft^2/day)	(m^2/day)	(ft/day)	(m/day)	(in./yr)	(mm/yr)	(gpm)	(m^3/min)
1. Western Mountain Ranges	Mountains with thin soils over fractured rocks alternating with valleys underlain by alluvial and glacial deposits.	5-5,382	0.5-500	0.03-66	0.01-20	0.1-2	3-50	13-264	0.05-1
2. Columbia Lava Plateau	Low mountains and plains with thin soils over thick lava sequences interbedded with unconsolidated deposits.	21,528-5.38E+06	2,000-500,000	3.28-9,843	1-3,000	0.2-10	5-250	238-47,551	0.9-180
3. Colorado Plateau and Wyoming Basin	A region of canyons, cliffs, and plains of thin soils over fractured sedimentary rocks.	5-1,076	0.5-100	0.03-16	0.01-5	0.1-2	3-50	13-528	0.05-2
4. Central Valley and Pacific Coast Ranges	Relatively flat valleys of thick alluvial deposits bordered along the coast by low mountains composed of semiconsolidated sedimentary rocks and volcanic deposits.	108-107,639	10-10,000	98.43-1,969	30-600	0.4-4	10-100	132-5,283	0.5-20
5. Great Basin	Alternating flat basins of thick alluvial deposits and short, subparallel mountain ranges composed of crystalline and sedimentary rocks.	108-107,639	10-10,000	32.81-1,640	10-500	0.2-2	5-50	132-2,642	0.5-10
6. Coastal Alluvial Basins	Relatively flat valleys of thick alluvial deposits separated by mountain ranges composed of volcanic, metamorphic, and sedimentary rocks.	108-10,764	10-1,000	16.40-328	5-100	0.2-2	5-50	132-2,642	0.5-10
7. Central Alluvial Basins	Relatively flat valleys of thick alluvial deposits separated by discontinuous mountain ranges composed of volcanic, metamorphic, and sedimentary rocks.	108-21,528	10-2,000	32.81-656	10-200	0.2-2	5-50	132-2,642	0.5-10
8. Sierra Madre Occidental	Thin regolith over a complex sequence of volcanic rocks.	1,076-107,639	100-10,000	32.81-1,640	10-500	0.4-4	10-100	132-5,283	0.5-20
9. Sierra Madre Oriental	Mountain ranges and valleys underlain by a thin regolith over sedimentary rocks.	108-10,764	10-1,000	3.28-164	1-50	0.2-2	5-50	132-1,321	0.5-5
10. Faja Volcanica Transmexicana	Mountainous area underlain by thin regolith over a complex sequence of volcanic rocks.	1,076-107,639	100-10,000	32.81-1,640	10-500	0.4-4	10-100	132-5,283	0.5-20
11. Sierra Madre Del Sur	Mountainous area underlain by thin regolith over metamorphic, sedimentary, and volcanic rocks.	54-53,820	5-5,000	3.28-984	1-300	0.4-4	10-100	26-2,642	0.1-10
12. Precambrian Shield	Hilly terrance underlain by glacial deposits over metamorphic rocks.	108-5,382	10-500	0.33-98	0.1-30	0.4-12	10-300	26-264	0.1-1
13. Western Glaciated Plains	Hilly plains underlain by glacial deposits over sedimentary rocks.	269-26,910	25-2,500	0.66-328	0.2-100	0.2-8	5-200	53-528	0.2-2
14. Central Glaciated Plains	Area of diverse topography, ranging from plains in Iowa to the Catskill Mountains in New York, underlain by glacial deposits over sedimentary rocks.	1,076-21,528	100-2,000	6.56-984	2-300	0.2-12	5-300	53-528	0.2-2
15. St. Lawrence Lowlands	Hilly area underlain by glacial deposits over sedimentary rocks.	1,076-21,528	100-2,000	6.56-984	2-300	0.2-12	5-300	53-528	0.2-0

Key to Figure 4, Groundwater Regions of North America; Areas 19, 20, and 21 Have Known SCW Installations *(continued)*

Region	Hydrogeoloic Situation[*]	Common RAnges in Hydraulic Characteristics of the Dominant Aquifers							
		Transmissivity		Hydraulic Conductivity		Recharge Rate		Well Yield	
		(ft^2/day)	(m^2/day)	(ft/day)	(m/day)	(in./yr)	(mm/yr)	(gpm)	(m^3/min)
16. Central Non-Glaciated Plains	Plains underlain by thin regolith over sedimentary rocks.	3,229-107,639	300-10,000	9.84-984	3-300	0.2-12	5-300	106-2,642	0.4-10
17. High Plains	Plains underlain by thick alluvial deposits over sedimentary rocks.	10,764-1.1E+05	1,000-10,000	6.56-328	2-100	0.0-6	1.150	106-2,642	0.4-10
18. Alluvial Valleys	Thick deposits of sand and gravel, in places interbedded with silt and clay, underlying floodplains and terraces of streams.	2,153-538,196	200-50,000	98.43-6,562	30-2,000	2.0-20	50-500	106-5,283	0.4-20
19. Northeastern Appalachians	Hilly to mountainous area underlain by glacial deposits over fractured metamorphic and igneous rocks.	538-5,382	50-500	0.98-164	0.3-50	1.2-12	30-300	26-528	0.1-2
20. Appalachian Plateaus and Valley and Ridge	Hilly to mountainous area underlain by thin regolith over sedimentary rocks.	3,229-107,639	300-10,000	9.84-984	3-300	0.2-16	5-400	106-2,642	0.4-10
21. Piedmont and Blue Ridge	Hilly to mountainous area underlain by thick regolith over fractured metamorphic and igneous rocks.	108-2,153	10-200	0.33-7	0.1-2	1.2-12	30-300	26-264	0.1-1
22. Atlantic and Eastern Gulf Coastal Plain	Low-lying plain of thick interbedded sand, silt, and clay deposits overlying sedimentary rocks.	5,382-107,639	500-10,000	16.40-328	5-100	2.0-20	50-500	132-5,283	0.5-20
23. Gulf of Mexico Coastal Plain	Low-lying plain of thick interbedded sand, silt, and clay deposits.	5,382-107,639	500-10,000	16.40-328	5-100	2.0-20	50-500	132-5,283	0.5-20
24. Southeastern Coastal Plain	Low-lying area of thick layers of sand and clay over semiconsolidated carbonate rocks.	10,764-1.1E+06	1000-100,000	98.43-9,843	30-3,000	1.2-20	30-500	1,321-13,209	5-50
25. Yucatan Peninsula	Low-lying area of thin regolith over semiconsolidated carbonate rocks.	5,382-53,820	500-5,000	32.81-1,640	10-500	0.8-8	20-200	132-1,321	0.5-5
26. West Indies	Hilly and mountainous islands of igneous and volcanic rocks, overlain by thin regolith.	1,076-1.1E+05	100-10,000	9.84-984	3-300	0.2-12	5-300	26-2,642	0.1-10
27. Hawaiian Islands	Mountainous islands of complex volcanic rocks, overlain by thin regolith.	1.1E+05-1.1E+06	1.0E+04-1.0E+05	656.17-9,843	200-3,000	1.2-39	30-1000	106-5,283	0.4-20
28. Permafrost Region	Glacial deposits, perennially frozen, overlying fractured igneous, metamorphic, and sedimentary rocks.	108-21,528	10-2,000	32.81-656	10-200	0.2-4	5-100	3-528	0.01-2

[*] An average thickness of about 5 m (16.4 ft) was used as the break point between thin and thick.

1988), but in parts of Atlantic Canada, where the bedrock is more permeable, the glacial deposits may remain unsaturated all year. According to the US Geological Survey (1995), groundwater movement in this region is totally dependent on secondary openings (fractures) in the bedrock; intergranular porosities are so small (0.7% to 2.8%) they can be considered insignificant. A brief description of the aquifers and well characteristics found in them are summarized in Table 7.

Groundwater chemical quality (the level of total dissolved solids in particular) is an important consideration for heat pumps and pumping equipment. Water in the crystalline rock aquifers is generally suitable for most uses because crystalline rocks generally are composed of virtually insoluble minerals.

Appalachian Plateaus and Valley and Ridge Region

A number of SCWs have been identified in the Appalachian plateaus and valley and ridge region (Region 20, Figure 4). This region includes the states of Pennsylvania, West Virginia, eastern Kentucky, eastern Tennessee, and northeastern Alabama. This includes the SCW at Pennsylvania State University (described by Mikler [1993]) and one at Kutztown, Pennsylvania. According to Mikler (1993), the test well at Pennsylvania State University is installed in limestone. Existing information suggests that the Kutztown well is also installed in carbonate rock. Other installations found in the survey include several in Kentucky and one in Alabama.

The Appalachian plateau and valley and ridge region is a hilly to mountainous region characterized by thin regolith underlain by sedimentary rocks. According to the U.S. Geological Survey (1997), the principal aquifers are the carbonate aquifers, primarily limestone, and sandstone aquifers. Groundwater flow is controlled by the presence of fractures in all aquifers as well as solution channels in carbonate aquifers. Limestone aquifers of the Waynesboro Formation in central Pennsylvania produce well yields reported to range from 25 to 210 gallons per minute. In contrast, well yields from sandstone in this area only range from 10 to 30 gallons per minute.

Groundwater quality in this region is reported to be suitable for municipal supplies and other purposes (U.S. Geological Survey 1997). Due to the solubility of carbonate rocks, these aquifers generally contain very hard water.

Piedmont and Blue Ridge Region

A number of SCWs have been identified in the Piedmont and Blue Ridge region (Region 21, Figure 3.2, Table 4). This region includes southern New Jersey, western Virginia, western North Carolina, western South Carolina, and northern Georgia. Of these states, several wells are known in New Jersey and some indicated (but not verified) in North Carolina.

Table 7. Aquifers of the Northeastern Appalachian Region[*]

State	Aquifer Description	Well Characteristics			
		Depth, ft (m)		Well Yield, gpm (L/s)	
		Common Range	Might Exceed	Common Range	Might Exceed
New York	Igneous and metamorphic rocks, generally confined	25-400 (7.6-122)	600 (183)	1-120 (0.06-7.6)	180 (11.4)
Connecticut	Gneiss and schist with some other metamorphic and igneous rock types. Generally unconfined in the upper 200 feet, might be confined at depth.	10-300 (3-91)	500 (152)	1-25 (0.06-1.6)	200 (12.6)
Maine	Igneous rocks include granite, gabbro, diorite, granodiorite, and pegamatite. Metamorphic rocks include schist, gneiss, quartzite, slate, and argillite. Locally confined at depth.	20-500 (6-152)	800 (244)	2-10 (0.12-0.6)	500 (32)
Massachusetts	Igneous and metamorphic rocks, predominantly gneiss and schist, confined.	100-400 (30-122)	1000 (30.5)	1-20 (0.06-1.2)	300 (20)
New Hampshire	Igneous and metamorphic rocks, generally confined.	100-600 (30-183)	800 (244)	1-10 (0.06-0.6)	100 (6.3)
Rhode Island	Indurated to metamorphosed sedimentary rocks in the vicinity of Narragansett Bay; igneous and metamorphic rocks, chiefly granite and gneiss, elsewhere.	100-300 (30-91)	500 (152)	1-20 (0.06-0.12)	50 (3.2)
Vermont	Igneous, metasedimentary, and metavolcanic rocks, generally confined.	100-600 (30-183)	800 (244)	1-10 (0.06-0.6)	100 (6.3)

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[*] Source: US Geological Survey (1995).

The Piedmont and Blue Ridge region is a hilly to mountainous region characterized by thick regolith (weathered rock) underlain by igneous and metamorphic rocks. It is geologically similar to the northeastern Appalachian region, except that it has not been glaciated. The regolith ranges in thickness from a feather to 131 ft (40 m) and the water table generally occurs near land surface in valleys and at depths of 26 ft (8 m) to 66 ft (20 m) in hilly areas (LeGrand 1988). Sustained well yields range from about 5 to 105 gpm (0.3-6.6 L/s) (LeGrand 1988). Groundwater in the crystalline rocks of this region is reported to be soft and of a quality suitable for drinking and other uses (U.S. Geological Survey 1997).

CONCLUSIONS

Data from 34 wells at 21 locations have been collected and are believed to be representative of current installation practice and geographical distribution. These installations all have heating-dominated loads. Heat extraction has accordingly been the main focus of these well designs. Bleeding of the well to induce flow of groundwater at more moderate temperatures into the well is a key feature of the well and system designs. Three sites have been identified where detailed data are available.

Construction differences existing in the reported standing column wells relate in part to the depth of the well rather than any other influencing parameter. Shallower wells (i.e., depths less than 150 m [500 ft]) tend to be dominated by placement of the pump near the bottom of the well with the return located near the top. Deeper wells (depth greater than 150 m [500 ft]) mostly use dip tubes (Porter Shroud) constructed of 100 mm (4 in.) diameter PVC pipe to the bottom of the well. The pump and return pipe ends are located near the top of the well, taking into account drawdown depths at bleed flow rates of from 2% to 25% of total heat pump flow depending on the application.

The location and hydraulic properties of the different "groundwater regions" of North America have been presented. The regions where standing column well installations have been identified are all in the Northeast of North America. These are the (1) northeastern Appalachians, (2) Appalachian plateau and valley and ridge region, and (3) Piedmont and Blue Ridge regions. Each of these regions has igneous or metamorphic rock where relatively high well capacities and good water quality are available. Standing column well technology could be applied in many other areas of the contiguous United States where similar conditions can be found.

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