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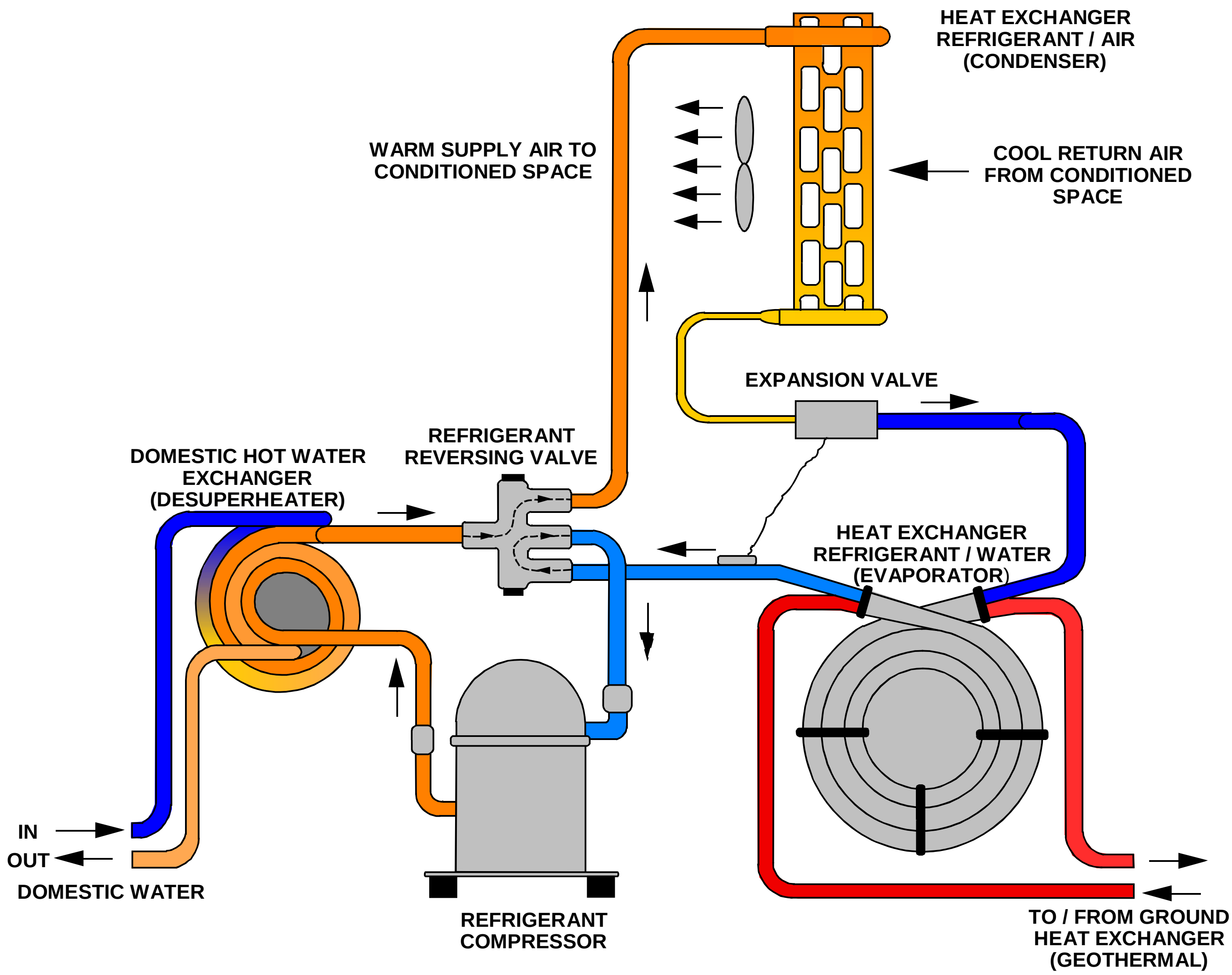

GEOTHERMAL HEAT PUMPS (GHP)

Vol. 22, No. 1 March 2001

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS

	Page
Geothermal Heat Pumps - An Overview John W. Lund	1
Feasibility Study on the Utilization of Geothermal Heat Pump (GHP) Systems in Japan Shinji Takasugi, Tsukashi Akazawa, Takashi Okumura and Mineyuki Hanano	3
Hot Water Supply Test Using Geothermal Heat Pump systems at PetroPavlovsk-Kamchatsky, the Capital of Kamchatka, Russia Ken Ikeuchi, Shinji Takasugi and Shin-ichi Miyazaki	9
Current Status and Future Directions of Geothermal Heat Pumps in Turkey A. Hepbasli, M. Eltez and H. Duran	13
Design Aspects of Commercial Open-Loop Heat Pump Systems Kevin Rafferty	16
Specificationof Water Wells Kevin Rafferty	25
A Guide to On-Line Geological Information and Publications for Use in GSHP Site Characterization Kevin Rafferty	31
Dual-Set Point Control of Open-Loop Heat Pump Systems Kevin Rafferty	38

Cover: GHP/GSHP in the heating mode. Modified from a drawing by IGSHPA, Oklahoma State University.

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GEOTHERMAL HEAT PUMPS - AN OVERVIEW

John W. Lund
Geo-Heat Center

Geothermal heat pumps (ground-source heat pumps) (GHP or GSHP) are used in two basic modes: ground coupled (vertical and horizontal)--closed loop, or groundwater types - open loop (Figures 1 and 2). These have been described extensively in a previous Geo-Heat Center Bulletin (Vol 18, No. 2 - April 1997) and in more detail in "An Information Survival Kit for the Prospective Geothermal Heat Pump Owner" by Kevin Rafferty--both of which are available on our website: <geoheat.oit.edu>.

The installation and use of geothermal heat pumps worldwide have had a large increase over the past ten years with almost a 10% annual increase during this time. Most of this growth has occurred in the United States and Europe, though interest is developing in other countries such as Japan and Turkey. The present worldwide installed capacity is 6,875 MWt and the annual energy use is 23,287 TJ/yr (22,088 billion Btu/yr or 6,453 GWh/yr) at the beginning of 2000 in 27 countries (Table 1). The actual number of installed units is around 500,000, but the data are incomplete. The equivalent number of 12 kW units installed is slightly over 570,000. The 12 kW (3.4 tons) equivalent is used as typical of homes in the United States and some western European countries. The size of individual units, however, range from 5.5 kW (Poland and Sweden) for residential use to large units of over 150 kW (Germany and the United States) for commercial and institutional installations.

In the United States, most units are sized for the peak cooling load and are oversized for heating (except in the northern states) and, thus, are estimated to average only 1,000 full-load heating hours per year (capacity factor of 0.11). In

Table 1. Worldwide Geothermal Heat Pump Installations in 2000

Country	MWt	TJ/yr	GWh/yr	Actual #	Equiv. # (12 kW)
Australia	24	57.6	16.0	2,000	2,000
Austria	228	1,094	303.9	19,000	19,000
Bulgaria	13.3	162	45.0	16	1,108
Canada	360	891	247.5	30,000	30,000
Czech Republic	8.0	38.2	10.6	390	663
Denmark	3	20.8	5.8	250	250
Finland	80.5	484	134.5	10,000	6,708
France	48	255	70.8	120	4,000
Germany	344	1,149	319.2	18,000	28,667
Greece	0.4	3.1	0.9	3	33
Hungary	3.8	20.2	5.6	317	317
Iceland	4	20	5.6	3	333
Italy	1.2	6.4	1.8	100	100
Japan	3.9	64	17.8	323	323
Lithuania	21	598.8	166.3	13	1,750
Netherlands	10.8	57.4	15.9	900	900
Norway	6	31.9	8.9	500	500
Russia	1.2	11.5	3.2	100	100
Poland	26.2	108.3	30.1	4,000	2,183
Serbia	6	40	11.1	500	500
Slovak Republic	1.4	12.1	3.4	8	117
Slovenia	2.6	46.8	13.0	63	217
Sweden	377	4,128	1,146.8	55,000	31,417
Switzerland	500	1,980	550.0	21,000	41,667
Turkey	0.5	4.0	1.1	23	43
UK	0.6	2.7	0.8	49	53
USA	4,800	12,000	3,333.6	350,000	400,000
TOTAL	6,875.4	23,286.9	6,453.1	512,678	572,949

Europe, most units are sized for the heating load and are often designed to provide just the base load with peaking by fossil fuel. As a result, these units may operate from 2,000 to 6,000 full-load hours per years (capacity factor of 0.23 to 0.68). Unless the actual number of full-load hours were known, a value of 2,200 hours was used for energy output (TJ/yr) based on data for several of the European countries. As an example, Finland has approximately 10,000 units installed, 70% horizontal installation, where the ground temperature is around 10ºC (50ºF).

Since performance of heat pumps is described in the papers in this Bulletin, several definitions are appropriate. Heating performance is defined by the index called COP (Coefficient of Performance), which is the heating affect produced by the unit (in Btu/hr) divided by the energy equivalent of the electrical input (in Btu/hr) resulting in a dimensionless number. Cooling performance is defined by an index called EER (Energy Efficiency Ratio), which (in the U.S.) is the cooling affect produced by the unit (in Btu/hr) divided by the electrical input (in watts) resulting in units of Btu/watt·hr.

The energy reported for heat pumps should be reduced from the installed capacity based on a COP (coefficient of performance) of 3.0, which allows for one unit of energy input (usually electricity) to three units of energy output. Thus, the geothermal component is 67% of the energy output. Newer units have COPs in the 4 to 5 range which increases the geothermal use to 75% to 80% of rated capacity.

In the United States, geothermal heat pump installations have steadily increased over the past 10 years with an annual growth rate of about 12%, mostly in the mid-western and eastern states from North Dakota to Florida. At the end of 1999, there are an estimated 400,000 units installed, with 45,000 installed annually. Today these figures are 450,000 and 50,000 respectively. Of these, 46% are vertical closed loop, 38% horizontal closed loop and 15% open loop systems. Projections for the future are that the growth rate will increase about 12% annually, so that by 2010 an estimated 140,000 new units would be installed in that year, thus, adding almost one million units for a total of about 1.5 million units. Over 600 schools have installed these units for heating and cooling, especially in Texas. Using a COP of 3.0 and 1,000 full-load hours per year in the heating mode, the 450,000 equivalent 12 kW (3.4 ton) units remove approximately 12,900 TJ/yr (12,250 billion Btu/yr) from the ground. The cooling mode energy is not considered geothermal, since this rejects heat to the ground; however, the cooling mode does replace other forms of energy and is, thus, considered in fossil fuel and greenhouse gases emission savings. It should be noted at this point, that in the United States, heat pumps are rated on tonnage (i.e., one ton of cooling power--produced by a ton of ice) is equal to 12,000 Btu/hr or 3.51 kW.

One of the recent converts to this form of energy savings is **President George W. Bush**, who recently installed a geothermal heat pump on his Texas ranch during the election campaign. Howard Newton, a consultant on the job, overheard the then President-elect explaining to Vice President-elect Dick Cheney and General Colin Powell that geothermal heat is "**environmentally hip"** (Julie V. Iovine, *The New York Times*, January 4, 2001). The unit total is 14 tons (49 kW) broken into five separate systems with desuperheater. The vertical closed loop installation cuts his heating and cooling cost by 40%.

Figure 1. Ground-coupled (closed-loop) types.

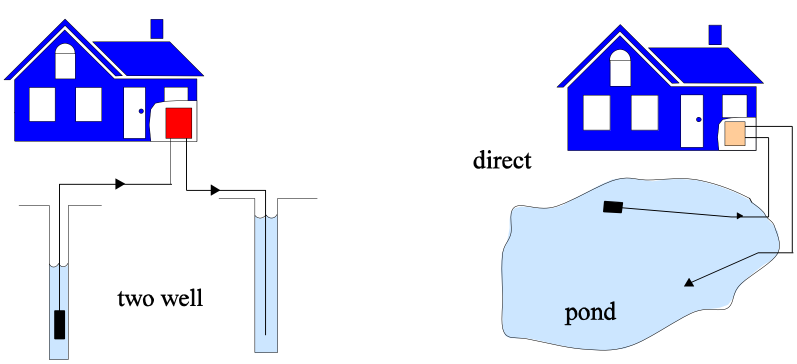

Figure 2. Groundwater (open-loop) types.

FEASIBILITY STUDY ON THE UTILIZATION OF GEOTHERMAL HEAT PUMP (GHP) SYSTEMS IN JAPAN

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ABSTRACT

Low-enthalpy geothermal resources have not been utilized to their potential in the past. However, since vast tracts of low-enthalpy geothermal resources exist as energy in the form of differential temperatures, the reserves are estimated to be enormous. As a result, there is growing interest in using this untapped energy in order to reduce carbon dioxide emissions which are the main cause for global warming, one of today's most serious issues as addressed by the U.S. Department of Energy and Environmental Protection Agency documents (e.g., EPA, 1993).

The purpose of this feasibility study is to investigate the different aspects of the problem with respect to cost, technology and measures affecting the introduction and widespread acceptance of geothermal heat pump (GHP) systems. Specifically, the study was conducted by collecting information from relevant literature, random surveys, discussion forums and expert groups.

STATUS OF THE GHP (GEOTHERMAL HEAT PUMP) SYSTEM

The GHP system is grouped under the following three systems on the basis of the objective or the manner in which heat is extracted (Kavanaugh, 1991; Oklahoma State University, 1997; GeoExchange, 1998).

- Earth heat exchanger (earth-coupled heat exchanger) type heat pump system. This type of heat exchanger can be placed vertically in boreholes or in shallow trenches, approximately 2 meters deep.
- Heat pump system using ground water directly.
- Heat pump system using surface (lake, marsh or river) water directly, or using it as the heat source. This system requires a series of coiled tubing to be placed into the appropriate lake, marsh or river.

The system to be examined in this survey is "one using a vertical ground heat exchanger type heat pump system (Figure 1)." It could be of the horizontal installation type (horizontal ground heat exchanger type) or the vertical installation type (vertical ground heat exchanger type) depending on the arrangement of the heat exchanger.

Many space heating and cooling systems utilizing the GHP system are being used worldwide, especially in the USA, Switzerland and northern Europe. The approximate (minimum) number of installed facilities includes 300,000 sets in the USA, 20,000 in Switzerland and 30,000 in northern Europe. While most of the systems are for single-family housing in Switzerland and northern Europe, many have been installed in large buildings in the USA. Since one heat pump might be sufficient for a house or large building, the number of installations does not necessarily correspond to the number of users, particularly in the USA (Rybach et al., 1992; Rybach and Eugster, 1997).

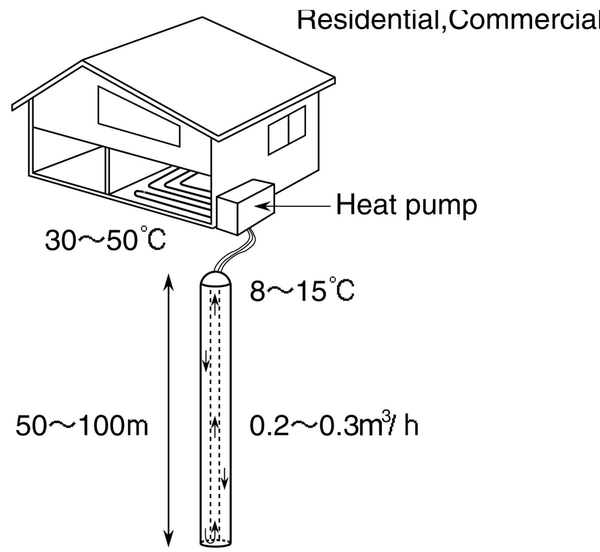

Figure 1. General layout of a GHP system using a borehole heat exchanger.

COST PERFORMANCE EVALUATION AND THE EFFECT OF AN INCREASED USE OF GHP SYSTEMS

Cost Performance Evaluation

The status of the research, development and utilization of GHP systems in Japan has been described by NEDO (New Energy Industrial Comprehensive Development Organization)(1999). The cost of these systems was compared with that of other space heating and cooling systems in Switzerland. A comparison with conventional systems in Japan has also been made.

These studies indicate that if the use of GHP systems becomes more popular, it will reduce the cost of drilling boreholes for the vertical ground heat exchangers, which is the main cause of the high initial cost. If also a 50% subsidy is obtained from the government to promote the introduction of these systems, the installation investment for the geothermal heat pump can be recovered in about two years. In addition if a 30% subsidy is assumed, the increased cost (i.e., the cost difference with respect to a conventional system) can be recovered in less than 10 years. If the cost over the life cycle of the system (i.e., 24 years) is considered, a savings of 2,050,000-3,490,000 yen (approx. a US$ 19,000 to 32,000) can be achieved assuming a 30% subsidy.

Table 1. Initial and operating costs of existing heating, cooling and hot water supply systems, compared with those of GHP systems installed an elderly peoples' home. Investment cost for facilities to lower carbon dioxide emissions. Carbon dioxide reductions associated with the installation of GHP systems in 10,000 homes for elderly people (1 US$ = 110 Yen–approx.).

		Existing system	GHP system		Cost difference	Number of years required for recovery of costs	Necessary subsidy rate for the assumed time of recovery (%)	Carbon dioxide reduction (ten thousand tons/year), Facilities investment		Facilities investment
Construction costs of an elderly people's home	Heating, cooling and hot water supply systems	Direct oil combustion/absorption type water heater/cooler (two units) (Capacity: 181,440kcal/h)	Heat pump (60 refrigeration tons capacity: 2sets) (Underground heat exchanger (200m: 17 sets) (inclusive of the drilling cost)				For 10 years	(ten thousand yen/ton)	(%)	(ten thousand yen/ton)
	Initial costs	20.05million yen	Without new subsidy	37.2million yen	17.15million yen	28	30	80	0.07	30 (18 with new subsidy)
			With new subsidy	18.6millon yen	−1.45million yen	0				
	Operating costs	2.9millon yen/year		2.3million yen/year	0.6million yen/year	?				
2/3 subsidy available	Initial costs	6.68million yen	Without new subsidy	12.4million yen	5.72million yen	9.5	0			
			With new subsidy	6.2million yen	−0.48million yen	0				
	Operating costs	2.9millon yen/year		2.3million yen/year	0.6million yen/year	?				

Table 2. Comparison of life-cycle costs (LCC) of existing and GHP systems described in Table 1 (for a 50-year evaluation period)(1 US$ = 110 Yen).

		1) Unit cost (ten thousand yen)	Life of the system	Number of systems	Number of years for the evaluation	Number of system replacements	LCC Note 3 (ten thousand−yen/ 50 years)	Total (a hundred million yen/50 years)	LCC difference (million yen/50years)
3) Existing system	2) Oil supply facilities	265	10	1	50	5	1325	2.45	
	Boilers	775	10	2	50	5	7750		
	Piping	190	10	1	50	5	950		
	Operating cost	290	–	–	50	–	14500		
4) GHP system	Heat pump	490	10	2	50	5	4900	1.99	0.45
	ground heat exchanger	2550	50	1	50	1	2550		
	Plumbing system	190	10	1	50	5	950		
	Operating cost	230	–	–	50	–	11500		

If a GHP system is installed in the home of the elderly where many people are living, the amount added to the initial cost can be recovered in 9.5 years, by applying **the existing government subsidy for this type of homes (i.e., 2/3 of the home construction costs).** If a 7% subsidy to promote the introduction of GHP systems is assumed, the additional can be recovered in 5 years (Table 1). A cost **reduction of 0.45 million** yen (US$ 4,000) can be achieved over the life cycle of the home (50 years) if no subsidy is applicable (Table 2).

Benefits of Using GHP Systems

The benefits resulting from the installation of large numbers of GHP systems are:

- Reduction in carbon dioxide emissions,
- Lower heat radiation from urban areas, and
- Decrease in peak power demands.

Regarding the first benefit, if all households in Japan would use the GHP system, the annual CO_2 emissions would be lowered by 52 million tonnes (a 4.3% reduction with respect to the 1990 emissions in Japan; Table 1). Since almost no waste heat is discharged to the atmosphere, the use of these systems is expected to contribute to a reduction of the heat island effect. It would also lower the demand for peak power.

TECHNICAL ADVANCES NEEDED FOR FUTURE GHP SYSTEMS

The following technical advances were considered to make GHP systems more effective and attractive in the future:

- Improvement of the performance of heat pumps, particularly for single-family housing.
- Selection of a heating and cooling system that is most suitable for GHP systems.
- Development of a highly efficient vertical ground heat exchanger.
- Implementation of new tools and techniques to reduce drilling costs.
- Preparation of drilling manuals.

Although there are no serious technical problems associated with the GHP systems, the most important projects to be considered to reduce their costs are the development of small-sized, highly mobile drilling rigs designed primarily for heat- exchanger holes, and the preparation of drilling manuals (items d. and e. in the list above).

TASKS TO ASSIST IN THE INTRODUCTION, PROMOTION AND WIDESPREAD ACCEPTANCE OF GHP

To promote the widespread introduction of GHP systems, the establishment of a support system is very important. This system should be primarily directed toward:

- **Basic Research**
  New developments to improve the thermal efficiency of vertical ground heat exchanger are expected in the future. While the basic studies on this subject have been mostly completed in Europe and the USA, presently in Japan the lack of the subsurface data needed to install vertical ground heat exchangers may slow down the introduction of GHP systems. The collection of such information is urgently needed.

- **Applied Research**
  Applied research on the use of GHP systems has also been mostly done in Europe and the USA, where the main efforts have been directed toward their introduction in different regions. On the other hand, in Japan the most urgent tasks to be undertaken are the standardization of systems, preparation of technical manuals, and testing the reliability of the systems by conducting demonstrations.

- **Promotion Activities**
  GHP promotion centers should be created. Their activities should include solving the various problems associated with the installation and use of GHP systems and for the preparation of subsidiary systems.

Basic Research – Development of Subsurface Temperature, Groundwater level and Geologic Maps for an Optimal Design of Borehole Heat Exchangers

A characteristic of the GHP system is that its heat exchanger is installed in boreholes. The installations above the ground surface are similar to those of conventional heating and cooling systems. Therefore, it is important to obtain the information necessary for designing and estimating the cost of the vertical ground heat exchanger. It must be made clear that all associated studies should consider the prevailing conditions (climate, topography, geology) of Japan, as well as the distribution of a) subsurface temperatures, b) geothermal gradients, c) soil thermal conductivities and d) groundwater flow conditions.

Besides the need to obtain the thermal gradient down to 100 m depth (Figure 2), data on the groundwater levels and, if possible, the groundwater flow direction and rate are very important. The design of vertical ground heat exchanged can be made easy if maps with the required information are available. Sometimes, the lack of adequate information results in an unnecessarily conservative design.

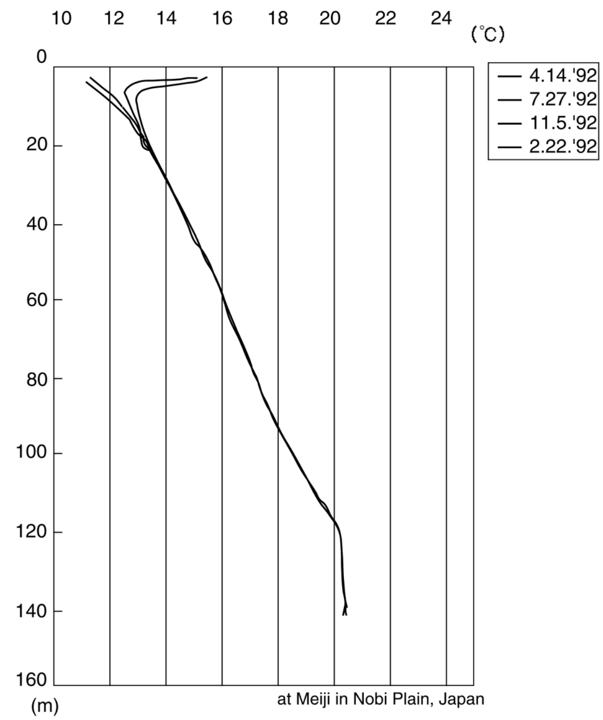

Figure 2. ***An example of downhole temperature logs.***

Appropriate geological information about the area where the vertical ground heat exchanger is going to be installed (less than the 100 m deep) allows the preparation of adequate drilling cost estimates. The data should include information on the presence of conglomerate layers, faults or bedrock (Marui, 1997; Uchida, 1998).

Applied Research - Standardization of the GHP System and Preparation of Manuals

To promote the installation of GHP systems, all the parties involved, including designers and system builders, must share common recognition and understanding of the system. This requires standardization of the system and preparation of manuals. By designing and installing GHP systems in accordance to the manuals the quality can be properly controlled and a high level of reliability assured.

The standardization of GHP systems and the preparation of manuals should be made as soon as possible also in Japan. In the USA, these activities are being promoted primarily by IGSHPA (International Ground-Source Heat Pump Association at Oklahoma State University) with the cooperation of universities, scientific societies and national laboratories.

The introduction of manuals already completed in Europe and the USA is considered very helpful to promote the systems in Japan. Therefore for the time being, we should introduce the overseas technologies and determine which are adequate for Japan and where to make additions and changes.

Promotion Activities - Demonstrations, Promotion Centers and Subsidy Program

- **Demonstration of GHP Systems**

  Demonstrations are extremely effective for recognizing the advantages and points of excellence of the GHP system. It is important to summarize the results of the demonstrations in case studies reports and to be used in promotion activities.

  At this time and for this study, a number of elderly peoples' homes will be selected as the demonstration targets. The selected types of homes shall be such that:

  – A substantial number of units are expected to be built.
  – Emphasis is placed on low-maintenance cost rather than low-investment cost units.
  – They are operational 24 hours a day for heating and cooling with a fairly large thermal capacity, including hot water supply.
  – They are public facilities requiring comfort and tranquility.
  – Their limited operation budget does not allow employing engineers for maintaining the heating and cooling facilities.
  – Elderly peoples' homes that fulfill these conditions are considered to be prospective targets for the installation of demonstration GHP systems. Subsidizing the cost of installing vertical ground heat exchangers is considered to be an effective promotion activity since it provides the incentive and motivation to introduce the GHP systems in elderly peoples' homes. Such homes should be utilized for demonstration and monitoring purposes. The results should be summarized and published in case study reports.

- **Creating Promotion Centers**

  The widespread installation of GHP systems will be environmentally effective and be helpful in leveling power consumption rates and lowering the heat island phenomenon. From this viewpoint, the Environmental Protection Agency, the Department of Energy, and power companies in the USA are promoting the installation of these systems and created the GHPC (Geothermal Heat Pump Consortium) as a part of joint government/private sector effort.

  .

  The GHP system is applicable to almost all areas of Japan. The fast growth in the number of installed units in Europe and the USA is an excellent encouragement for Japan. A rapid adoption of the system, even faster than in Europe and the USA, can also be expected in Japan by creating adequate GHP promotion centers.

  For 1996, the number of installed GHP systems in the USA was reported to be 50,000. The subsequent yearly growth rate is about 20%. Although the rate is below the target proposed by GHPC, it is still fairly high. However, in Japan the system is not well known by parties that could benefit from it, including consumers, architects, engineers, builders and manufacturers (HPTC, 1998).

  Considering that presently Japan is still in the initial state of GHP system application, it is essential that NEDO should lead promotion and demonstration efforts by creating centers to assist in the introduction of systems suitable for the Japan's conditions. It is essential to study the systems in the USA and Europe very closely, and to determine which is the optimal system for Japan and set target(s) before starting the promotion activities.

- **Subsidy Program**

  When promoting the use of the GHP system, one should stress its economic merits, along with its beneficial effects like energy peak demand reduction and global environmental preservation. The most important point on its economic merits should be that the higher installation costs can be reduced. In this connection, the application of subsidies is considered very important for increasing the system's economic advantages. In view of the present situation of low number of installations in Japan, the application of a subsidy program is expected to have an immediate effect on promoting the introduction of GHP systems and creating an initial demand.

  To help in the creation and design of a subsidy program for the introduction of GHP systems, one could learn from those for solar and wind energy. These types of energies seem to have become economical partly because of the existence of subsidies.

  A possible subsidy program for introducing and increasing the use of GHP systems should include subsidies for:

- Private persons who desire to install the systems in their house,
- Manufacturers, builders and/or dealers who produce, install and sell the systems, and
- Organizations that promote the use of the systems. The funds might be used to cover operational costs, provide infrastructure, prepare manuals, and perform preliminary investigations, including planning.

The subsidy program for private persons would pay for a certain percent of the GHP system installation costs. This would be similar to the program encouraging the introduction of solar energy generation units; it covers the cost **difference with respect to a conventional space heating and cooling system**. In addition, the financial or tax incentive program used to promote wind power projects would also be important.

The subsidy program for manufacturers, builders and/or dealers is expected to be funded by the power companies. It would be similar to the one paying manufacturers 20,000-50,000 yen (US$ 180 - 450) for each kW of the peak shift achievable by the ice-energy storage-type air-conditioning system called "Eco-Ice." The subsidies to manufacturers and builders was offered so that the new technology would be commercially **feasible**, allowing the repair of the facilities as they become old.

Further energy savings could be realized if the electricity for the GHP system compressor could be generated using solar or wind energy, and the Eco-Ice. In this way, the impact of the subsidy program would be further enhanced.

If the economy and performance of the GHP system in Japan could be demonstrated, its use could also be promoted in neighboring Asian countries, as part of the environmental yen loan program being conducted under the Kyoto Protocol adopted at the Third Conference of Parties to the UN Convention on Climate Change (COP3).

CONCLUSIONS

The results of the GHP feasibility study in Japan can be summarized as follows:

- **Present Situation**

Currently the number of GHP systems installed in the USA is about 400,000, and is expected to increase by approximately 50,000 units per year (i.e., about 12% annual growth). In Switzerland, there are about 50,000 systems and the number is growing at an annual rate of 20 % (L. Rybach, pers. comm.). With the more favorable subsurface temperature conditions prevailing in Japan, the introduction of these systems has been found to be feasible. Geothermal heat pump systems **(with vertical and horizontal ground heat exchanger, lake loops, etc.)** are considered to suit the requirements of Japan from both the topographical and environmental points of view.

- **Costs and Widespread Acceptance of GHP Systems**

Studies have shown that if drilling costs for the subsurface heat exchanger can be reduced by an increased number of installed systems, the additional installation costs of a GHP system for an average residential building can be recovered in two years assuming a cost subsidy of 50%, and in 10 years for a 30% subsidy (assuming that the subsidies are available during the initial stages of GHP installation). When the costs are considered over the operating life of the system (typically 24 years), a saving of 2,050,000 - 3,490,000 yen (approx. US$ 19,000 - 32,000) can be achieved with a 30% subsidy.

When the installation of a GHP system in an elderly peoples' home is evaluated, the additional initial costs of the GHP system is recoverable in 9.5 years by applying subsidies currently available (a subsidy of 2/3 of the home construction cost), and recoverable in five years (Table 1) when the subsidy is increased by an additional 7%. When the operating life is extended to 50 years, it can be shown that a project lifetime savings of 0.45 million yen (US$ 4,000) is possible even without subsidies (Table 2).

It can be shown that if all residential buildings in Japan would install a GHP system, a reduction of 52 million tonnes in carbon dioxide emissions could be achieved (a reduction of 4.3 % compared to 1990's emissions; Table 1). In addition, as almost no waste heat is released into the air, these systems are expected to lower heat island effects and reduce peak electric power demands.

- **Technical Tasks**

Although there are no specific technological problems, several aspects of the GHP systems could be improved, including the development of small-scale drilling rigs specially designed for installing GHPs and for drilling into soft and hard rock formations. Also drilling manuals should be prepared, including sections showing the distribution of geologic formation and faults that might affect drilling performance.

- **Tasks to Assist in the Introduction, Promotion and Widespread Acceptance of GHP Systems**

  These tasks include the gathering of geological data, the standardization of systems, the preparation of manuals, the demonstration and monitoring activities, the establishment of a GHP system distribution network, and the creation of a subsidy program. Proposals, relating to GHP systems in Japan, have been based upon examples from Europe and the United States.

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HOT WATER SUPPLY TEST USING GEOTHERMAL HEAT PUMP SYSTEMS AT PETROPAVLOVSK-KAMCHATSKY, THE CAPITAL OF KAMCHATKA, RUSSIA

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ABSTRACT

"Fundamental investigation of the promotion of a joint implementation for the fiscal year 1998 - The fundamental investigation related to local heating utilizing geothermal in Kamchatka, Russia" was carried out with the support of the New Energy and Industrial Technology Development Organization (NEDO). It was carried out as a feasibility study and to implement the "joint implementation."

As the results, it was verified that heating by geothermal heat pump (GHP) can be used instead of the existing boiler heating in the severe climate condition in Kamchatka. In this report, the results of the GHP test as a part of this feasibility study is summarized.

INTRODUCTION

The third conference (COP3) of the parties for the United Nations Framework Convention on Climate Change was held in Kyoto in December, 1997. In order to prevent the global warming by the effects of greenhouse gases such as carbon dioxide, the protocol in Kyoto adopted reduced targets for the quantity of greenhouse gas exhausted in developed countries. Further, in the protocol in Kyoto, the methods of achieving the targets were made flexible, such as by "joint implementation," among developed countries.

With this background, "The fundamental investigation related to local heating utilizing geothermal in Kamchatka, Russia" was carried out. The region selected for this project was Petropavlovsk-Kamchatsky, the capital of Kamchatka (hereinafter called "P-K city") and its environs (Figure 1). P-K city faces the Bay of Avanchiskaya located a little to the south of the center of the east Pacific coast. Three hundred thousand of the state's total population of about 350,000 live in the city and it is the center of administration and industry of the Peninsula. It is located 30 km from the Erizoho airport, the gateway to Kamchatka.

There is a district heating system using hot water in P-K city. This includes two systems for the supply of hot water from exhaust heat of the power plant and the supply of hot water furnished by heavy oil combustion. Sixty five percent of local heating in P-K city is supplied by hot water from heavy oil combustion through a pipeline.

The purpose of this test was to verify that the heating can be carried out adequately by GHP instead of the boiler heating in Kamchatka, a severe cold district.

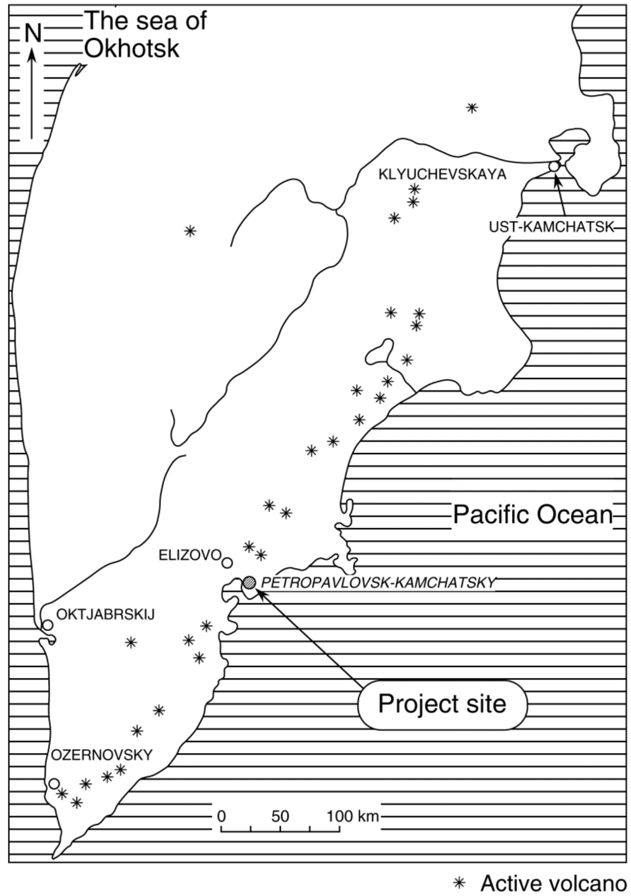

Figure 1. Southern part of Kamchatka peninsula.

GEOTHERMAL HEAT PUMP TEST PROGRAM
Selection of Test Site

The GHP test began by selecting the test site. As the conditions of the test site, the vertical ground heat exchanger type heat pump system was adopted. Because the site area was comparatively unrestricted for the location of the heat pump test, it was possible to drill boreholes. Accordingly, as the result of the proposal by Russia and the preliminary discussion, four locations were selected as the proposed test sites. Then the on–site investigation of these proposed test sites were carried out, taking the following into consideration:

1. Geographical position,
2. Geological conditions,
3. Existing heating system,
4. Social importance of installation site,
5. Reliability of electric power supply to the installations, and
6. Issue of ownership and the of approval of the test.

As the result of the comparison and investigation of the four proposed sites, the sanatorium of Kamchatka Energo Company (electric power company) in Aginuk region was selected as the test site. This sanatorium is located in the Paratunsky hot spring area 60 km from P-K city.

This sanatorium is the property of Kamchatka Energo Company, used as a children training camp in summer and as the lodging facility for the employees and their families of Kamchatka Energo Company in winter. The facility consists of two hotel-type residential buildings, an administration building, a pool and auxiliary buildings. The area was most suitable for the GHP test site as a well can be drilled anywhere. Electricity is supplied by independent power generation for twenty-four hours. The heating of all buildings is centralized in a heavy oil boiler system. The temperature is controlled by the outdoor temperature and is operated manually. There were no problem in use or that could occur in the drilling and approval. The room selected for the test has the advantage in being easily compared with the adjacent room in which the existing equipment is used. Further, there is no problem in opening to the public or for advertisement because it is a public building and the facility is suitable for PR, such as observation.

It was expected that the underground water level existed at a depth of about 3 m. The static formation temperature is 7-8ºC at a depth of approximate 90 m, measured in an existing borehole.

This potential test facility consisted of the administration building in the sanatorium and the lodging building. The administration building was under construction and thus, the piping work and the observation of the heating conditions was made easy. Further, a half of the administration building was not scheduled for use. From these points of view, the administration building was adopted as the test house. The plan also considered setting the GHP system in a separate house and putting it on the side of the administration building.

Trial Design of Heat Pump Test

Since the sanatorium of Kamchatka Energo Company in Aginuk region was selected as the test facility, the project was designed to take the site conditions into consideration. Half of the rooms of the administration building were assigned to be observation rooms in which the test was carried out; that is, five rooms were to be heated by GHP. The observation rooms were selected by locating the heating pipes coming into the administration building so that the supplied hot water only entered approximately half of the heating pipes. To heat the half of the administration building of double windows with walls made of concrete, 5.7 kW or more of GHP capacity was enough. Therefore, the capacity of GHP was set to 6.7 kW using a ready-made article, providing a margin of safety. In Switzerland, the peak heat output to be recovered from the heat exchanging well in the

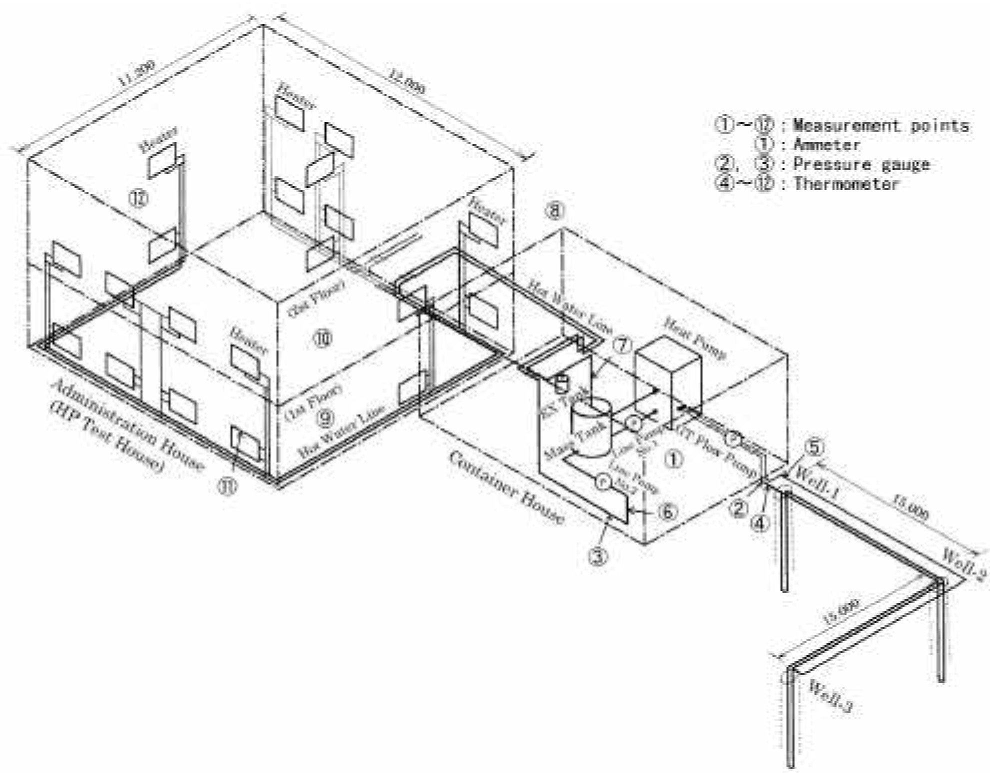

Figure 2. GHP piping system diagram.

GHP system is 45 W/m (Rybach and Eugster, 1997), so the peak output of 4.5 kW can be obtained in the case of the well of 100 m depth. The formation temperature is low in the severe cold district such as Kamchatka; thus, the COP would be poorer than in a warmer district and the heat output from the well was thought to be less. Since the capacity of the GHP used in this test was 6.7 kW, 2.2 wells of depth 100 m were required. It was estimated that 3 kW could be obtained from a well of depth 100 m. Therefore, three wells of depth 100 m were drilled in this test. The system diagram is shown in Figure 2.

GEOTHERMAL HEAT PUMP TEST

Purpose of Investigation

When we visited the Kamchatka Energo Company's sanatorium in the Aginuk region, the existing heating was controlled by a supply temperature of 50°C (0.4 MPag) from the supplied hot water and 40°C (0.16 MPag) return temperature. This facility is also utilized as a sanatorium in winter by using this heating system. Therefore, the purpose of this test using this sanatorium was to prepare the hot water for heating of at least 50°C or more by GHP and to verify that the heating can be carried out sufficiently by GHP instead of the boiler heating in Kamchatka, a severe cold district.

Result of Investigation

Temperature Measurement of Heat Exchange Borehole

The temperature in the well measured on April 17, 1999 is shown in Table 1. These values were measured in Well-2 (standing time was one month or more) which was finished first with water level at a depth of 20 m. These values were measured separately by using a maximum temperature thermometer (max.100°C). The maximum temperature in Well-2 was 13°C at a depth of 100 m and it was a little higher than the estimated value (7 to 8°C at a depth of 90 m).

Table 1. Results of Well-2 Temperature Measurement (measured on April 17, 1999).

Depth	Temperature
20 m	10°C
50 m	10°C
100 m	13°C

Conditions of GHP Installation

The drilling was carried out using a truck mounted rig. The polyethylene U-shape tubes, with outside diameter of 33.4 mm, were inserted just after completion of drilling to be used as the heat exchanger (Oklahoma State University, 1997), and a casing was set for the reason of timing problems in the installation. The space between the casing and the U-shape tubes were back-filled with pure bentonite. After that, glass wool insulation was wound around the surface piping. The house for the heat pump system was installed in the space between the administration building and the wells. The heat pump and the observation unit were placed in this building.

Result of GHP Test

The piping system diagram of the GHP test is shown in Figure 2 and the results of the observations are shown in Table 2. The test was started at the end of April and the observation period of the test was 18 days. Half of the rooms in the administration building were scheduled to be heated by GHP according to the initial plan, but as shown in Figure 2, a system to heat the whole administration building was adopted because of a problem in welding the piping at the site. Therefore, the head of the circulating pump of the initial plan was not adequate and a sufficient quantity of hot water could not be circulated in the entire administration building. The positions of the respective measurement channels (ch.) in Table 2 are shown in Figure 2. Since May 2-4, during the measurement period, was a public holiday in Russia, data were not obtained. Further, channel 11 which measured the temperature of the face of the heating pipe, did not measure the temperature from May 5 to May 10 because of a faulty sensor. After May 11, since air entered into the heater, the hot water could not be circulated around the temperature sensor and thus, heating was insufficient. Therefore, channel 11 values are small.

As shown in Table 2, the outdoor temperature was about 5°C and the room temperature was kept at 18-20°C. This temperature was sufficient in the heating condition of the periphery of P-K city. Further, in this GHP test, as shown in Figure 2, the system with the buffer tank (called the mass tank) was provided to store the hot water created by the GHP. The stored hot water in the tank was then circulated. As shown in Table 2, the temperature of the hot water delivered from the mass tank was about 44°C to 46°C and the return temperature was about 41°C to 43°C, resulting in the supply of heat equivalent to about 3°C.

The temperature difference between the delivered hot water and the return hot water was maintained about 3°C. The room temperatures of channels 9, 10 and 12 were kept at 18-20°C; while, the output temperature of the hot water on channel 6 decreased daily. This means that the capacity of the GHP is not enough for all rooms of the administration building.

On the other hand, the reason that the hot water could not be circulated around channel 11 temperature sensor was that the circulated pump capacity was not enough due to heating twice of the number of test rooms as planned.

Because of the above-mentioned reasons, we could not circulate enough hot water. However, the test room could be heated adequately in the environment where the outdoor temperature was close to 0°C (sometimes, below-zero at night).

From these tests, it was verified that heating by GHP can be used instead of the existing equipment in the severe climate condition in Kamchatka. Moreover, it is possible to decrease the discharge of carbon dioxide with the local GHP heating system.

CONCLUSIONS

Summarizing the GHP test: the proposed test sites were selected first, the final test site was then decided between

Table 2. Result of GHP Test Observation.

Measurement item / Date	No.1ch (Amp)	No.2ch (MPa G)	No.3ch (MPa G)	No.4ch (°C)	No.5ch (°C)	No.6ch (°C)	No.7ch (°C)	No.8ch (°C)	No.9ch (°C)	No.10ch (°C)	No.11ch (°C)	No.12ch (°C)
4/30/1999	8.0	0.06	0.06	0.6	3.0	41	37	7	22	21	35	19
5/1	7.6	0.06	0.06	0.5	2.7	43	40	6	18	20	31	18
2												
3												
4												
5	7.5	0.06	0.06	0.3	2.2	46	43	3	19	17	--	19
6	7.5	0.06	0.06	0.3	2.3	46	43	4	20	17	--	19
7	7.6	0.06	0.06	0.3	2.4	46	43	5	20	18	--	20
8	7.6	0.06	0.06	0.3	2.5	47	43	6	20	18	--	20
9	7.6	0.06	0.06	0.4	2.6	47	44	7	20	18	--	20
10	7.7	0.06	0.06	0.5	2.7	47	44	9	21	18	--	21
11	7.7	0.06	0.06	0.5	2.6	47	44	10	21	18	22	21
12	7.7	0.06	0.06	0.6	2.5	47	44	9	21	18	22	21
13	7.7	0.06	0.06	0.6	2.4	46	43	8	21	19	23	21
14	7.8	0.06	0.06	0.6	2.3	44	41	7	21	18	23	20
15	7.8	0.06	0.06	0	2.1	44	41	7	21	19	23	18
16	7.7	0.06	0.06	0.4	2.2	44	41	7	22	19	22	18
17	7.8	0.06	0.06	0.3	2.2	44	41	6	21	18	22	18

Note) No.1 ch : Electric current used in GHP system (Amp. 300 V)
No.2 ch : Delivery pressure of circulating water for heat exchanger well (MPa G)
No.3 ch : Delivery pressure of hot water for heating
No.4 ch : Delivery temperature of circulating water for heat exchanger well (°C)
No.5 ch : Return temperature of circulating water for heat exchanger well (°C)
No.6 ch : Delivery temperature of created hot water mass tank for heating (°C)
No.7 ch : Return temperature of created hot water mass tank for heating (°C)
No.8 ch : Outdoor temperature (°C)
No.9 ch : First floor observation room temperature (°C)
No.10 ch : Second floor observation room 1 temperature (°C)
No.11 ch : First floor observation room heating panel temperature (°C)
No.12 ch : Second floor observation room 2 temperature (°C)
Data could not be obtained because May 2-4 was the public holiday of Russia.
(The continuous record chart is under obtaining.)

No. 11 channel could not obtain the data because of a faulty sensor, from May 5th to 10th. Further, the sensor operated after May 18th, but due to air entering the inside of the pipe, the channel could not be heated.

them, three wells for the ground-coupled heat exchanger were drilled at that site, and then the on-site actual test was carried out.

The test was started at the end of April and the observation period was 18 days. The test rooms could be heated adequately in the environment which the outdoor temperature was close to zero (sometimes, below-zero at night). Therefore, it was shown that the heating equipment by the GHP can be used instead of the existing equipment in the severe climate condition in Kamchatka. This will also decrease the discharge of carbon dioxide using the local GHP heating system in Kamchatka.

ACKNOWLEDGMENT

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CURRENT STATUS AND FUTURE DIRECTIONS OF GEOTHERMAL HEAT PUMPS IN TURKEY

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ABSTRACT

Ground-source or geothermal heat pumps (GHPs) are attractive alternative to conventional heating and cooling systems owing to their higher energy utilization efficiency. In this regard, GHPs have had the largest growth since 1995, almost 59% or 9.7 annually in the United States and Europe. The installed capacity is 6,850 MW_t and annual energy use is 23,214 TJ/yr in 26 countries. The actual number of installed units is around 500,000. The utilization of GHPs in residential buildings is new in Turkey, although they have been in use for years in developed countries. In other words, GHPs have been put on the Turkish market for about three years. There are no Turkish GHPs' manufacturers yet. It is estimated that 43 units are presently installed in Turkey, representing a total capacity of 527 kW. Considering the ongoing installations, the total installed capacity will reach 3,763 kW in this year, with a total of 282 units. The majority of the installations are in the Marmara region of Turkey (in Istanbul). High-income earners also prefer these systems. The current status of GHPs in Turkey is discussed and two case studies are described, of which the first one relates to the University of Ege, Izmir, Turkey while the second one includes a commercial application, which replaced a furnace.

GHPS APPLICATIONS IN TURKEY

In Turkey, the concept of the ground-source (or geothermal) heat pumps (GSHPs), in general heat pumps, is not new. However, the utilization of GSHPs in residential buildings is new in Turkey, although they have been in use for years in developed countries and the performance of the components is well documented. The first residential geothermal heat pump system in the country was installed in a villa with a floor area of 276 m^2 in Istanbul, in 1998; while, the first experimental study was carried out in the Mechanical Engineering Department, METU (Middle East Technical University) in Ankara, in 1986 (for more detail see Babur, 1986; Hepbasli and Gunerhan, 2000). The residential system consisted of a heating-only heat pump with a scroll compressor (15.6 kW heating) coupled to a 160-m (525-ft) vertical 1 ¼ inch U-bend ground coupling. The representative firm of Swedish GSHPs' manufacturer imported the heat pump itself and its relevant ground coupling materials and this system has been successfully operated since its installation.

In this context, the studies carried out on GHPs in Turkey can be divided into three groups (for more detail, see Hepbasli and Gunerhan, 2000); a) university studies, b) case studies (heat pump industry), and c) standardization studies.

University Studies

University studies on GSHPs can be classified into two categories: theoretical and experimental. Up to date, only three experimental studies were carried out by Babur (1986), Kara (1999) or Kara and Yuksel (2000) and Hepbasli (2000). Table 1 shows the main characteristics of GHP systems installed at the three different universities. The theoretical studies performed were described elsewhere (Hepbasli and Gunerhan, 2000).

Table 1. Main characteristics of GHPs installed at the Turkish Universities as of January 2001 (Babur, 1986; Kara, 1999, 2000; Hepbasli, 2000)

Name of University	Year built	System type	HP cap. kW
Middle East Technical University (Ankara)	1986	A single pipe-horizontal heat pump system for the heating only with R-12; 10 m of ground coil at 1.5 m depth with a spacing of 0.6 m; COP: 1.1 to 1.3.	0.95
Ataturk University (Erzurum)	1999	A water-to-water geothermal heat pump system for the heating only with R-22; an actual COP value of 2.8; Geothermal water inlet/outlet temp. 35/30 ºC at a flow rate of 1,100 L/h	7.02
Ege University (Izmir)	2000	A GSHP system for both heating and cooling with a vertical-single U-bend heat exchanger; 4 ½ inch of a bore diameter with a boring depth of 50 m	5.2

Heat Pump Industry (Market)

GSHP systems installed so far in Turkey are few in numbers. There are not any Turkish GSHPs' manufacturers yet. Currently, there are three companies, of which one is the pioneer of GSHPs in Turkey (Firm D) and has installed many systems. The remainder deals with water-loop heat pump systems imported from the USA (Firm A; Firm C), excluding one (Firm B). Besides these, the others are trying to introduce GSHPs into the Turkish market nowadays. In order to determine the number of GSHPs installed, information from 16 case studies was collected on residential and commercial systems from Turkish GSHP sellers (and also contractors) throughout Turkey. "Firm A" installed in 1998 a water-loop heat pump system (WLHPS) at Kaya Building consisting of 12 storeys in 1998 which was the biggest one in Turkey and is still active. Based on the data given by the "Firm B," six projects have been implemented for building heating ranging from an air-conditioned floor area of 650 m^2 to 24,900 m^2 by means of GSHPs. Two of them were completed in 1999 and the remaining is in progress. In fact, no reliable data were obtained from "Firm B" and it is heard that this firm went bankrupt. Besides these, no data was obtained from "Firm C." Therefore, only data given by the "Firm D," which is at present the single one in the installation of GSHPs in Turkey, were taken into account. The distribution of GHP systems installed by "Firm D" so far amounts to 16 vertical and 5 horizontal closed-loop systems, with 275 vertical ones in progress. In 1998 when the first installation was began, two GHP systems with a total capacity of 26 kW were completed, representing a total floor area of 596 m^2. These systems have had the largest growth since the beginning of the year 2000. Today, the installed capacity is 527 kW while the number of installed units is 23, totaling 43 units with the equivalent number of 12 kW. The 12 kW equivalent is used as typical of homes in the United States and some western European countries (Lund and Freeston, 2000). The size of individual units is in the range 9 to 46 kW and 38 to 46 for residential and commercial uses, respectively. Considering the ongoing installations, the total installed capacity will be 3,763 kW, with a total of 282 units ranging from 7.3 to 46.2 kW for both residential and commercial uses. In addition, by taking into account the new works, which are at the design stage, with a total 130 villas ranging from 120 to 310 m^2 of floor areas, it is estimated that the installed capacity will reach about 5 MW. Of the GHP systems installed up to date, 80% were vertical ground-coupled GHP systems while about half was designed for both heating and cooling. The diameter of U-bend tubes was 1 ¼ inches for the both applications. The heating and cooling loads were approximately 80 and 95 W/m^2, respectively. The majority of the installations are in the Marmara region (in the province of Istanbul).

Standardization Studies

Turkish standards relating to heat pumps are few in numbers. Up to date, 14 standards were issued on heat pumps by TSI (Turkish Standards Institution), of which only two contained the water to water type heat pumps (Hepbasli and Gunerhan, 2000). This means that standardization studies are also new in Turkey.

CASE STUDIES

In the following, the two case studies will be described. Of these, the first one relates to the University of Ege, Izmir, Turkey while the second one includes a commercial application, which replaced a furnace.

Case Study 1: Ege University

The water (ground)-to-water type heat pump (GSHP) system was connected to a 64-m^2 classroom of the Solar Energy Institute Building (SEIB) at the University of Ege, Izmir, Turkey. The building constructed in 1986 uses passive solar techniques and hence it was well insulated. It has three floors and a total floor area of 3,000 m^2. The GSHP system mainly consisted of three separate circuits, which are called the ground coupling circuit (brine circuit or water-antifreeze solution circuit), the refrigerant circuit (or a reversible vapor compression cycle) and fan-coil circuit (water circuit). The system was commissioned in July 2000. Performance tests still continue. From the measurements, the specific heat extraction rate was found to be 84.4 W per meter of borehole length, while the COP for cooling was about 3.1.

Case Study 2: Office Building

The building, located in Izmir, has 49 offices. The heating and cooling loads of the structure are 259 and 294 kW, respectively. The building was formerly designed for the heating only and hence heated by a 406-kW oil-fired hot water generator through fan-coils. The GSHP system replaced this hot water generator in June 2000 and has operated since that time. It was designed for both heating and cooling. No performance data were obtained from the installer. The measurement devices were missing in order to monitor the performance of the system.

CONCLUSIONS

The importance of energy as an essential ingredient in economic growth as well as in any strategy for improving the quality of life human beings is well established. In this context, energy, which can be defined as money and even cash from the viewpoint of energy efficiency, is the mainstay of the modern society. So, GHPs are attractive alternative to conventional heating and cooling systems. GSHPs are receiving increasing interest in Turkey. The technology is well established with over 500,000 units installed worldwide. The soil type and moisture content on the performance of GSHP have recently been reported by some investigators (Morino and Oka, 1994; Leong *et al*., 1998; Allan, 2000). However, in Turkey, this cost reduction factor, which can be achieved by decreasing the necessary ground loop length with the optimal selection of the backfill material, is not taken into account in the design. Besides these, for the successful development of GHPs in Turkey, the other issues given elsewhere (Hepbasli and Gunerhan, 2000) should be taken into account.

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GHPs Installations with Conventional Horizontal Ground Loop in Turkey as of January 2001

Situation of Application	City of Region	Building Type/No. of Buildings	Total Floor Area (m^3)	No. of HP Units (type)	Total Pipe Length (m)	HP Capacity (kW)	Total HP Capacity (kW)	Total Equiv. Number of 12 kW Units
Completed	Istanbul/ Marmara	Villa / 2	1,400 + 400 = 1,800	2 / (HC)	1,690 + 600 = 2,290	38 and 15	53.0	10
	Ankara/ Central Anatolian	Villa / 1	525	1 / (H)	850	46.2	46.2	
	Bolu/ Black Sea	Bungalow / 1	240	1 / (H)	420	9.0	9.0	
	Mersin/ Mediterrean	Villa / 1	435	1 / (H)	600	15.0	15.0	
TOTAL		5	3,000	(2HC 3 H)	4,160		123.2	

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DESIGN ASPECTS OF COMMERCIAL OPEN-LOOP HEAT PUMP SYSTEMS

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ABSTRACT

Open loop (or groundwater heat pump systems are the oldest of the ground-source systems. Common design variations include direct (groundwater used directly in the heat pump units), indirect (building loop isolated with a plate heat exchanger), and standing column (water produced and returned to the same well). Direct systems are typically limited to the smallest applications. Standing column systems are employed in hard rock geology sites where it is not possible to produce sufficient water for a conventional system. Due to its greater potential application, this paper reviews key design aspects of the indirect approach. The general design procedure is reviewed, identification of optimum groundwater flow, heat exchanger selection guidelines, well pump control, disposal options, well spacing, piping connections and related issues.

INTRODUCTION

Open-loop or Groundwater Heat Pump (GWHP) systems are the oldest and most well established of the ground-source heat pump systems. Despite this, little formal design information has been available for them until recently. Although seemingly simple in nature, these systems require careful consideration of well design, groundwater flow, heat exchanger selection and disposal in order that an efficient and reliable system results.

Several variations on the open loop system are in use. The most common of these are illustrated in Figure 1. The direct use of the groundwater in the heat pump units is largely

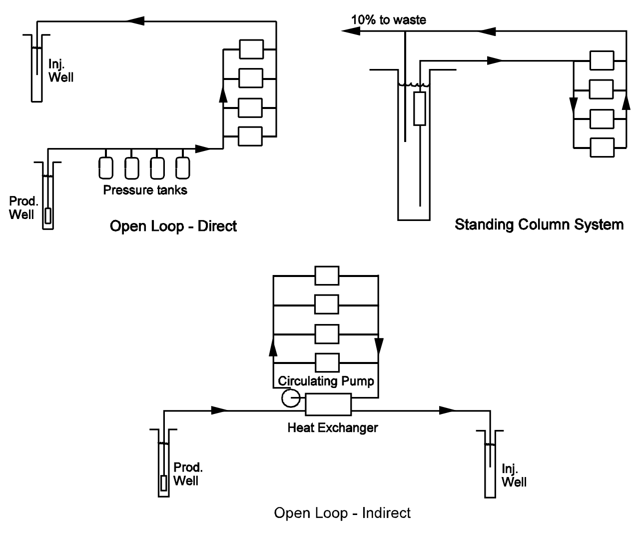

Figure 1. Open-loop systems.

an extension of residential design and is sometimes used in very small commercial applications. It is very susceptible to water quality induced problems, the most common of which is scaling of the refrigerant-to-water heat exchangers. This design is recommended in only the smallest applications in which practicality or economics precludes the use of an isolation heat exchanger and/or groundwater quality is excellent (the determination of which requires extensive testing). The standing column system has been installed in many locations in the northeast portion of the U.S. Like the direct groundwater system, it too is subject to water quality induced problems. In general, water quality in the area where most of the installations have been made (New England) is extremely good with low pH and hardness (little scaling potential). Standing column systems are used in locations underlain by hard rock geology; where, wells do not produce sufficient water for conventional open loop systems and where water quality is excellent. Well depths are often in the 1000 to 1500 ft range and the systems operate at temperatures between those of open and closed loop systems. In colder climates, this sometimes precludes the use of a heat exchanger to isolate the groundwater.

Indirect open loop systems employ a heat exchanger between the building loop and the ground water. This eliminates exposure of any building components to the ground water and allows the building loop and ground water loops to be operated at different flows for optimum system performance. Water can be disposed of in an injection well or to a surface body if one is available. These systems offer energy efficiency comparable to closed loop systems at substantially reduced capital cost. Due to the elimination of water quality and geology limitations this system type is the most widely applicable of the three and will be the focus of the balance of this paper

The design of an open loop system is one in which the performance of the system is optimized based on the power requirements of the well pump, loop pump and heat pumps. In a system of this configuration, it is apparent that the greater the ground water flow, the more favorable will be the temperatures at which the heat pumps will operate. As the ground water flow is increased, the improvement in heat pump performance is increasingly compromised by rising well pump power. At some point, increasing well pump power overshadows the improvement in heat pump performance and the total system performance begins to decline. The task in open loop design is to gather enough information about the well pump, loop pump and heat pumps to permit the identification of these trends and to select the optimum system performance point. It is the SYSTEM EER or COP that is the focus of the design not simply the performance of the heat pumps. The general procedure is to evaluate the well pump power required to produce a range of groundwater flows and combine that with the heat pump performance at those same groundwater flows. The optimum relationship between pumping power and heat pump performance is established at the design condition and system performance at off peak conditions is maintained by accurate well pump control. A spreadsheet used to make these calculations will be described at the end of this paper. Prior to that, however, it is useful to review some in the individual design issues of these systems.

WATER WELL TERMINOLOGY

Wells are the foundation of open loop systems and as such it is useful to review certain key terms prior to a detailed discussion of system design. Figure 2 provides a generalized diagram of a water well. In any well there will be a water level at which the water stands in the well under non-pumping conditions. This level is indicative of the water table level in unconfined (or water table aquifers) or the piezometric level in a confined (or artesian) aquifer and is known as the static water level (SWL). When the pump is started, water level will normally drop to a new, lower level referred to as the pumping level. The pumping level is a function of the rate at which the

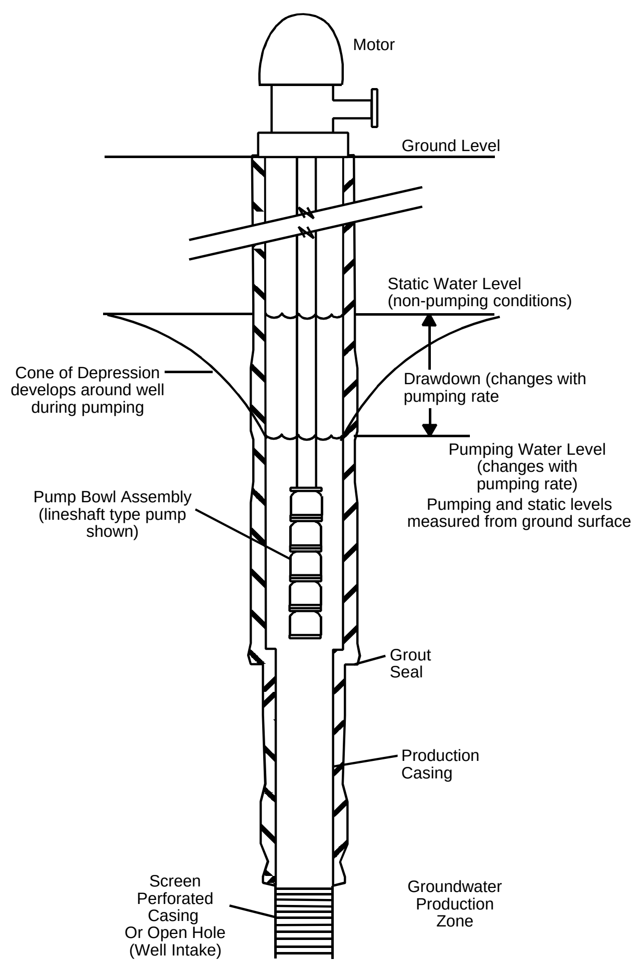

Figure 2. Water Well Terminology.

well is being pumped, the greater the rate the lower the pumping level. The difference between the SWL and the pumping level is referred to as the drawdown. Drawdown at a given pumping rate, divided by the rate results in a value known as specific capacity with units of gpm/ft (L/s·m). Specific capacity is a useful value for indicating the ease with which the aquifer produces water. A high value (2.1 L/s·m [10 gpm/ft]) would indicate a "good" well; whereas, a value of 0.1 L/s·m (0.5 gpm/ft) would be a "poor" well. For artesian aquifers, specific capacity will be a constant value over a broad range of flows. In water table aquifers, specific capacity will diminish as pumping rate increases.

The drawdown at a given rate is the manifestation, at the well, of the cone of depression that forms in the aquifer around the well during pumping. The size and shape of the cone and the depth of the drawdown are a function of the aquifer and it's ability to deliver water.

The construction of a well is also a function of the aquifer as. In "competent" rock formations, often the bottom of the well is uncased. This is referred to as open hole completion. In formations in which there is a tendency to cave, a slotted casing or possibly screen may be placed. In very fine sands and in thinly stratified formations, it may be necessary to place a "gravel pack" around the screen to provide additional filtering and to increase the permeability of the near well materials.

PRODUCTION WELL INFORMATION

A key part of the design process is the determination of the well pump power required for a range of ground water flow rates. To calculate these values it is necessary to know something about the performance of the production well in terms of the head (static water level plus drawdown) it imposes on the pump to produce the water. The best source of information are the results of a pump test of the well. This data normally includes pumping water level at three different flow rates and the pre-test static water level. Form this it is possible to calculate the pumping level at a wide range of flows and to incorporate this data into the design calculations.

Pump tests for GWHP systems are normally carried out in a period of from 2 to 12 hours. Water level and flow rate are monitored and readings are taken at frequent (5 min) intervals initially and less frequently (30 min) later in the test. Instrumentation is typically an orifice plate discharging to atmosphere and a manometer type differential pressure gage. Well water level is measured with an electronic continuity device with depth graduations on the wire. The length of the test determined to a large extent by the time required to reach apparent water level equilibrium at each flow rate. Once the level has stabilized, the rate can be increased to the next step. The result of the test is a table on which the flow rate, water level and time of each reading are recorded.

A second method of determining the performance of the wells at the site is to base it upon the performance of nearby wells in the same aquifer. Results from these wells may also provide information useful for the design of the new well. Construction details and sometimes pump test results are included in the well completion reports submitted by the driller upon completion of the well. They are normally kept on file (in some cases available on the internet) by the state water resources regulatory agency and are public information.

It is important that the well be completed in such a way as to minimize the production of sand. This is especially true if an injection well is to be used for disposal of the water. A well producing just 10 ppm of sand, operating a total of 1000 hr per year at 19 l/s (300 gpm) will produce 680 kg (1500 lbs) of sand. Sand production is best controlled by the careful specification of the well completion. Water well construction specifications are available from several sources (Roscoe Moss Co, 1985; EPA, 1975; Rafferty, 1999) and should be incorporated into the construction documents for the project. Key portions of the specifications related to sand are the screen slot size and gravel pack gradation. Both should be based upon a sieve analysis of the cuttings from the production zone. Allowable sand content is normally incorporated into the development portion of the specification.

If it is not possible to complete the well in such a way as to limit sand production, some form of surface separator will be necessary. Open tanks are not acceptable for this purpose. These tanks allow oxygen to enter the water and CO_2 to evolve from the water. If ferrous iron is present in the water, the addition of oxygen will alter it to a ferric state having much lower solubility. The result will be fouling of the heat exchanger. Evolution of CO_2 will raise the water pH thus making calcium carbonate scale more likely. The most effective surface sand removal device is a strainer. Strainers assure that effective removal will be accomplished at any flow rate or condition. Centrifugal devices are generally not designed to achieve the very low sand contents required for this type of application and they are subject to poor performance at pump start up and shut down.

WELL PUMPS

Open loop systems typically use submersible type pumps equipped for the most part with nominal 3,600 rpm motors. As a result, they are able to produce a higher flow per unit diameter than line shaft pumps which typically operate at speeds of 1800 rpm or less. The higher speed of the submersible also results in a greater susceptibility to erosion if significant sand is produced from the well. Submersibles are somewhat more sensitive to voltage variation than surface motors and adequate voltage (allowing for any drop in wiring to the well and down well) should be verified.

Calculating the head for a well pump involves some different issues than a similar calculation for a circulating pump. There are three main components to the total head: lift, surface losses and injection head. Lift is composed off the static water level plus the drawdown at the design rate. Its name derives from the fact that this is the vertical distance the water must be "lifted" by the pump to get it to the surface. Data to determine these values comes from the flow test of the well serving the system (preferred) or from information on nearby wells. Also included in the lift is the friction loss in the pump column (between the pump and the ground surface) which is usually on the order of 0.3 to 0.9 m (1 to 3 ft). Surface losses are those associated with the piping from the well to the building, mechanical room piping and equipment (heat exchanger, etc.) and piping from the building to the disposal point. Unless there are significant elevation considerations or distances involved, surface losses normally amount to less than 15 m (40 ft) assuming a 35 kPa (5 psi) loss in the heat exchanger. The type of disposal can have an impact on the total pump head. In surface discharge applications, often a pressure sustaining valve is used to maintain a small (less than 35 kPa [5 psi]) back pressure on the system to keep it full of water. For injection, the impact may result in added pump head (if a positive pressure is required at the surface) or reduced pump head (if the water level in the well remains below ground surface). A short discussion of injection well head considerations is presented in Kavanaugh and Rafferty, 1997. Table 1 provides an idea of the variation of pump head with flow for a system.

Table 1. Well Pump Head Example

Flow(L/s)	Lift(m)	Surface Losses(m)	Injection(m)	Total(m)
7.9	36.6	10.7	-7.0	40.3
9.5	39.0	12.8	-3.8	48.0
11.0	42.4	14.4	-0.6	56.2
12.6	43.6	7.9	2.5	54.0
14.2	46.1	8.2	5.7	60.0
15.8	48.8	8.5	8.9	66.2
17.4	51.9	9.2	12.1	73.2
18.9	54.3	9.5	15.3	79.1

This example is based upon a confined aquifer with a 23 m (75 ft) static level, specific capacity of 0.62 L/s·m (3.0 gpm/ft) a heat exchanger head loss of 70 kPa (10 psi) and 240 m (800 ft) total equivalent length of pipe and fittings. It is apparent that the lift is the most significant single component. The drop in the surface losses is due to a pipe size change. Most unusual is the injection head which changes from a negative value (water level in the injection well below the ground surface) to a positive value as the pressure builds with greater injection flow rate. Overall, the total head approximately linear with flow rate in this case. This is characteristic of well pumping applications and results from the heavy influence of the lift component.

Key components in the connection of the production well to the system are illustrated in Figure 3. Not shown in this diagram is a pump column check valve which would be located at the base of the column near the bowl assembly. The check valve maintains the column full of water and in doing so prevents damaging reverse thrust on start up. Submersible motors are equipped with a thrust bearing to resist the down thrust developed in normal operation. When starting with an empty column, a pump can exert a temporary up thrust on the motor which if encountered often enough can result in premature failure of the motor. To prevent this submersibles should be equipped with a column check valve.

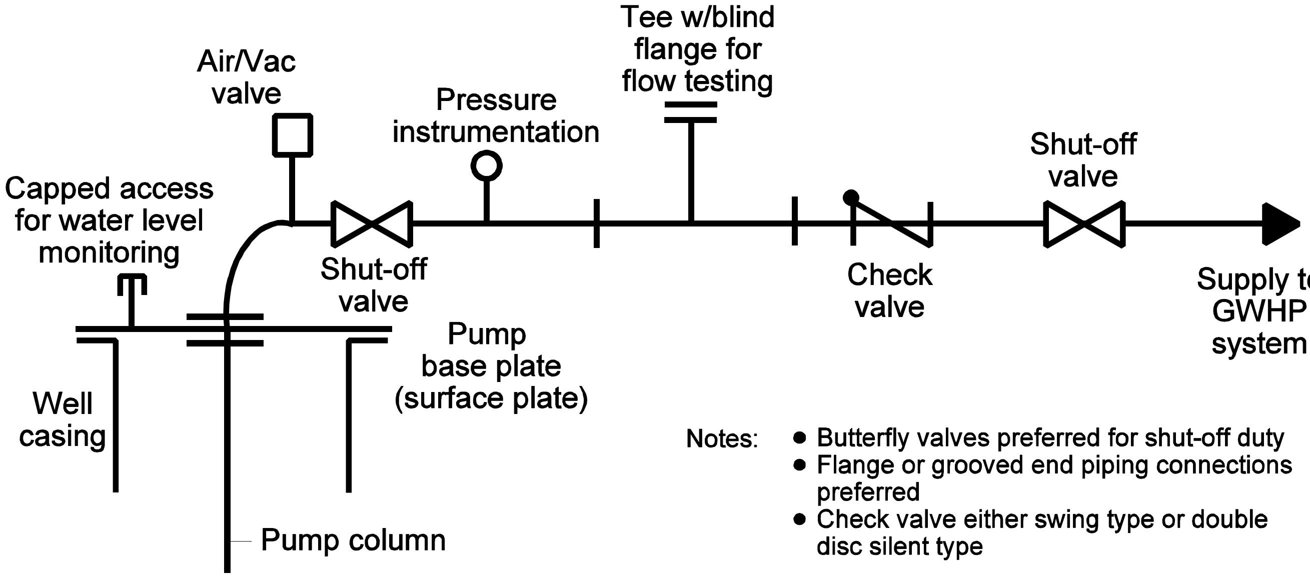

Figure 3. Key connection components for a production well.

Control of the well pump can be accomplished by numerous means. In the smallest systems (typically those without an isolation heat exchanger), the water is pumped to a number of pressure tanks arranged in parallel and the water admitted to the system from the tanks. Due to the extensive tankage required to accommodate this approach it is not normally employed in large systems. In these systems, typically one of three methods is employed: dual set-point, multiple-well (staged pumps), and variable-speed.

The dual set-point approach is fairly common in systems with a single production well and is reminiscent of the control used in water loop heat pump systems. Well pump operation is initiated above a given building loop return temperature in the cooling mode and below a given temperature in the heating mode. Between these two temperatures, the loop "floats." In actuality, the loop operates not between two temperatures but between two temperature ranges in order to adequately control cycling of the pump. For example, if the design indicated an optimum loop return temperature of 26.7 ºC (80ºF) in the cooling mode, the pump might actually start at a loop temperature of 28.3ºC (83ºF) and stop at 25ºC (77ºF). A similar, though smaller, range would exist around the heating mode temperature. The size of the range required around the control temperatures is heavily influenced by cycling limitations on the submersible motor (typically 15 min between starts) and the thermal mass of the building loop. Table 2 presents some guidelines for selection of the ranges based on the building loop thermal mass of the system as measured in gallons of water per peak block ton. This table is based on applications in which the cooling load is the dominant load on the system. This method can result in very large controller range requirements when system thermal mass is less than 8 - 10 l/kW (7 - 9 gal/ton). For such conditions, an alternate control method should be selected or some mass added to the loop. Additional detail on this topic is presented in Rafferty, 2000, and in this Bulletin.

Table 2. Controller Temperature Range for Dual Set Point Control ºC (ºF)

Motor kW (hp)	System Thermal Mass - l/kW (gal/block ton) 2	4	6	8	10	12	14
	COOLING MODE - ºC (ºF) RANGE						
<3.7kW(5hp)	16(28)	8(14)	5(9)	4(7)	3.3(6)	3(5)	2(4)
>3.7kW(5hp)	31(56)	16(28)	11(19)	8(14)	6(11)	5(9)	4(8)
	HEATING MODE - ºC (ºF) RANGE						
<3.7kW(5hp)	9(16)	4(8)	3(5)	2(4)	2(3)	2(3)	1(1)
>3.7kW(5hp)	18(32)	9(16)	6(11)	4(8)	3(6)	3(5)	3(5)

In systems in which multiple wells are required due to aquifer hydrology or redundancy, it is possible to employ a staged ground water pumping arrangement. This approach offers somewhat greater control than the single well approach above, but shares the same general approach. Since the pumps are staged, the required controller ranges can be reduced and the issue of system thermal mass is less influential.

Variable-speed control of well pumps is the least common of the three strategies. One of the reasons for this is that the primary purpose for using variable speed control, energy savings, is largely absent in well pump applications. Since a large portion of the well pump head is static head ("lift" described earlier) the nature of the relationship between flow and head is such that savings arising from the use of the drive are substantially less than they would be in a friction head application. Variable-speed control does offer more accurate control, allows optimization of the groundwater flow at any load and eliminates any considerations of system thermal mass. When using variable-speed, it is important to require confirmation from the contractor that the motor manufacturer is aware that his product will be used in a variable-speed application. Issues of conductor length (drive to motor) drive switching frequency, critical speeds and motor cooling must be carefully coordinated with and approved by the motor manufacturer to avoid operational problems.

HEAT EXCHANGERS

Open loop systems employ plate and frame type heat exchangers almost exclusively. These exchangers are key to the reliability of the system since they protect the building loop from exposure to the groundwater. In most cases, the cost of the exchanger is on the order of $7 to $8.50 per kW ($25 to $30 per ton)--a small price for the protection provided. Presence of the exchanger essentially eliminates water quality limitations to the use of open loop. The only common water quality problem which should trigger consideration of alternate design is iron bacteria. Issues of importance to the designer with respect to heat exchangers include pressure drop, approach temperature, materials, and installation issues.

In most commercial applications, the optimum design dictates a flow of 0.045 - 0.054 L/s·kW(2.5 to 3.0 gpm/ton) on the building loop side of the exchanger and 0.018 - 0.045 L/s ·kW(1 to 2.5 gpm/ton) on the groundwater side. As a result of this, the approach or minimum temperature difference between the two flows occurs at the building loop return (heat pump leaving water) and groundwater leaving end of the exchanger. Selecting the approach value is a trade off between operating costs (lower at low approach temperature) and heat exchanger capital cost (higher at lower approach). Dropping from an 4.4°C (8°F) to a 1.6°C (3°F) approach will normally gain approximately one full point in system EER. Due to the much flatter performance in the heating mode relative to EWT, the gain in heating mode performance for the added heat exchanger are amounts to approximately 1/3 of this value. As a result, the selection of heat exchanger approach is largely a function of annual system operating hours. The greater the operating time of the system, the easier it is to justify added exchanger area to achieve lower operating cost. For normal occupancy offices and schools, a 2.2°C to 3.3°C (4 to 6°F) approach is often the most economical.

Pressure drop selection is also a trade-of between operating cost and capital cost. Higher pressure drop in a plate exchanger results in higher overall heat transfer coefficient ("U") and lower transfer area (cost) for the same duty. The higher pressure drop however translates into pump head and operating cost. In open loop systems, the higher pressure drop is normally on the building loop side due to the higher flow rate. For systems involving a constant speed pump on the building side, a pressure drop of no greater than 35 kPa (5 psi) on the building side, should be specified. For systems using variable-speed on the building side, a pressure drop of no greater than 70 kPa (10 psi) should be used.

Materials considerations for plate heat exchangers are rarely a major issue. Most manufacturers offer 304 or 316 stainless steel as the base material for the plates and Buna-N (medium nitrile rubber) as the gasket material all of which are generally suitable for groundwater applications. In applications in which the groundwater contains more than 150 ppm chloride, 316 plates should be used in place of 304. For chloride concentrations greater than 375 ppm (a very rare occurrence), titanium plates should be specified. Piping connections and placement of plate exchangers should be configured in such a way as to allow easy access for disassembly and cleaning. If piping connections are required on the movable end plate, the piping should be of flanged or grooved end material to permit easy disassembly. It is generally not necessary to specify a two heat exchanger installation. Exchangers can normally be disassembled, cleaned and reassembled in a single shift. Contractors should be required to furnish at least one spare plate for each type of plate in the exchanger (usually at least two types of plates). Gaskets for the plates should be provided as well and glued in place (if of the "glue in" type).

DISPOSAL

There are two basic options for water disposal from an open loop system: surface and injection. Both options are subject to regulatory oversight and permitting. Surface disposal the most common method used in the past is less expensive, but requires that the receiving body be capable of accepting the water over a long period. Injection is more complex and costly but offers the certainty that the groundwater aquifer will not be adversely affected (aquifer decline) by the operation of the system over the long term since the water is "recycled."

For surface disposal, it may be advisable to place a pressure sustaining valve on the end of the system to maintain the piping full when the pump is not operating. Some designers prefer to simply place a motorized valve at this point in the system and interlock it with the pump (through an end switch). Distance from the building has some influence on the strategy used as the motorized valve requires a control signal and power source and the pilot-operated valve does not.

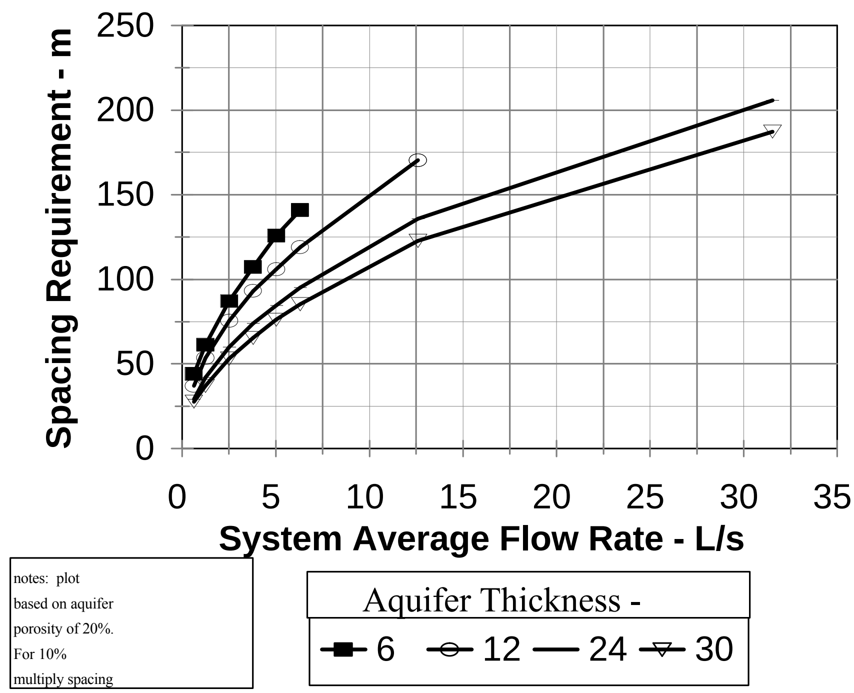

Figure 4. Well spacing requirements - minimum (from Kazmann and Whitehead data).

Injection is a more mysterious strategy to most mechanical engineers. Key issues are well design and well spacing. In theory, the only difference between an production and an injection well is the direction of flow. In practice, there are some differences in the design depending upon the type of aquifer penetrated. For wells completed in unconsolidated materials, and equipped with a screen, the screen area should be twice that used in the production well. The rule of thumb for injection wells is that the entrance velocity of the water through the screen openings (slots) should be limited to 0.015 m/s (0.05 ft/sec); whereas, production wells are normally based upon 0.030 m/s (0.1 ft/sec). This does not mean that a larger diameter well is required in all cases. The reduced velocity could also be accomplished by screening more of the aquifer, particularly in the case of wells penetrating water table aquifers. For wells completed in fractured rock and completed "open hole," there is often no difference between the injection and production well design. Sealing is an important issue in injection wells. Because it is likely that the water level in the well will be higher than the static water level when in operation, it is important that the seal (grout placed between the borehole and the outside of the casing) be carefully placed and that it extends from the top of the aquifer to the ground surface. This prevents the injected water from finding a path up around the outside of the casing to the surface.

Well spacing, or the distance required between the production and injection wells is an important consideration. It is not necessary that the injection well be sited in such a way as to prevent any flow from the injection to the production well, just that any inter-well flow be sufficiently low that it arrives at the production well at a temperature close to the aquifer temperature. For unconsolidated aquifers, the method developed by Kazmann and Whitehead provides a guideline for minimum spacing. In order to use the method, it is necessary to know the aquifer thickness, porosity, system average flow rate and the period of duration (days) of the dominant load. The method is covered in detail in Kavanaugh and Rafferty, 1997. A summary of spacing information appears in Figure 4.

Connection of the system piping to the injection well is illustrated in Figure 5. Of particular importance is the injection "dip tube" in the well. Injected fluid should always be released below the static water level in the well so as to minimize the formation of air bubbles. Bubbles entering the injection zone can impede water flow just as an accumulation of particulate would. The air release valve also helps to minimize the air in the injection well. This component is especially important in systems which cycle the well pump. A means of diverting the water flow in the event that the well must be removed from service allows the system to continue operation with temporary surface disposal. Finally, the provision for pressure (or water level) monitoring is important in injection wells as a means of monitoring the performance of the well and any accumulation of particulate in the injection interval.

There is a perception that injection wells often fail. This is false. In fact, the failure is normally that of the designer not the well. Poor production well performance in terms of sand content coupled with the lack of a surface removal system inevitably means that this material will be deposited in the injection well. Successful injection requires clean, particle free fluid. The system must be designed with this as the goal.

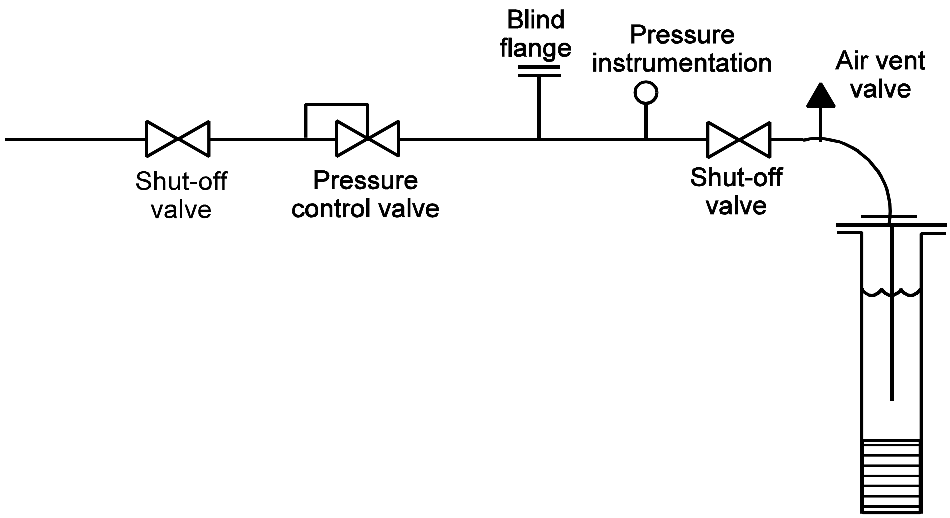

Figure 5.   Injection well piping connections.

Wells								
GW temp	60	F	**Syst EER**	13.10		**Syst COP**	3.49	
Static	75	ft	Flow	149	gpm	loop pump	4.76	kW
Spec cap	2	gpm/ft	gpm/ton	1.75	gpm/ton	Unit COP	4.3	
Flow	40	gpm				Loop out	54.2	F
Drawdn	25	ft	**Pump**			Loop in	47.9	F
Aquifer t	150	ft	Flow	149	gpm	GW lvg	50.9	F
Inj Well ?	0	1-Y, 0-N	Head	186	ft			
Inj Eff	0.8		Setting	174	ft	**GCHP**	12.70	EER
			Heat Ex					
Building			GW in	60.0	F			
Load	1020000	Btu/hr	GW out	76.6	F			
Htg Load	900000	Btu/hr	Loop in	80.6	F			
Htx dp	7	psi	Loop out	69.0	F	**Control**		
Hd loss	37	ft	Area C	265.0	sq ft	cool on	86	F
Approach	4	F	Area H	204.6	sq ft	cool off	75	F
Loop flow	213	gpm	Inj Well			heat on	44	F
Loop head	65	ft	Distance	0	ft	heatoff	51	F
HP brand	8		Inj press	0	psi			
Syst vol	1000	gal						

EWT	LWT	h/p EER	LWT GW	GW Flo	gpm/ton	GW head	GW kW	SYS EER
53.00	64.26	19.40	60.26	9192.54	108.1	262.0	157.075	0.00
55.00	66.31	18.90	62.31	1044.50	12.3	262.0	65.693	0.00
57.00	68.34	18.50	64.34	556.32	6.5	262.0	41.684	0.00
59.00	70.38	18.10	66.38	379.88	4.5	301.9	35.108	0.00
61.00	72.43	17.60	68.43	288.77	3.4	256.4	23.664	11.81
63.00	74.47	17.30	70.47	233.35	2.7	228.7	17.509	12.56
65.00	76.51	16.90	72.51	195.97	2.3	210.0	13.742	12.93
67.00	78.56	16.50	74.56	169.10	2.0	196.6	11.409	13.08
69.00	80.61	16.10	76.61	148.87	1.8	186.4	9.722	13.10
71.00	82.66	15.70	78.66	133.09	1.6	178.5	8.452	13.05
73.00	84.71	15.30	80.71	120.45	1.4	172.2	7.468	12.93
75.00	86.74	15.10	82.74	109.97	1.3	167.0	6.676	12.91
77.00	88.77	14.90	84.77	101.21	1.2	162.6	6.032	12.87
79.00	90.82	14.55	86.82	93.88	1.1	158.9	5.506	12.69
81.00	92.88	14.20	88.88	87.61	1.0	155.8	5.065	12.49
83.00	94.94	13.85	90.94	82.18	1.0	153.1	4.691	12.27
85.00	97.00	13.50	93.00	77.44	0.9	150.7	4.370	12.04
87.00	99.03	13.30	95.03	73.16	0.9	148.6	4.085	11.92
89.00	101.07	13.10	97.07	69.35	0.8	146.7	3.835	11.80
91.00	103.13	12.80	99.13	66.02	0.8	145.0	3.620	11.58
93.00	105.19	12.50	101.19	63.04	0.7	143.5	3.429	11.36

Figure 6.   Spreadsheet for open-loop system design.

DESIGN PROCEDURE

Figure 6 provides a summary of a spreadsheet developed to design open loop systems. This spreadsheet was developed in English units and no SI version is available. The spreadsheet illustrates the information necessary to accurately design an open loop system. Unshaded values are input and shaded values are output. In general, all of the information concerning the well or wells would be available from the driller's completion report and/or the flow test results. With the exception of the groundwater temperature, all of the values are used primarily for the calculation of well pump power. Such items as the static water level, specific capacity (entered only for confined aquifers), flow and drawdown (entered only for unconfined aquifers) and aquifer thickness (used in the determination of well spacing) are all characteristics of the aquifer itself and although necessary as inputs, they are not "adjustable" by the designer. The final two well related inputs indicate whether or not an injection well will be used and if so, what the injection efficiency is expected to be. Injection efficiency is a value used to adjust the drawdown (from the flow test) to calculate the expected pressure buildup at the injection well for the same flow. It is used in the calculation of the well pump head.

Building loop related inputs include the building block cooling and heating loads (expressed as space loads), the pressure drop for which the heat exchanger will be selected, surface head losses for the groundwater loop (piping, heat exchanger, fittings etc), heat exchanger approach (between groundwater leaving and building loop entering), building loop flow rate and head loss, heat pump brand (to calculate COP, EER), and system water volume (to calculate loop thermal mass and well pump control set points).

The table in the lower portion of the figure indicates the calculations for the cooling mode. The spreadsheet calculates heat pump performance at a series of entering water temperatures (EWT's), and using the performance and EWT, calculates a series of LWT's. Using the LWT value (assumed to be equal to the building loop heat exchanger entering temperature), and the specified heat exchanger approach a ground water heat exchanger LWT is calculated. Using the load information and the groundwater temperature rise, the groundwater flow is calculated. With the input data on the well performance, the head on the well pump at each of the flows is calculated and from this, pump horsepower and kW are determined. Combining the well pump power, loop pump power and heat pump power, the final calculation is the system EER. A similar calculation is made for the heating mode (Figure 7).

The spreadsheet is configured to look at the cooling load as the primary load and it selects the peak EER value from the table and displays it along with the groundwater flow in the output section. This is the flow rate for which the well pump would be selected. Well pump design information is located just below the cooling mode output. Shown are the flow rate and head for which the pump would be selected along with the setting depth for the bowl assembly (depth at which the pump suction should be located). Heat exchanger data includes the cooling mode entering and leaving temperatures at the peak condition along with calculated surface area requirements in the heating and cooling modes. These surface area values are not intended to be specified to the vendor but are used to give the designer an indication of which mode (heating or cooling) is dominant in the system design. If an injection well was specified in the input, the spreadsheet, using the aquifer thickness and flow rate, calculates a separation distance requirement for the production and injection wells. Based on the flow test drawdown or specific capacity and the injection well efficiency specified, the spreadsheet calculates the injection well pressure (at the ground surface) at peak flow.

Peak heating mode performance values are displayed in the next column. All values shown are based on an assumed heat exchanger approach as specified in the input. In most cases, the heat exchanger area required for cooling exceeds that for heating. As a result, the system will operate at more favorable temperature than that which is indicated in

EWT	LWT	h/p COP	LWT GW	GW Flo	GW head	GW kW	SYS COP
35	28.8	3.68	32.8	48.3	136.1	2.20	3.35
37	30.8	3.75	34.8	52.4	138.2	2.42	3.40
39	32.8	3.81	36.8	57.1	140.6	2.69	3.44
41	34.7	3.88	38.7	62.8	143.4	3.02	3.48
43	36.7	3.94	40.7	69.6	146.8	3.42	3.51
45	38.7	4.01	42.7	77.9	151.0	3.94	3.54
47	40.6	4.08	44.6	88.3	156.2	4.62	3.56
49	42.6	4.14	46.6	101.8	162.9	5.56	3.56
51	44.6	4.21	48.6	119.9	172.0	6.91	3.55
53	46.5	4.27	50.5	145.5	184.8	9.01	3.49
55	48.5	4.34	52.5	184.6	204.3	12.64	3.37
57	50.5	4.41	54.5	251.5	237.7	20.03	3.12
59	52.4	4.47	56.4	392.4	308.2	40.53	2.53
61	54.4	4.54	58.4	883.4	262.0	77.55	0.00
63	56.4	4.60	60.4	-3661.6	-1718.8	2108.74	0.00
65	58.4	4.67	62.4	-599.7	-187.8	37.74	0.00

Figure 7. Calculations for the heating mode (from Figure 6).

this column. The spreadsheet includes a heat exchanger analysis module to make this evaluation.

For convenience, the performance of a vertical closed loop system using the same heat pumps and designed for 11 ºC (20 ºF) above the undisturbed soil temperature is displayed in the output to provide the designer with a comparison system.

Finally, set point temperature for the well pump in the heating and cooling modes are displayed based on the system volume specified in the input. These temperature assume the use of a single production well with a single speed pump.

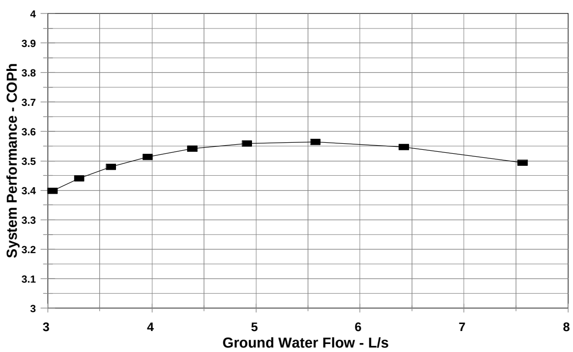

Figure 8. Heating performance.

Graphs of the heating and cooling mode performance are shown in Figures 8 and 9. These provide a clearer indication of the systems performance in the different modes and permits the designer to evaluate the impact at operation at other than the peak performance selected by the spreadsheet.

CONCLUSION

Open loop systems can offer the owner performance comparable or in some cases better than that of closed loop systems. Despite their long history of use and perceived simplicity, care is required in the design and installation in order that the ful potential of the systems be achieved. Some important guidelines along with a useful design tool are illustrated in this paper. The following "10 Commandments" of open loop design will help to keep the designer on track to a reliable and efficient system:

THINK SYSTEM - well pump, heat pumps, loop pumps
PUMP LESS WATER - reasonable loop and groundwater flows
KNOW THE LOAD - design for block load not installed capacity
KNOW THE AQUIFER - static level, specific capacity, drawdown, flow test
KNOW THE RULES - verify groundwater regulatory issues
DO YOUR HOMEWORK - previous groundwater experience in the area, other wells
KNOW THE GROUND WATER - complete chemistry test if used directly
KEEP THE AIR OUT - no open tanks
ISOLATE THE GROUND WATER - use a plate heat exchanger
KNOW YOUR LIMITATIONS - in complex settings use a hydrogeologist

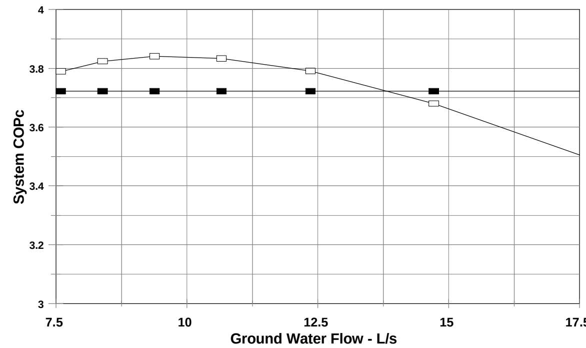

Figure 9. Cooling performance.

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SPECIFICATION OF WATER WELLS

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ABSTRACT

The water well or wells serving a Ground-Water Heat Pump (GWHP) system are as pivotal part of the mechanical design as the boiler and cooling tower would be in a water loop system. As such they should warrant the same degree of attention with respect to specification as the more conventional components would receive. Unfortunately, this is rarely the case and the HVAC design engineers lack of familiarity with the topic is sometimes at fault. This paper is intended to identify the key sections of water well specifications and briefly discuss their contents.

INTRODUCTION

Design and construction of water wells is a topic unfamiliar to many, if not most mechanical engineers. As a result, the task is often poorly handled or worse, ignored. This rarely results in a well completed in the best interests of the owner. Although the HVAC engineer may not always be directly responsible for the design of the well, it's specification or construction management, it is, in the context of a ground-source heat pump system, a critical part of the mechanical design. Consequently, it is in the interest of the HVAC design engineer to become familiar with the terminology of water wells and the key specification issues relating to their construction. The goal of this paper is not to provide suggested specification text but to briefly discuss the key sections found in a well specification document and comment on the contents of each.

WATER WELL TYPES

The design of a water well and the preparation of the construction documents related to it is a function of several issues including the purpose (domestic, municipal, irrigation, injection, etc.), capacity (low <10 gpm [0.6 L/s], medium 10 - 100 gpm [0.6 - 6.0 L/s], high >100 gpm [>6.0 L/s]), geology penetrated (consolidated, unconsolidated, combination) and construction method (mud rotary, air rotary, reverse circulation, cable tool) (NWWA, 1975). Since this paper is limited to wells serving commercial GWHP systems (normally medium to high capacity, rotary constructed), the primary influence on design and specification is the nature of the geology penetrated in the process of construction.

Although, there are an infinite number of well construction designs for a substantial part of the country, the alternatives can be reduced to some variation on one of the two basic designs as shown in Figures 1 and 2. Special modifications to these basic designs can be made to accommodate conditions such as artesian aquifers, injection rather than production, corrosive water etc. The simplest well is one completed in rock formations in which the water is produced from fractures in the rock. In these wells, sometimes called open-hole completions due to the nature of the geology, no casing or screen is necessary to stabilize and filter the aquifer materials adjacent to the well bore. Casing is normally placed in the upper portion of the well for a short distance to accommodate the installation of a surface seal.

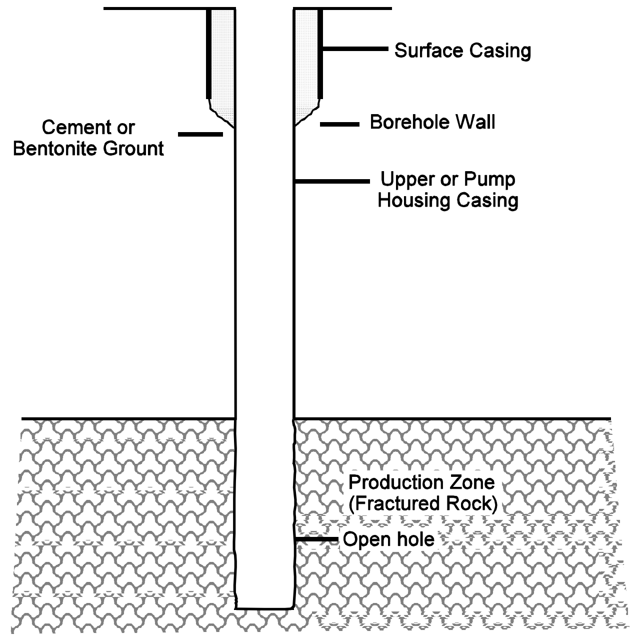

Figure 1. Open-hole well completion.

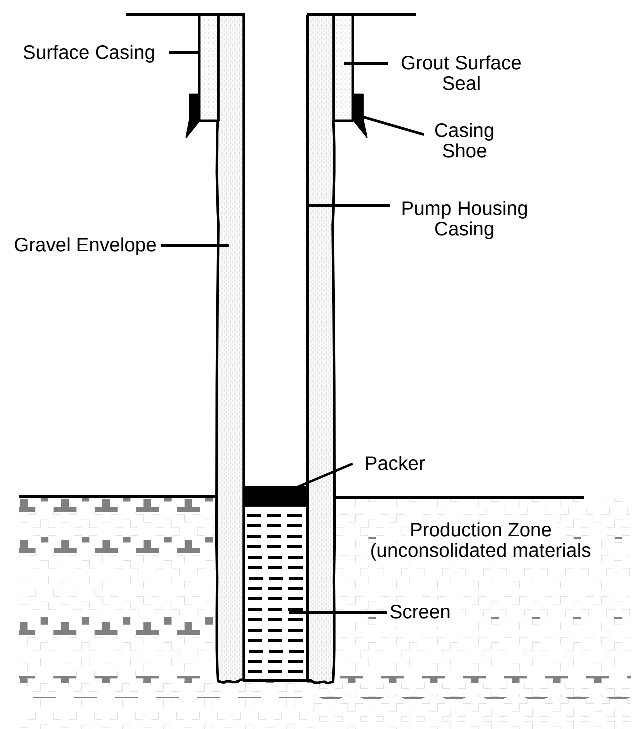

Figure 2. Gravel envelope well.

The second type of well, completed in unconsolidated materials (sand, gravel, clay, soil and mixtures thereof) is more complex. In these applications the well is completely lined with casing, screen and sometimes an artificial filter or "gravel pack." In unconsolidated settings, the variation in the size of the aquifer materials results in the need to adequately filter the water entering the well to control the content of sand in the water produced. In some cases, a screen alone, attached to the bottom of the casing, will provide the necessary filtering of the water. In other cases, the screen must be accompanied by an artificial filter or gravel pack located between the screen and the borehole wall. This gravel is sometimes only a formation stabilizer of relatively uncomplicated description. For other situations, a more carefully specified filter gravel must be used. The need for accurate description of these components and their installation results in a more voluminous specification document for these wells compared to an open-hole well.

WATER WELL TERMINOLOGY

Prior to discussing the details of individual well specifications sections, it is useful to review a few of the key terms relating to water wells and their operation. Figure 3 includes many of these terms. In any well, under non-pumping conditions, the level at which the water resides in the well is known as the static water level. When the pump is started, the water level will drop to a new level known as the pumping level and this level is a function of the pumping rate. The difference between the static water level and the pumping level is referred to as the drawdown. Dividing the pumping rate by the drawdown yields a value known as the specific capacity with units of gpm/ft (lps/m). This value provides a rough indication of the aquifer/well capacity to produce water. The drawdown is the manifestation, at the well, of the "cone of depression" which forms around the well in response to pumping.

The lower portion of the well in the production zone may be completed with only a borehole (in rock formations), a screen or with a screen and artificial filter (gravel pack) depending on the nature of the aquifer materials. Casing is placed in the well to support the borehole and prevent collapse, to accommodate the installation of a pump, or to facilitate the placement of a seal. The diameter of the innermost well casing (known as the pump housing casing)is primarily a function of the size pump to be installed. Submersible pumps, the type most often used in GWHP systems due to their operation at 3600 rpm, often require one size smaller casing than line shaft driven pumps which normally operate at 1800 rpm or less. Other well casing is sometimes installed in the upper portion of the well to accommodate the installation of the surface seal. The surface seal, often a cement grout, prevents surface water from draining down between the casing and borehole into the subsurface.

WELL SPECIFICATION ISSUES

There are several areas which should be addressed in the course of preparing a specification for a water well and

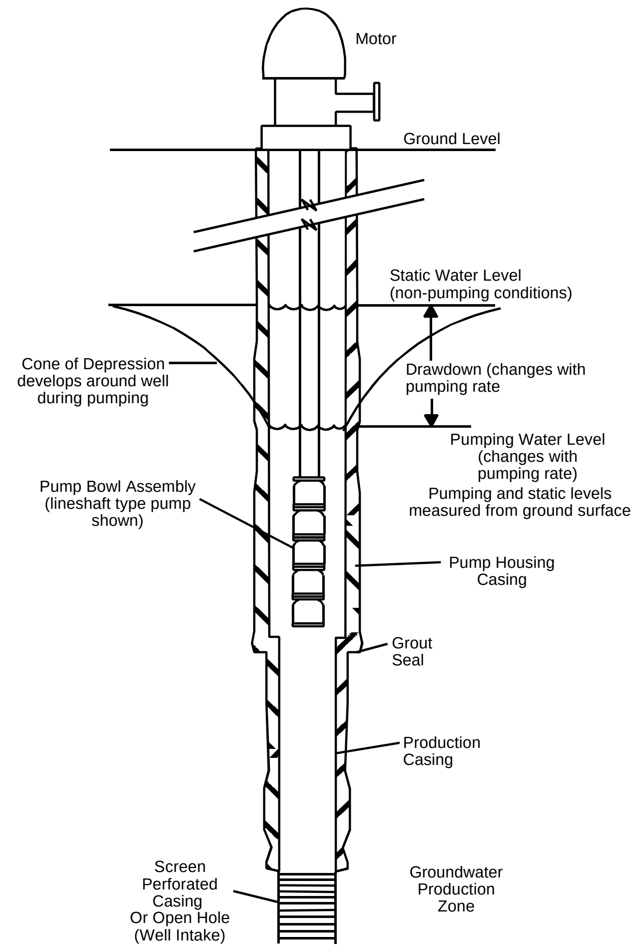

Figure 3. Water well terminology.

Table 1 presents the most important of these. Some issues relate only to certain types of wells or conditions, but this table is a useful checklist for the specification process. There are two approaches to the design and specification of a water well. If there are other wells nearby producing from the same formation and of approximately the same yield, the design of a new well can be based upon the existing wells. This is an acceptable practice assuming the existing wells operate without problems. In other cases, the well design is determined to a large extent by the geology and aquifers it penetrates. A preliminary design can be developed, but it may be necessary to modify this in the course of construction.

Table 1. **Key Water Well Specification Sections (gravel pack well)**

Scope of Work	Logs/Records	Flow testing
Non-Technical Well Issues	Plumbness/Alignment	Sterilization
Equipment Requirements	Casing	Abandonment
Drilling Fluid	Screen	
Drilling Program	Gravel	
Formation Sampling	Development	

For a well completed in a consolidated formation (rock), the sections on screen, gravel and sometimes development can be eliminated.

SCOPE OF WORK

This is the section in which a general description of the work is provided. The scope at a minimum, includes the type of drilling rig to be used, approximate depth and number of wells along with the expected yield for production wells. When available, the scope may also provide additional detail on the general construction of the well in terms of casing size, depth, screen type diameter, location and development method. If a performance guarantee with respect to yield, or specific capacity is required, this is also included in the scope section (Roscoe Moss, 1985).

NON-TECHNICAL WELL ISSUES

Non-technical well issues (a phrase used in this paper and not in the specification document) include items not directly related to the technical details of construction. Contractor qualifications, site description, noise control, archeological discovery and facilities provided by owner are normally covered as individual sections, but are grouped together here for simplicity.

The contractor qualifications paragraph normally includes a minimum experience requirement (number of wells similar to the current project, and years in business) and a licensing requirement. Details for a list of reference projects may also be spelled out. The site description is especially important, particularly if potential drillers are from outside the area. A physical description of the site is provided along with background on the geology/hydrogeology. If available, well completion reports from nearby wells are a key part of this information. Noise is normally addressed through the specification of acceptable operating hours for drilling operations. Facilities provided by the owner is one of the few specification issues actually requested by contractors–particularly in the case of site access and water availability. Sufficient water supply for the drilling operation is a critical issue.

EQUIPMENT REQUIREMENTS

In this section, either a specification is made with respect to the drilling rig capabilities required and/or a form is provided on which the contractor must submit a description the equipment to be used in the construction of the well. In cases of shallow wells, such issues as mast, hook and draw-works load limits are not often approached even for small rigs. As a result, it is possible to omit this section in some small projects.

DRILLING FLUID

This is a section that relates primarily to conventional (direct) rotary drilling operations. In this section, an acceptable value (or range of values) for key drilling fluid (sometimes called “mud”) parameters is provided. The drilling fluid or mud is circulated down the rotating drill pipe, out the bit and back up the annular space between the borehole wall and the drill pipe. It serves to lubricate and cool the bit, carry away the cuttings and form a “cake” stabilizing the borehole walls. Included are such characteristics as weight (11 lbs/gal maximum), marsh funnel viscosity (32-38 seconds maximum), 30-minute water loss (15 cc maximum), filter cake formation (2/32" [1.6 mm] maximum) and sand content (2% maximum). It should be understood that fluid parameters are regularly adjusted in the course of drilling to accommodate situations encountered in the construction process. In some fluid specifications, reference is made to a requirement for a drilling mud engineer’s involvement in the project. On small projects, these services are usually available to the drilling contractor from the mud vendor and the specification of a mud engineer’s availability to the contractor rather than his on site presence is appropriate.

DRILLING PROGRAM SUBMITTAL

This section provides the requirements for submission, by the contractor, of a schedule of tasks to be completed in the process of completing the well. Included are personnel, schedule of tasks (drilling, casing, screen gravel installation, development), and details of the drilling fluid make-up (additives) (Roscoe Moss Company, 1985)

FORMATION SAMPLING

Formation sampling, described in this section is a pivotal part of the well drilling process. It is the samples from the production zone of the well from which decisions are made as to the screen slot size and gravel pack gradation necessary for completion. In rotary drilled wells, if a pilot bore is used, the samples are taken as the pilot hole progresses. If the approximate depth of the producing zone is known, it is normal practice to specify a regular interval over which samples will be taken, the handling, appropriate containers and labeling of the samples along with the individual (or organization) to whom they should be delivered. Sieve analysis of these samples provides the data upon which screen slot size and gravel pack size distribution are based. This consists of passing the samples through a set of progressively finer sieves or screens to determine the size distribution of the sampled material.

LOGS/RECORDS

Depending on the depth, drilling method and purpose for the well, a variety of logs and reports may be specified in this section. For wells of the type used for GSHP systems, it is normally sufficient to specify that the driller report on the depth and physical description of strata penetrated, depth of water producing intervals, and associated static water levels and penetration rates accomplished. If well completion reports are required by regulatory agencies, copies should be provided to the owner/engineer as well. Reporting requirements for flow testing, development and plumbness/alignment are covered in those respective sections.

PLUMBNESS/ALIGNMENT

Plumbness (deviation from the vertical) and alignment (“straightness”) of the well are issues of importance with respect to the installation of a pump in the well. In particular, lineshaft type pumps are much more sensitive to the alignment issue than are submersible pumps. With a rotating shaft extending from the surface to the pump (sometimes hundreds of feet down in the well), wells in which lineshaft pumps are to be installed must be held to tighter tolerances than submersible installations. Two approaches can be taken to this specification. For small projects using a submersible pump, the required test often involves a 40 ft (12 m) section of pipe ½"(12 mm) smaller in diameter than the inside of the casing, which must be capable of passing freely through to the bottom of the pump housing casing. For larger wells or those using lineshaft pumps, a more sophisticated test involving a device for measuring deviation of the bore is necessary.

CASING

Casing is a term that refers to tubular material extending from the surface to some depth in the well. It is installed to accommodate the sealing of the well, to stabilize the walls of the borehole or to allow the installation of screen or liner (tubular products not extending to the surface). In shallow wells of the type serving GWHP systems, at least two types of casing are often found. Surface casing is installed a short distance (to the first impermeable strata or minimum of 18 ft [6 m] by many codes) from the surface to a depth sufficient to allow the installation of the surface seal (usually cement grout) between the surface casing and the wellbore. The surface casing also helps to support near surface unconsolidated materials during the drilling operation. Sometimes, this surface casing is removed as the grout is placed.

The second casing type is the pump housing casing which as the name implies is the casing in which the pump is installed. This casing is installed inside the surface casing, from the surface to the top of the screen in gravel pack wells or to the top of the producing interval in shallow open hole wells. If used, the screen would be attached to the bottom of the pump housing casing.

In the casing portion of the specification, information is provided on the size, wall thickness, material, and installation method of the casing along with the location (depth), in some cases. Surface casing is normally at least two inches larger than the pump housing casing in order to accommodate the placement of the grout to an adequate thickness. Diameter of the pump housing casing is a function of the pump to be paced in the well. Generally, it is desirable to have a pump housing casing of two nominal sizes larger than the pump to be installed. Pump bowl (impeller housing) diameter is related to pump type and flow rate. Submersible pumps, which typically operate at 3600 rpm, produce more flow per unit diameter than lineshaft pumps which operate at 1800 rpm or less. In most commercial applications, a minimum of 6"(150 mm) casing would be used with 8" (200 mm) for flows >100 gpm (6 L/s) and 10"(250 mm) for flows >300 gpm (18 L/s)(Kavanaugh and Rafferty, 1997). Casing wall thickness is normally specified in this section. Wall thickness requirements vary with drilling method, depth, diameter and seal placement. In general for sizes up to 14" (350 mm) and depths to 600 ft (180 m), 0.250"(6 mm) wall thickness is acceptable (AWWA, 1997). Most wells serving commercial applications use carbon steel well casing. Plastic materials can be used in very shallow applications permit. Detailed specifications are available on the placement of the casing; however, drilling method (rig type) largely determines the techniques used and in many cases, this issue simply adds needless detail to the well specification.

SCREEN

The screen plays a critical role in the performance of the well since it provides the filtering of the water entering the well. In this section, the type of screen, aperture size, diameter, length, entrance velocity, and material of the screen is described along with the installation method. The determination of aperture (slot) size is made based on the results of a sieve analysis of the drill cutting samples from the production interval of the well. On occasion, when sufficient information is available, the screen can be specified based on the performance of existing wells in the same aquifer. For this to be an effective strategy, detailed knowledge of the geology must be available. In applications where no gravel pack will be used, the screen slot size is specified as that which will retain 30 to 50% of the aquifer materials depending on the corrosiveness of the water and the uniformity coefficient of the aquifer materials. In applications where a gravel pack will be used, the slot size is selected for retainage of 70 to 100% of the gravel pack materials (AWWA, 1997). All slot size selections are based on the aquifer materials sieve analysis distribution curve. The specification can allow the contractor to have a lab do the analysis with the results delivered to the owner/engineer for approval or the samples can be delivered directly to the owner/engineer for analysis.

There are several types of screens available and two of the most common are wire wound and louvered. Wire wound screens (continuous slot) provide a higher degree of open area, through which the water can pass (a critical issue in fine sand aquifers), are generally more expensive than other types and in larger diameters are lower in collapse strength. Louvered screens are generally less expensive, have higher collapse strength, lower open area and provide for more effective development using swabbing. Entrance velocity specification influences the type of screen. In many references (some written by a major manufacturer of wire wound screen), an entrance velocity limit of 0.1 ft/sec (0.03 m/s) is cited. This low velocity tends to require the use of screens with high open area ratios (wire wound). Other research suggests that entrance velocities of as much as an order of magnitude greater than this do not significantly reduce well performance in many applications. Wire wound screens are normally constructed of 304 stainless steel to reduce corrosion problems. Louvered screens can be of carbon steel in many applications due to their higher strength.

Placement of the screen, like the placement of the casing is best left to the contractor; since, it is determined to a large extent by drilling method.

GRAVEL

Gravel is sometimes placed outside the screen to support the aquifer materials (called formation stabilizer) or to increase near bore permeability and to assist in filtering aquifer materials (called artificial filter). Regardless of function, the common term for the practice is gravel pack. The importance of the selection of the size distribution of the gravel material is much greater when it is intended to serve as an artificial filter. Issues to be addressed are size, gradation (uniformity coefficient), geology, thickness and placement.

As in the case of the screen slot size selection, the determination of the gravel pack parameters is based on the cuttings sieve analysis results. One common criteria for the gravel pack specifies that it have a 70% retained grain size of 4 to 6 times the 70% grain size of the cuttings sample and a uniformity coefficient (40% size divided by 90% size) of not greater than 2.5 (NWWA, 1975). Gravel material should be clean and well rounded with a maximum of 10% flat surfaces and should be a minimum of 95% siliceous in content (to avoid dissolution in low pH water).

The thickness of the gravel pack should be between 3 and 8" (75 and 200 mm) thickness. Placement of the gravel is generally accomplished by either pouring from the surface (in shallow wells) or by placement through a tremie (in wells of greater than 1000 ft depth [300 m])(Roscoe Moss Company, 1985). In most shallow wells of the type serving GWHP systems, the pack material will be poured from the surface. This is done while circulating drilling fluid down the drill pipe and up the annular space (between the casing and the bore wall). A key part of the specification is the requirement to maintain drill fluid density below a specific density limit (9.1 lb/gal). The fluid tends to pick up drilling mud from the walls of the borehole as the gravel is placed. The viscosity limit requires this material to be continuously removed during the process. The gravel placement should be completed in one continuous operation.

DEVELOPMENT

The process of development is one in which the fines in the aquifer material or gravel pack and any remaining drilling fluids in the near bore area are removed by a variety of methods. The development process is divided into two phases--initial development using the drilling rig and final development by pumping after the rig has been removed. To some extent, the type of development is influenced by the geology and well type. Specifications describe the type of development, when it should be terminated and most importantly in the final development, what the acceptable sand production for the well is.

In gravel pack wells, preliminary development is often by the so called "flushing" method using a tool known as a "double swab" which can be accomplished with the rotary rig. A more effective method known as line swabbing requires the use of a cable tool rig. Both of these methods are best applied with louver type screens. Jetting is a development technique often used most effectively with wire wound screens and it involves directing high velocity water jets at the screen/gravel pack. Air lift pumping and sand pumping (used in naturally developed wells) are other methods of development.

Preliminary development is carried on until all of the fines and sediment have been removed from the gravel pack and the pack ceases to settle. Final development is carried on until the specified sand content of the production water is reached. This limit is typically expressed as a sand content in ppm after some period of pumping. Water samples for chemical analysis can be taken toward the end of the preliminary development or during final development pumping.

WATER SAMPLES

Water samples for the purpose of analysis for system design (corrosion and scaling) should be taken during the development pumping. The specification describes the size of the sample and the type of container in which it will be stored (normally a container supplied by the lab doing the analysis) and when the sample should be taken (after 1 hr of pump operation). Finally, the chemical constituents to be tested for are listed. All major anions and cations along with alkalinity, total hardness, carbon dioxide, hydrogen sulphide and oxygen should be included.

FLOW TESTING

Flow testing of the well provides important data for the design of the heat pump system, since the groundwater flow rate chosen is based on pumping power (flow and drawdown).

There are several types of flow tests which can be done on a production well. In many cases, a step drawdown test is done for wells serving GWHP systems. In this test, the well is pumped at three rates until water level has stabilized. The specification describes the flow rates, instrumentation (for water level and flow data), frequency of readings, length of test and facilities for disposal of the water. This so-called single well test provides information primarily on the well itself (yield, drawdown, and specific capacity). A more sophisticated test in which nearby wells are monitored, provides information on the aquifer. These tests are rarely done for GWHP systems.

Generally, the flows chosen approximate 1/3, 2/3 and full design flow anticipated for the system served. Starting with the lowest flow the pump is operated at constant rate until the water level in the well has stabilized at which time the flow is increased to the next rate. Water level is typically measured with an electric continuity device on the end of a calibrated spool of wire. Flow is measured with an orifice plate discharging to atmosphere and pressure across the plate monitored with a manometer. Flow tests are often sub-contracted to a well pump contracting firm.

Some jurisdictions require that any well penetrating a potential drinking water aquifer be sterilized. The paragraph relating to sterilization describes methods, chemical concentration and length of the sterilization procedure which normally consists of chlorine treatment.

ABANDONMENT

In the event that the well is unsuccessful and cannot be used for the intended purpose, it must be abandoned according to the requirements of the regulatory agency responsible for water wells. Most states have very specific regulations covering abandonment which typically require filling the well with an impermeable material--often cement grout. It is not necessary to cover these procedures in detail. Referencing the appropriate state administrative rule will suffice.

INJECTION WELL ISSUES

Injection wells, used for disposal of the water after passing through the heat pump system, differ from production wells in several ways. Two of the more important are screen design and seal placement. Most references recommend a water velocity through the screen of one half that used in the production well. It appears that this guideline is primarily related to the allowance for plugging of the injection screen with particulate carried into the well with the water. From this comes the widely held perception that the injection well should be a larger diameter than the production well. This is not the case. The reduced screen velocity can be achieved by screening more of the aquifer since production wells in water table aquifers normally screen only the lower ½ to 1/3 of the aquifer. Beyond this, the need for the additional screen area assumes the presence of particulate in the injected fluid. If the production well is sand-free or if a surface strainer is used to minimize sand, the additional screen may not be necessary.

Sealing of an injection well should be done in much the same way as a production well penetrating an artesian aquifer. The reason for this is that in the course of the operation of the well, the pressure exerted on it is greater than the natural pressure of the aquifer it penetrates. As a result, there is a tendency for water to migrate up around the casing toward the surface. If the well is exposed to a positive pressure at the ground surface, the potential exists for water to leak out around the casing at the surface. To prevent this, injection wells should be sealed from just above the injection zone, continuously to the surface with a minimum 2" (50 mm) annular (between the casing and the wellbore wall) cement seal.

The injection stream should be introduced into the well using an injection tube terminating below the water surface. This prevents the injected water from cascading down from the well head and generating air bubbles in the process. Bubbles driven out into the aquifer can act as an obstruction to water flow in much the same fashion as particulate matter.

SPECIFICATION TEXT

The goal of this paper has been to identify the key sections necessary in the specification document for a water well and to comment on the general contents. Actual guide specification text has been published by many others (Roscoe Moss Company, 1985; AWWA, 1997; EPA, 1975, Montana Water Well Drillers Assoc, 1970). In many cases, these references are published in the form of guidelines for the specification of water wells in which explanatory paragraphs are included ahead of actual specification sections. Editing is normally required to use these sources in construction documents.

REFERENCES

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Roscoe Moss Company, 1985. The Engineers Manual for Water Well Design, Roscoe Moss Company, Los Angeles, CA.

A GUIDE TO ON-LINE GEOLOGICAL INFORMATION AND PUBLICATIONS FOR USE IN GSHP SITE CHARACTERIZATION

Kevin Rafferty
Geo-Heat Center

ABSTRACT

The ground-source heat pump industry has historically failed to take full advantage of the public information sources available for site characterization. Virtually every state and province in North America maintains a website (or sites) dedicated to either groundwater or geology or both. These sites vary greatly in terms of the information available, but in many cases, offer a wealth of data useful in the characterization of site geology and hydrology. Sites are typically maintained by federal and state geological surveys and water resources agencies.

Information may include various types of geological maps, publications, databases, water well completion reports, comprehensive reports on water and geology, and monitoring well water level data. From these sources, it is possible to determine site geology, depth to bed rock, water levels aquifer presence or absence, aquifer type, well yields, ground and groundwater temperatures, well design data, drilling rig types which have worked successfully in the area, and a host of other useful information. This paper outlines the types of data available, provides a tutorial on reading water well completion reports, and lists websites URLs for sites in the 12 most active GSHP states.

INTRODUCTION

One of the first steps in the consideration of a GSHP system is a characterization of the site in terms of geology and groundwater availability. Information concerning aquifer (or aquifers) available at the site, their ability to produce water, depth to water, geology, depth to bedrock and the nature of the soil and rock (hydraulic and thermal properties) are key issues. This information guides the designer in the selection of the type of GSHP system to be used and in the design of the system.

The ground-source industry has not taken full advantage of available geological information resources in the past. This document is an effort to introduce GSHP designers to some of these information sources and the nature of the data that is available. A special emphasis has been placed on Internet based resources operated by government agencies--primarily the USGS and state geological surveys. The following section provides some background information on the maps and other information sources in general. This is followed by summaries of information available for the most active GSHP states.

GEOLOGICAL TERMINOLOGY

One of the hurdles engineers encounter in the process of consulting references such as those referenced below is the terminology used in the field of geology. Contributing to the confusion is the fact that geology is something of a mix between science and history. Publications and maps often refer to materials not by their physical characteristics (the issue we as GSHP professionals are interested in) but by the period in the earth's history in which the material was deposited. For geologists, with a background in the science and a familiarity with the geographical area, the age of the material carries with it a rough idea of the physical characteristics. For engineers or those lacking this background, more information is required. To a large extent, there is no simple solution to this other than experience in reading and interpreting geological maps and data, but there are some useful references on the Internet to assist us in translating geology-speak into something we can understand. The Kentucky Geology Survey's web site (http://www.ky.edu/KGS/home.htm) has a comprehensive glossary of geological terms. The Indiana Geological Survey's website (http://adamite.igs.indiana.edu/index.htm) has a good summary of geological time with a chart and a brief explanation. It is useful to have these sites book marked for future reference. An extensive glossary of aquifer and hydrology terms is available on the Kansas State Geological Survey's site at: http://www.kgs.ukans.edu/highplains/atlas/glossary/htm.

KEY REFERENCES

USGS Groundwater Atlas of the United States
http://sr6capp.er.usgs.gov/gwa/gwa.html

This document may be the best regional scale (many figures readable to +/- 1 mile), groundwater and geological reference available. It is published in 13 volumes each covering a multi-state region of the country. It provides detailed descriptions of aquifer locations and physical characteristics, water quality, geology, physiography, cross sections and a host of data useful for both open loop and closed loop site characterization. All 13 volumes are accessible through the web site with full text and color illustrations and maps. They are also available as a hard copy publication. This is a document that answers the questions: Is there an aquifer accessible at the site suitable for an open loop system? What is the general geology of the site?

Water Well Completion Reports

The single best source of information for any site are water well completion reports from wells on or near the site. These are reports filed (with the state agency responsible for water well regulation) by the well driller upon completion of the construction of the well. There is a host of information (water level, well construction, pump test results, lithology. etc.) on these documents that is of use for both open and closed loop system site characterization. The availability of well completion reports varies from state to state. An increasing number of states, as detailed in the state summaries below, have these reports available on the Internet.

Anatomy of a Water Well Report

Figures 1 and 2 are examples of water well reports from the state of Oregon. This form is typical of many western states. The level of detail is somewhat less for states in the east and mid-west.

The report contains information on the owner in Section 1 and the nature of the work that was done (new well, deepening, repair etc) in Section 2. The drilling method (Section 3) is of interest since it indicates what type of rig has worked successfully in the area before. As you can see, well 1 was completed in a hard rock formation with an air rotary rig and well 2 in unconsolidated materials with a cable tool rig.

Section 3 details the hole diameter or diameters used and this information along with the casing description(Section 6) and screen (Section 7) provide a very clear picture of the well construction. The screen information is very useful for design of new wells. If the screen/gravel pack described has been successful in terms of minimizing sand production, it is an effective guide for future wells in the same area. As you can see, well 1 was completed in a rock formation with no screen or casing in the lower portion of the well (called open hole completion). Well 2 was completed with a stainless steel "V slot" screen with 0.50 slot size (openings) between 167 and 182 ft. The lower portion of the well drilled to 246 ft was backfilled and plugged to 202 ft due to the lack of water production in that zone. The 8" casing was cemented from 2 ft to 152 ft .

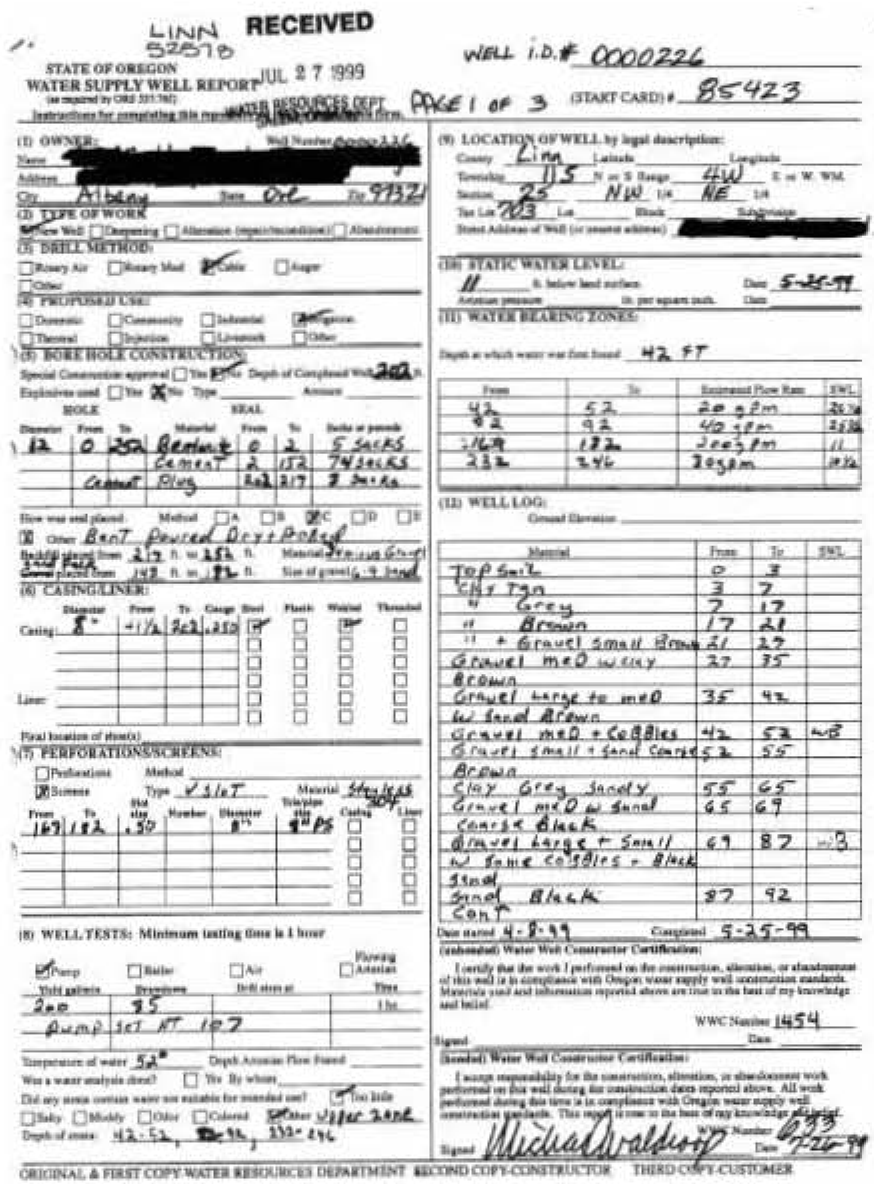
Section 8 is especially important for open loop design. As it presents information concerning the well's ability to produce water is presented along with the water temperature. The temperature is also important for closed loop design since it's temperature is the same as the "undisturbed soil/rock temperature" in the same area. Of the two examples, well 1's data is less useful than well 2. For well 1, the driller indicates that the well produced 100 gpm but does not show the drawdown information. Instead he shows that the drill stem was at 145 ft. This does not tell us what the water level was in the well at this flow (although it is clear that it was above 145 ft). Well 2's data indicates both the flow rate and the drawdown. This allows us to calculate a specific capacity for this well of approximately 2.4 gpm/ft of drawdown (200 gpm/85 ft)--a useful value in making well pump head and system design calculations.

Sections 10 and 11 information permits additional conclusions to be drawn as to the type of aquifer in which the well is completed. The static water level has an impact on pumping for open loop systems and may influence the type of rig used for drilling (wells or boreholes). Beyond that, the static water level when considered in the context of the depth at which water was encountered, suggests the type of aquifer present. This is most clear in the well 2 report. This well was constructed in such a way that all the water bearing zones were cased off except the one between 167 and 182 ft. The static water level in this well is at 11 ft. It is clear that this is an artesian (confined) aquifer since the water bearing zone starts at 167 ft but the water level is 156 ft higher. This 156 ft difference represents the pressure in that aquifer.

Section 12, the well log is valuable information for closed loop systems since it indicates the type of materials encountered in the subsurface. From this information, some idea of the heat transfer characteristics of the material can be determined. For well 1, most of the hole is rock (the black rock indicated is the reference this driller uses for basalt) and would likely have a fairly high thermal conductivity. In addition, the time to complete the well may offer some information concerning the drilling difficulty encountered. Well number 1 was completed in a single day in rock. On the other hand, well 2 required a month and a half to complete in soft drilling conditions. It is likely, however, that the difference in construction period is related more to the rig type since well 2 was constructed with a cable tool machine--a very slow process relative to a rotary rig.

Useful Maps

One very good source of information on the geology of an area is a "geological quadrangle" map. These maps, of which there are over 1700, show bedrock, surficial or engineering geology of selected 7.5 and 15 minute quadrangles of the U.S. Each map is accompanied by an explanatory text printed on the map margin or sometimes as a separate pamphlet. Some maps include cross sections and columnar sections illustrating stratigraphy. These maps are typically published in 1:24,000 scale and use the topographical map (a map which shows surface elevations) of the same area as the base. As a result, they bear the same name as the topo map for the area. These names are often related not to a town or city but to a local geological feature making the process of identifying the correct map difficult. Most of the map lists on the sites described below are indexed by the name of the map. Unless the name is known, it is not possible to easily locate the map you need. The USGS maintains a site to simplify the search process. At: http://maping.usgs.gov/mac/findmaps.html, click on the **Map Finder (through GLIS)** link. The next page allows you to locate the correct map by entering the zip code for the area or by clicking on an interactive map of the U.S. In either case, a map of the general area will come up showing the quadrangles for that area.



LINN 52578 **RECEIVED** JUL 27 1999 WATER RESOURCES DEPT

STATE OF OREGON
WATER SUPPLY WELL REPORT

WELL I.D.# 0000226

PAGE 1 OF 3 (START CARD) # 85423

(1) OWNER: [redacted]
City Albany State Ore Zip 97321

(9) LOCATION OF WELL by legal description:
County Linn
Township 11S N or S Range 4W E or W. WM.
Section 25 NW 1/4 NE 1/4
Tax Lot 703
Street Address of Well (or nearest address) [redacted]

(10) STATIC WATER LEVEL:
11 ft. below land surface. Date 5-25-99

(11) WATER BEARING ZONES:
Depth at which water was first found 42 FT

From	To	Estimated Flow Rate	SWL
42	52	20 gpm	26½
92	92	40 gpm	25½
169	182	200 gpm	11
232	246	30 gpm	10½

(5) BORE HOLE CONSTRUCTION:
Depth of Completed Well 262 ft.

Diameter	From	To	Material	From	To	Sacks or pounds
12	0	252	Bentonite	0	2	5 sacks
			Cement	2	152	74 sacks
			Gravel Plug	242	217	3 sacks

Other Bent Poured Dry + Poked

(6) CASING/LINER:

	Diameter	From	To	Gauge
Casing:	8"	+1½	262	.250

(7) PERFORATIONS/SCREENS:
Screens Type V slot Material Stainless
From 169 To 182 Slot size .50 Diameter 8" Tele/pipe size 8" PS

(12) WELL LOG:

Material	From	To	SWL
Top Soil	0	3	
Clay Tan	3	7	
Grey	7	17	
" Brown	17	21	
" + Gravel Small Brown	21	27	
Gravel med wclay Brown	27	35	
Gravel Large to med w sand Brown	35	42	
Gravel med + Cobbles	42	52	wB
Gravel small + sand Coarse Brown	52	55	
Clay Grey Sandy	55	65	
Gravel med w sand coarse Black	65	69	
Gravel Large + Small w Some Cobbles + Black Sand	69	87	
Sand Black Cont	87	92	

Date started 4-8-99 Completed 5-25-99

(8) WELL TESTS: Minimum testing time is 1 hour
Pump
Yield gal/min 200 Drawdown 85
Pump set at 107

Temperature of water 52°
Depth of strata: 42-52, 92, 232-246
Other Upper zone

WWC Number 1454

ORIGINAL & FIRST COPY-WATER RESOURCES DEPARTMENT SECOND COPY-CONSTRUCTOR THIRD COPY-CUSTOMER

Figure 2.

KLAM 51782 **RECEIVED** APR 6 1999 WATER RESOURCES DEPT SALEM, OREGON

STATE OF OREGON
WATER SUPPLY WELL REPORT

WELL I.D. # L 26856
START CARD # 108474

(1) OWNER: [redacted]
City BONANZA State OR Zip 97623

(2) TYPE OF WORK: New Well
(3) DRILL METHOD: Rotary Air
(4) PROPOSED USE: Domestic

(5) BORE HOLE CONSTRUCTION:
Depth of Completed Well 230' ft.

Diameter	From	To	Material	From	To	Sacks or pounds
10	0	119	CEMT& BENT.	0	119	29 SKS / 7 SKS
6	119	230	OPEN			

(6) CASING/LINER:

	Diameter	From	To	Gauge
Casing:	6"	+1	119	.25

Final location of shoe(s) NONE
(7) PERFORATIONS/SCREENS: Method NONE

(9) LOCATION OF WELL by legal description:
County KLAMATH
Township 39 S Range 12 E
Section 7 SW 1/4 NE 1/4
Tax Lot 101
Street Address of Well (or nearest address) [redacted]
BONANZA, OR 97623

(10) STATIC WATER LEVEL:
86 FT. ft. below land surface. Date 03-30-99

(11) WATER BEARING ZONES:
Depth at which water was first found 98 FT.

From	To	Estimated Flow Rate	SWL
98	230	300 GPM	86

(12) WELL LOG:
Ground Elevation 4150

Material	From	To	SWL
TOP SOIL	0	2	
YELLOW CLAY	2	10	
BROWN SANDSTONE	10	53	
SOFT BROWN ROCK	53	60	
BROWN CLAY	60	63	
BLACK ROCK	63	64	
BROWN CLAY	64	71	
YELLOW CLAY	71	83	
GRAY CLAYSTONE	83	98	
BLACK ROCK (WB)	98	137	86
BROWN ROCK (WB)	137	163	86
BLACK ROCK (WB)	163	185	86
BROWN ROCK (WB)	185	204	86
BLACK ROCK (WB)	204	226	86
BROWN ROCK	226	230	86

Date started 3-28-99 Completed 3-30-99

(8) WELL TESTS: Minimum testing time is 1 hour
Air
Yield gal/min 100 GPM Drill stem at 145 FT.

Temperature of water 65 F Depth Artesian Flow Found NONE
Depth of strata: NONE

WWC Number 777 Date 4-2-99

ORIGINAL & FIRST COPY-WATER RESOURCES DEPARTMENT SECOND COPY-CONSTRUCTOR THIRD COPY-CUSTOMER

Figure 1.

Other maps that may be of interest for GSHP site characterization include bedrock topography maps, surficial geology maps and Quaternary geology maps. Bedrock Topography maps indicate the depth to the top of the local bedrock or stating it another way, the thickness of the overburden materials. This information is useful in determining the drilling conditions and in making decisions as to the depth of the boreholes at the site.

Surficial Geology maps, in areas in which there is a thick sequence of unconsolidated material above the bedrock, may be the only maps necessary for characterization of site materials. For sites with less than 100 ft of unconsolidated materials, these maps would be used in conjunction with bedrock geology maps. As the name implies, these maps focus on the materials close to the surface, normally the unconsolidated materials deposited in recent geological time (what geologists refer to as Quaternary (the last 2 million years) or Tertiary (from 65 million to 2 million years ago).

SUMMARIES OF INFORMATION AVAILABLE IN SELECTED STATES

The following section presents summaries of information available for the states with the most active commercial GSHP markets. Similar information for other states can be accessed through two very useful sites. The American Association of State Geologists site http://www.kgs.ukans. edu:80/AASG/AASG.html#STATES includes an interactive map of the U.S. Clicking on any state brings up the website for that particular states Geological Survey (or equivalent state agency). The USGS site http://search.usgs.gov/ contains a similar interactive map of the U.S. (click on the **USGS by state link** to access it). Clicking on a state brings up the USGS information resources for that state including groundwater, surface water and geology. These two websites provided the starting point for all of the information presented below.

TEXAS

Texas Bureau of Economic Geology (http://www.utexas.edu/research/beg/) no online maps, list of geological quadrangle maps (but no online index map), list of hydro-geological reports, recommended publications (click on Publications, Best Sellers): **The Geology of Texas, Vol 1, Stratigraphy**, by Sellards, Adkins and Plummer, 1007 pages, $18 #BL3232, **Geologic Atlas of Texas**, published as individual sheets (listed on the web site), color, scale 1:250,000, $6 ea.

Texas Water Research Institute (http://twri.tamu.edu/index.html) appears to be primarily a surface water group but has a good general report in downloadable format **Groundwater in the Great Basin** (click on icon on first page) also a good links page including links to many Water Research institutes in other states.

Texas Water Development Board (http://www.twdb.state.tx.us/). Online publication **Aquifers of Texas** (click on Publications on first page) has maps of nine major and 20 minor aquifers in the state along with descriptions of typical well yields and aquifer geology.

Online water well completion reports database is accessible by clicking on the Well Information icon on the first page (at the bottom of the page). This database takes a little time to get into and it appears to be well construction and water quality focused. No driller's logs (lithology log).

USGS Texas information Site (http://usgs.tx.gov/) online data for water levels at about 25 locations in Texas. Data is in real time. Access by clicking on Groundwater under the **Online Data** heading.

PENNSYLVANIA

Pennsylvania Topographic and Geologic Survey (Dept of Conservation and Natural Resources) (http://www.dcnr.state.pa.us/topogeo/indexbig.htm). A map and listing of libraries which serve as repositories for Geological Survey maps and Publications can be accessed on the Publications page. Geological quadrangle maps in black and white online and downloadable. These maps are of limited value for GSHP applications since they typically do not contain cross sections. They can be accessed by clicking on **Publications** on the first page and then **Atlas of Preliminary Geological Quadrangle Maps of Pennsylvania.** A useful feature of this online publication is that clicking on the List of Quadrangles link brings up a alphabetical listing of the Quadrangle maps with a summary of other publications available in that same quadrangle.

Recommended Publications:

PA Ground Water Information System CD - this is a database of water well completion reports for the entire state $35. Information about the database is available on the site. Click on the Pub title on the first page of the site.

The Geology of Pennsylvania - 888 pages, $24, description can be found under Publications.

Map #7 - Geology of Pennsylvania (**Free** upon request)
Map #15 - Limestone and Dolomite (**Free** upon request)
Map #64 - Surficial Materials (**Free** upon request)
Map #59 - Glacial Deposits (**Free** upon request)

USGS PA Water Information Site (http://pa.water.usgs.gov/). Online, real time depth to water for approximately 25 sites in PA. Click on **Statewide Groundwater Conditions** on the first page of the site.

NEW YORK

New York State Geological Survey (http://www.nysm.nysed.gov/geology.html). Online maps of both bedrock and surficial geology accessible by clicking on **Maps and Digital Data** on the first page of the site. User must have ArcView/ArcInfo software to access the maps. List of geological quadrangle maps (but no online index map) by clicking on **Publications** and then **Geology.**

Recommended Publications:

Geology of New York: A simplified Account, Isachsen and others, 1991, $18.95

Geology of New York: A Short Account, $5

USGS New York Groundwater Information Site (http://ny.water.usgs.gov). Online, realtime depth-to-water information for 15 sites in the state. Also historical information on another 40 sites which are now discontinued. For access, click on the **Groundwater** under the **Data** heading on the first page.

Water table Altitudes in Kings and Queens Counties NY in PDF format under **News and Features**. It has map of water levels.

Evidently, water well driller registration and the filing of water well completion reports was not required in New York state (except in a few counties on Long Island) until 1 Jan 2000. As a result there is no database of this information as there is in other states. Water well regulatory functions are the responsibility of the Department of Environmental Conservation, Division of Water.

TENNESSEE

Department of Environment and Conservation, Geology Division (http://www.state.tn.us/environment/tdg/index.html). Good generalized geologic map of the entire state (no cross sections) online. Click on the **Big Map** link for the best scale.

List of geologic quadrangle maps. Click on **Publications** on first page then click on **Geologic Quadrangle Maps** on menu on left of page. $3 ea

Recommended Publications:

State Geologic Map - in 4 sheets (West, W Central. E Central and East). 1:250,000 scale (1" = 4 miles), color, formation descriptions. $4 per sheet.

Department of Environment and Conservation, Division of Water Supply (http://www. state.tn.us/environment/dws/index.html). List of Licensed Water Well Drillers in TN - click on **Water Well Drillers List** link on first page of site. Lists drillers by name, Lic. number and phone number.

USGS TN Water Information Site (http://tn.water.usgs.gov/). It appears that USGS, as of 1995, was monitoring water level in 48 wells in the state. Online information is not available for these wells as it is in other states. However, this information would be available by contacting the state USGS office (email link on site).

Online publication **Public Water Supply Systems and Associated Water Use in TN, 1995** contains good information about production from public water system wells throughout the state. This data is attached as appendices to the report in table form. Access report by clicking on **Publications and Product Information** on the first age of the site and then **Selected Tennessee Publications** and then the report title.

KENTUCKY

Kentucky Geological Survey (Univ of Kentucky) (http://www.ky.edu/KGS/home.htm). This is the only state for which there is 100 % coverage in geological quadrangle maps. List available on site

Hydrologic atlas maps list. These maps include information about water wells, aquifers, availability, chemistry, depth to water etc. Click on **Mapping** icon at top of first page, then **Maps for sale by Commodity**. Maps available by county, groups of counties and in some cases by quadrangle (1:24,000 scale). $4.50 to $12.

Simplified map of Geology of Kentucky online. Click on the **Geology of Kentucky** icon at the top of the first page. Includes cross section and explanatory text. Good summary of geological time scale.

A detailed treatment of the geology on a county by county basis is ongoing. Only Fayette County is currently online.

Possibly the most useful information for GSHP would be searches of the **Kentucky Hydrologic Data Base** and **The KGS Oil and Gas Data Base**. The hydrologic information includes results from 39,000 water wells and 18,000 water chemistry analyses. Information on water well construction, yields, depth, static level and water quality data, etc. Database is not searchable online. Contact is Bart Davidson (bdavidson@kgs.mm.uky.edu) or 606-257-5500. Oil and gas data includes driller logs, wireline logs (geophysical data) etc. Contact is Brandon Nuttall at KGS (bnuttall@kgs.mm.uky.edu) or 606-257-5500. Minimum fees for these services appear to be $30 to $40.

Downloadable geologic and hydrologic GIS maps available on the site. ArcView/ArcInfo software required for viewing. Click on **Mapping** icon at top of first page then, **GIS Coverages**. Under **State Hydrology Series**, the **Water Wells** map appears to be the most useful (data on depth, depth to water, date, use, depth to bedrock, etc.). Using the same approach but clicking on **Geology Series**, the **Oil and Gas wells** and **Generalized Geology** maps should provide good information on the subsurface.

Kentucky Groundwater Development Commission (http://dlgnt1.state.ky.us/wrdc/). This organization is working on a Digital Atlas of Groundwater in Kentucky in conjunction with the KY Geological Survey. Based on the hydrologic atlas series published in the 1960's, new information will be added and corrections made. Water well, groundwater availability and quality and aquifer descriptions will be included. Data not yet available.

VIRGINIA

Virginia Department of Mines, Minerals and Energy, Div of Mineral Resources (http://www.mme.state.va.us/dmr/home.dmr.html). General **Geology of Virginia** (access by clicking on the phrase at the top of the first page) explains the general geology and physiographic provinces of the state. Text describes the rock types and faulting etc.

Geological quadrangle maps listed. Click on **maps and publications**, **geological** and then geological quadrangle maps.

Oil and Gas Database--includes well location, status and stratigraphy. Not available online. Contact Dave Spears 804-951-6361

The state is working on the digitizing of both 1:100,000 and 1:24,000 geological maps but this work is in progress. Some maps may soon be available on CD-ROM. Inquire.

Recommended Publications:

Geologic Map of Virginia and expanded explanation (1993). 1:500,000, 80 pages, $9.50 .

Geological map and generalized cross sections of the Coastal Plain and adjacent parts of the Piedmont, VA, R B Mixon, 1:250,000 1989, $6.75.

USGS VA Water Information Site (http://va.water.us.gov). Online water level information for 11 sites in VA. Click on **Groundwater Levels** under VA Drought Conditions.

INDIANA

Indiana Geological Survey (http://adamite.igs.indiana.edu/index.htm). This is one of the most comprehensive and useful state geological sites.

Excellent glossary of geological terms. Click on **Reference Library** on the first page and then **Glossary of Geological Terms**.

Glossary and descriptions of stratigraphic units in inches. Click on **Reference Library** and the **Compendium of Paleozoic Rocks**. Detailed descriptions on rock units.

Online maps of both bedrock and surficial geology for the entire state. Click on **Reference Library** then **Maps and Charts**. Bedrock geology shows the types of bedrock units and their location along with a brief explanation of the material (point to the material on map and description is displayed). Surficial Materials shows the type and depth of these materials on a state map. This allows the determination of the depth of the "overburden" materials and the type.

Databases of core and well samples are "Coming Soon."

Recommended Publications:

Regional geological maps 1°x2°. These maps show both bedrock and unconsolidated deposits. Scale 1:250,000. $2.50 ea. To access list, use publications search engine and select "regional geological maps."

IN Dept of Natural Resources, Division of Water (http://www.state.in.us/dnr/water). Online water well completion reports. Click on **databases** then search **water well records**. Full well report info available–depth, flow test, construction details, lith log, etc.

Several excellent publications on groundwater availability on river basin (regional) and county by county basis. See publications list.

MARYLAND

Maryland Geological Survey (http://mgs.dnr.md.gov). Online publication **A Brief Description of Maryland Geology**. Click on Earth Science Information Center on the first page, then the document title. Contains a map of the Physiographic provinces of the state and a general geological map with formation descriptions and explanatory text. Publication also includes a downloadable file of the geological map.

Recommended Publications:

Most useful appear to be the **county geological maps** (some of which are out of print). Click on County Topographical and Geological Maps $7.50 ea. Also publication #69-02-1 **Groundwater Aquifers and Mineral Commodities of Maryland** (also out of print but should be available at MGS repositories a list of which is on the websites).

USGS Maryland Water Information Site (http://md.water.usgs.gov/groundwater/county).
Site has historic water level data for at least one well in each county in both MD and DE. Includes a graph of past levels and a description of well construction and location.

MISSOURI

Missouri Department of Natural Resources - Division of Geology and Land Survey (http://wwwdnr.state.mo.us/dgls/homedgls.htm). Nothing of help for the GSHP designer on this web site. This organization is also responsible for administering the states water well industry but no online data is available.

Email address for questions regarding geology, stratigraphy and surficial materials: gspgdam@mail.dnr.state.mo.us

OHIO

Ohio Geological Survey (http://www.dnr.state.oh.us/odnr/geo_survey/). Online maps of bedrock, surficial geology and Physiographic provinces in the state. Click on Geology of Ohio on the first page, then map title.

Online "Geo Facts" publications - #1 Bedrock Topography of OH. Explains the topic and includes map ordering info.

#20 Geology of OH - The Cambrian Useful maps available from the Survey: Bedrock Topography Maps, by county. Shows the depth to bedrock as contours. Scale is 1:24,000 and cost is $4 ea; Geologic Map of Ohio 1:500,000, $5, order #M1; Quaternary Geologic Map of OH, 1:500,000, $10, order #M2

Department of Natural Resources - Division of Water (http://www.dnr.state.oh.us/odnr/water/). Online searching of water well completion reports. Click on **Online searching of water well logs** under New Items on the first page. Can locate wells by county and road or well number. Information on water level, production, construction, lithology etc.

Online map of generalized water well production (in gpm)for entire state. Click on **Publications**, **then Groundwater Publications**, **Maps**, **Generalized State Groundwater Map of Well Yields**.

Online index map to individual county groundwater availability maps. Navigate to same location described immediately above for well yield map. Click on **Ground-**

water Resources Map Availability. Includes state map indicating status of individual county maps and ordering information.

NEW JERSEY

New Jersey Geological Survey (Dept of Environmental Protection) (http://www.state.nj.us/dep/njgs/index.html). Online map Geology of New Jersey on first page of site. Link at bottom of map for download of Adobe file with map and text providing a description of the geology in each of the major physiographic provinces of the state. Also a link to ordering info for the newest three map set on New Jersey Geology.

Online map of major aquifers in the state with well yields indicated. Click on **GEODATA**, **Groundwater icon**, **Aquifers of NJ (1:250,000)**. Map and data are downloadable but requires ARC/INFO software. Click on **image** for online display of map.

Publications search engine online. Best strategy is to use the county name as a key word to locate publication for the site you are interested in.

USGS NJ Water Information Site (http://nj.water.usgs.gov/). Online geologic map of NJ click on **Groundwater**, **Geologic Map.** Also at same location, Aquifers of NJ with maps, text and tables describing aquifers of the state. Groundwater levels for 172 wells in the state including both current and past water level data.

MINNESOTA

Minnesota Geological Survey (http://www.geo.umn.edu/mgs/index.html). Online map of bedrock geology of MN with descriptions. Click on **more information on MN geology** on the first page of the site, **state maps** then map title. Same location also has map of Quaternary geology and cross section of the state.

More detailed information on both the bedrock and Quaternary geology of the state are available in two online (and downloadable publications). Click on **more information on MN geology** on the first page and then **Minnesota at a glance** and then the title of the publication (in Adobe Acrobat). Documents have maps and descriptions of the geology of the entire state.

Geology of central MN presented in some detail in the online document of the same name including text maps and formation descriptions. Click on more information on MN geology, regional information then the title of the document.

Water well information is contained in the County Well Index (CWI). Not available online. Database is available on disks (typically 1 disk per county) for $5 ea. User manual available for $6. Ordering and general information by clicking on the CWI link on the first page of the site. Database contains well construction, production, lithology, static water level information, etc.

Recommended Map Publications:

County Geologic Atlases. Order numbers C-1 thru C-12 Regional Hydrologic Assesments Order numbers RHA-2 thru RHA-5 Geologic and Surficial maps, typically 1:24,000 scale. Most recent are available online. Order numbers M-1 thru M102. M-83 thru M102 are online.

DUAL-SET POINT CONTROL OF OPEN-LOOP HEAT PUMP SYSTEMS

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ABSTRACT

Control of well pumps in open-loop heat pump systems is a topic which has been largely overlooked in the literature. Three primary methods are in use: dual-set point, variable speed and multiple well (normally employed when multiple wells are required for hydrologic or redundancy). This paper explores the issues involved in the dual-set point method. Establishing the system operating set points requires consideration of peak loop loads, loop thermal mass, well pump motor cycling limitations and heat exchanger performance. Guidelines for pump controller operating range are presented along with the method of establishing the optimum loop temperatures at peak load conditions.

INTRODUCTION

The design of open-loop heat pump systems and the procedure for identifying the optimum groundwater flow for maximum system performance (EER or COP) is discussed in detail in existing references (Kavanaugh and Rafferty, 1997; ASHRAE, 1999). Basically, this procedure consists of calculating the power requirements of both the well pump and the heat pumps over a series of groundwater flows to determine the system optimum groundwater flow at the dominant peak load (normally the cooling mode in large commercial buildings). Above this flow, system performance degrades due to increasing well pump power consumption. Below this flow, system performance degrades due to increasing heat pump power consumption. The issue left largely undefined in the existing literature is the control of the well pump at conditions other than peak load. A variety of strategies have been used and the three most common are dual-set point, multiple well and variable-speed. Multiple well control is normally a strategy chosen when more than one production well is required for hydrologic or redundancy purposes.

The dual-set point method is somewhat similar to the temperature control scheme used in water-loop heat pump systems. The well pump is enabled above a given temperature in the cooling mode and below a given temperature in the heating mode. The multiple well approach is similar in terms of the temperature initiated response of the well pumps; however, the use of multiple wells provides the ability to stage

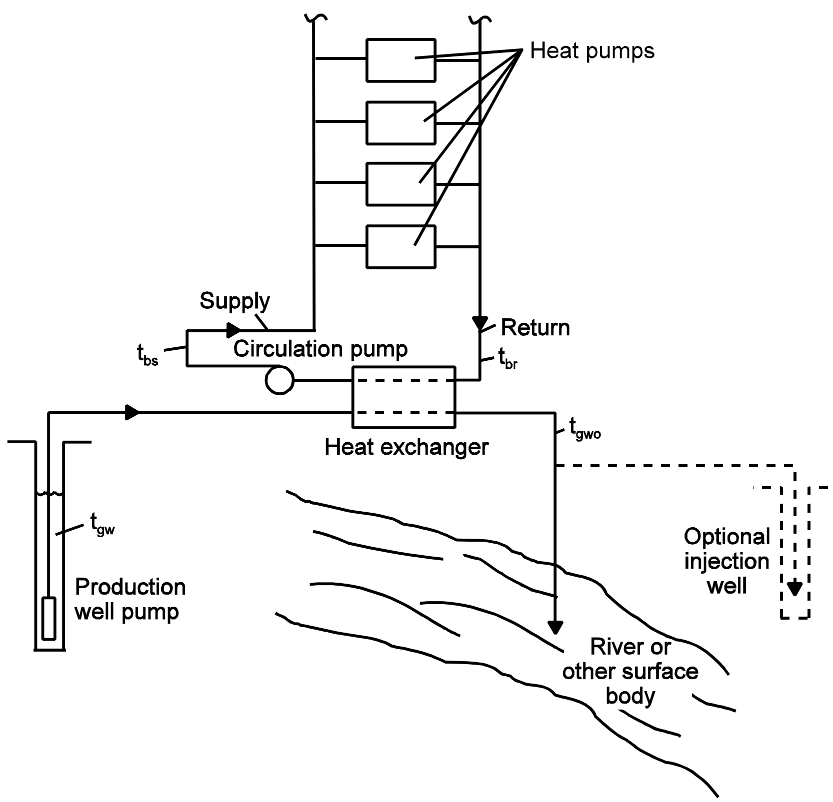

Figure 1.

the groundwater flow and sometimes, better match the different heating and cooling mode flow requirements. Variable-speed control of well pumps permits an infinitely variable groundwater flow for any system load or mode provided sophisticated enough controls are available.

There is no "best" among the methods listed above. The strategy is selected based on the system size, well design parameters specific to the site and the capabilities of the owners operating personnel. Discussion of well pump control from this point will focus on the dual-set point approach and assume a system configured as indicated in Figure 1.

DUAL-SET POINT CONTROL

As indicated above, dual-set point control is similar to the cooling tower/boiler control employed on water-loop heat pump systems--in which the cooling tower is employed above a specific loop temperature in the cooling mode and a boiler is used below a specific temperature in the heating mode with the loop "floating" between these two set points. In this case, it is the well pump that is used to temper the loop in both cases. Ideally, at the peak condition, the pump runs continuously. At less than peak loads, the well pump is cycled in response to the size of the load. In fact, there are four rather than two set points as the name implies: pump on temperature and pump off temperature in the cooling mode, and pump on and pump off temperatures in the heating mode. Each of these pairs of set points are normally arranged symmetrically about the optimum building loop return temperature for that mode.

Properly done, the design process for an open-loop system identifies a groundwater flow rate, which results in the highest system performance (system EER or COP) at peak load. Once this flow has been determined and the heat exchanger selected, the operating temperatures at the peak conditions are fixed. Based on the thermal mass of the system and the loop thermal load, the well pump operating range around the optimum temperature in the dominant mode (usually cooling) is established. System performance is determined in the peak secondary load (usually heating) and the operating range around the loop return temperature at the secondary load peak is established based on the loop thermal load and the system thermal mass. This general procedure establishes an optimum relationship between the well pump power, heat pump power and building load. Maintaining this optimum relationship at off peak conditions is accomplished by cycling the well pump.

Consider the following example system: peak cooling block load 85 tons (299 kW), groundwater temperature 60ºF (15.6ºC), production well static water level 75 ft (23 m), aquifer specific capacity 2 gpm/ft (0.04 L/s-m), building loop flow 213 gpm (13.4 l/s), surface groundwater head losses of 37 ft (11.3 m) and a heat exchanger selected for a 4ºF (2.2ºC) approach temperature (between the building loop return [to the heat exchanger] temperature and the groundwater leaving temperature). Under these conditions, the optimum groundwater flow would be approximately 1.75 gpm per ton (0.031 l/s-kW) or 150 gpm (9.5 l/s). System performance in the peak cooling mode vs. groundwater flow is illustrated in Figure 2.

Figure 2. Example system performance.

At the design load and the flow of 150 gpm (9.5 l/s), the groundwater would enter the exchanger at 60ºF (15.6ºC) and leave at 76.6ºF (24.8ºC). The building loop side would enter at 80.6ºF (27ºC) and leave at 69ºF (20.6ºC). The building loop return temperature is most commonly used for control of the well pump. In this case, since the return temperature under optimum conditions is approximately 81ºF (27.2ºC), this would be the value around which the well pump would be controlled. In order to limit the cycling of the well pump, some range around this temperature must be established such that pump operation is initiated at a temperature above the optimum value (pump on temperature) and operation terminated at a temperature below the optimum (pump off temperature). The size of the range between these two values is a function of the thermal mass of the system (gallons of water per peak block ton [liters of water per peak block kW])and the allowable time between starts for the well pump motor.

SUBMERSIBLE PUMP MOTOR CYCLING

Submersible motors, like any other motors, are limited in terms of the starts to which they can be subjected over a given interval of time. Due to the thermal spike imposed on the motor windings at start up, sufficient time must be permitted to dissipate this heat between starts to avoid damage to the insulation and other thermal cycling damage to the motor. The recommended limitations are a function of the motor size and electrical characteristics (primarily whether it is single or 3 phase). This information is summarized in Table 1

Table 1. Recommended Limitations for Number of Starts per Day for Submersible Motors (Franklin, 1999)

Motor hp	Single Phase	3-Phase
<5	100	300
7 ½ to 30	50	100
>30	–	100

Most larger commercial open loop system pumps will fall into the 100 starts per day imitation category. In the context of the heat pump system, a more useful unit would be 15 minutes between starts.

BUILDING LOOP THERMAL MASS

The nature of the dual-set point approach is such that the building loop is drafted over some temperature interval (difference between the pump on temperature and the pump off temperature). The range between these two temperatures must be sufficient, given the thermal mass of the loop and the load imposed on it to accommodate the 15-minute limitation between starts. In the example system above, the pump might be started when the loop reaches 84ºF (28.9ºC) and operated until the loop is reduced to 78ºF (25.6ºC), a 6ºF (3.3ºC) range. The time required for the loop to be reduced from 84ºF (28.9 ºC) to 78ºF (25.6ºC) (while the pump is running), combined with the time required for the loop to rise from 78ºF (25.6ºC) to 84ºF (28.9ºC)(pump off), is the time between starts and must be no less than 15 minutes.

Obviously, the thermal mass of the building loop is constant as is the capacity of the groundwater (via the heat exchanger) to remove heat from the loop. As a result, the primary variable in terms of the time between pump starts is the building thermal load imposed on the loop. Figure 3 expresses the relationship between this parameter (in units of gallons of water per ton of peak block load) and the number of minutes between pump starts per ºF of difference between pump on and pump off temperature. This plot is based on space load (1 ton = 12,000 Btu/hr [3.52kW]) and incorporates an assumed heat pump unit EER of 14.6, resulting in a loop load of 14,800 Btu/hr (4.34 kW) per ton.

Figure 4 provides the same information for the heating mode of operation. The heating mode plot is also based on space load (1 ton = 12,000 Btu/h [3.52 kW]) and incorporates a heat pump unit COP of 3.5 which results in a loop load of 8,600 Btu/hr (2.52 kW) per ton. Due to the impact of compressor heat, the thermal mass/controller range requirements needed to avoid short cycling in cooling load dominant applications are substantially larger than in heating dominant applications.

Although the phenomenon of short cycling in system components is normally considered to be a problem at minimum load, it is apparent that in open loop systems, the well pump cycling issue is of most concern at 50 % load. This arises from the fact that it is the time between starts (the time for one off-cycle plus one on-cycle) that is of interest. At high-loop thermal load, the pump on-cycle will be long. At low-loop load, the pump off-cycle will be long. Either of these two situations lengthens the time between starts. Thus, it is at the mid point that the time between starts for the well pump is minimized. It is at this 50% load point that the range for the pump control is established. For the example system in the cooling mode, assuming a loop thermal mass of 8 gal/ton (1.1 min/ºF from Fig 3)(106 l/kW(1.98 min/ºC), a range of 15/1.1 or 13.6 ºF (7.6 ºC) would be required. This would result, in the cooling mode of a pump-on temperature of 81 + (13.6/2) = 87.8ºF (31ºC) and a pump-off temperature of 81 - (13.6/2) = 74.2 ºF (23.4 ºC). At a loop thermal mass of 14 gal/ton (186 l/kW), the necessary range would be reduced to 15/1.9 = 7.9º F (4.3 ºC).

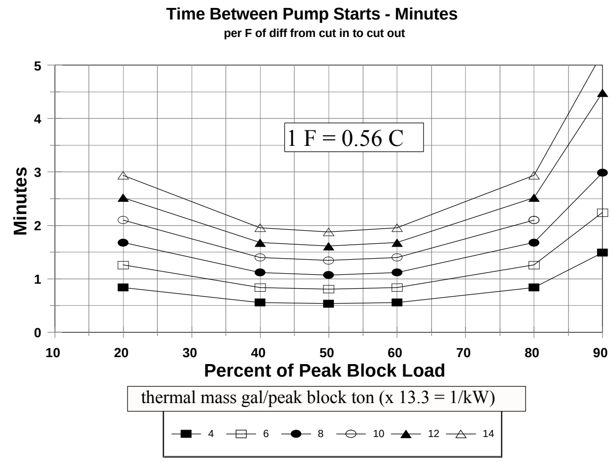

Figure 3.

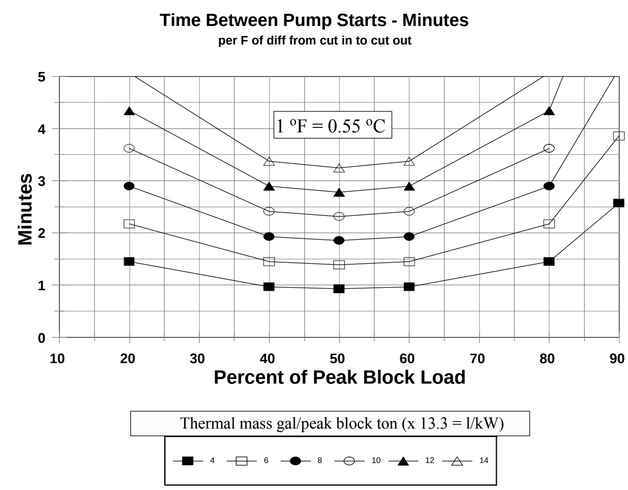

Figure 4.

Values for building loop thermal mass of between 4 and 14 gal per peak block ton (53.2 to 186 l/kW) are considered in the plot; since, these represent the extremes which the author has witnessed in these systems. Generally, small multistory office type buildings with a small foot print tend toward the lower end of the spectrum and large single story large footprint (schools) tend toward the upper end of the range.

GUIDELINES FOR WELL PUMP CONTROLLER TEMPERATURE RANGE

To simplify the process of range selection, Table 2 was developed. The table offers guidelines for minimum well pump controller range in ºF (ºC) with examples for large (>5 hp [3.7 kW]) and small (5hp [3.7 kW] and less, 3 phase) pumps and both cooling load and heating load dominant applications. The values in the table are the minimum temperature ranges necessary to assure adequate time between starts for the system well pump in a single production well application.

Table 2. Minimum Controller Range Requirements ºF(ºC)

Motor hp(kW)	System Thermal Mass - gal/block ton (l/kW) 2(27)	4(53)	6(80)	8(106)	10(133)	12(160)	14(213)
			COOLING MODE - ºF (ºC) RANGE				
<5hp(3.7kW)	28(16)	14(8)	9(5)	7(4)	6(3.3)	5(3)	4(2)
>5hp(3.7kW)	56(31)	28(16)	19(11)	14(8)	11(6)	9(5)	8(4)
			HEATING MODE - ºF (ºC) RANGE				
<5hp(3.7kW)	16(9)	8(4)	5(3)	4(2)	3(2)	3(2)	2(1)
>5hp(3.7kW)	32(18)	16(9)	11(6)	8(4)	6(3)	5(3)	5(3)

It is apparent that at system thermal mass values of less than 8 gal/ton (106 l/kW)(cooling mode dominant), the required range on the well pump controller becomes very large. Although it is reasonable to assume that a system operating over a small temperature range about an optimum point will, on average achieve the optimum performance, as the range becomes larger system performance suffers. As a result for systems with very low mass, it may be worth considering an alternate method of well pump control or the addition of some mass to the system. For small systems, the addition of sufficient storage to reach the 10 gal/ton(133 l/kW) threshold is achievable for reasonable capital cost. Otherwise, use of the variable-speed or multiple well approach should be considered.

SECONDARY LOAD SET POINTS

The discussion, to this point, has focused on the dominant system load using the cooling load as the example since this is normally the dominant load in most large building applications. A similar approach is used for establishing the well pump controller range at the secondary load peak condition. The difference is that since the groundwater flow rate and the heat exchanger are sized for the dominant load peak, some calculation is necessary to determine the building loop operating temperatures in the secondary load peak condition. Once this value is determined, the appropriate minimum range can be selected from Table 2 to arrive at the pump-on and pump-off temperatures.

To determine the operating temperatures at the secondary load peak, it is necessary to evaluate the performance of the heat exchanger at the reduced thermal load imposed by the secondary peak. This can be done by manual calculation or with analysis provided by the heat exchanger vendor. Using the example 85 ton (299 kW) system established above and assuming a peak heating load of 900,000 Btu/hr (264 kW), it can be calculated that the building loop return temperature at peak heating conditions would be 49ºF (9.4ºC). From the previous calculations, it was established that the system has a building loop thermal mass of 8 gal/ton (106 l/kW) based on the cooling load. As a result, for the heating mode, the value would be (85 tons * 8 gal/ton)/(900,000/12,000) = 9.1 gal/ton (121 l/kW). From Table 2, this would result in the selection of a minimum well pump controller range of approximately 4ºF (2.2ºC). As a result, in the heating mode, the well pump for this system would be started at 49 - (4/2) = 47ºF (8.3 ºC) and stopped at 49 + (4/2) = 51ºF (10.6ºC).

ADDITIONAL CONSIDERATIONS

The issue of thermal mass is an important one in the context of range size determinations. Since the critical point for pump cycle time occurs at 50% load, a more useful term might be effective thermal mass for systems with variable-speed. In systems with variable-speed control of the building loop pump, at 50% load by definition, 50% of the heat pump capacity will be idle. The water in the branch piping to the idle heat pumps is not available to contribute to the thermal mass of the system as far as calculations for well pump cycling are concerned. This influence is a complicated one and more amenable to adjustment after the system is in operation rather than calculation at the design stage. Again, this is an issue more in small compact buildings than extensive, large footprint buildings.

The system thermal mass used in the development of the guidelines sited in this paper considers only the water volume. No credit has been taken for the heat pump refrigerant-to-water heat exchangers or the building loop piping itself. The building loop piping increases the loop thermal mass by approximately 25% for steel and 10% for copper and PVC materials relative to the water only thermal mass. As a result of this impact, the temperature ranges sited in Table 2 can be decreased accordingly. The exact impact is influenced by the pipe sizes involved. In smaller diameter pipe, the relative contribution of the pipe material to the total thermal mass (pipe plus water) on a per foot basis, is much higher than it is in larger diameter pipe. For example, in 1-1/4" (32mm) schedule 40 steel pipe, the pipe material constitutes 28% of the total thermal mass on a per foot basis and at the 6"(152mm) size the pipe material constitutes only 15%. The variation with pipe size is less for copper and PVC materials.

CONCLUSIONS

The dual-set point method of well pump control for open loop heat pump systems is a simple, efficient and widely used strategy. To properly apply it, it is necessary to fully consider the issues of dominant and secondary loads, building loop thermal mass, submersible motor cycling limitations, and heat exchanger performance. For cooling load dominated buildings, it may be necessary to consider another method of control or the addition of volume to the building loop in applications with less than approximately 8 gal/ton (106 l/kW) thermal mass.

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