GEOTHERMAL HEAT PUMPS
FOUR PLUS DECADES OF EXPERIENCE

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INTRODUCTION

Despite the fact that commercial geothermal heat pump (often called ground-source heat pump or geo-exchange) systems first gained moderate popularity as early as the late 1940s and early 1950s, widespread acceptance of the technology by architectural and engineering firms, mechanical design teams, developers, and building owner/operators has been extremely slow. And although there was a momentary increase in the installation of geothermal heat pump systems following the oil crises of the 1970s, it has not been until the past few years that interest in commercial geothermal heat pump systems has once again been on the rise. However, uncertainty over first cost, life cycle cost, operation and maintenance questions, and system long-term reliability have continued to plague the industry and prevent greater adoption of the technology.

In order to meet this need, a number of studies have been completed to document maintenance and operation histories, equipment replacement requirements, actual cost of service, and long-term system reliability. The number of such studies has, however, been fairly limited and good data has not always been readily available as few building owners maintain good records and often ownership has changed, some times several times, since the system was first installed. In order to improve and strengthen the operation and maintenance data base Washington State University (WSU) has completed a series of case studies of commercial geothermal heat pump systems.

The United States, and especially the state of Washington, has long been a leader in geothermal heat pump installation and use following the first successful demonstration of the technology at the Commonwealth Building in Portland, Oregon, in 1946. Most of these early systems are still providing a high level of service to building owners, and include systems in Tacoma (Tacoma City Light Building, 1954), Vancouver (Clark County PUD, 1956) Walla Walla (Whitman College 1964), Ephrata (Grant County PUD, 1955).

Data obtained through the course of the current study indicates that geothermal heat pump technology is energy efficient with total building electrical energy use for those buildings where data was available ranging from 9.40 to 24.7 kWh/sq.ft./year while HVAC-related energy use ranged from 8.43 to 10.14 kWh/sq.ft./year. Maintenance costs were also found to be very attractive and averaged $0.17/sq.ft./year (Table 1). The most interesting findings of this work, however, were the high level of reliability that most systems had provided over periods exceeding 25 to 30 years if routine maintenance procedures were followed and the very high level of owner satisfaction that was witnessed during the course of the interviews that were conducted.

PRESENT STUDY

The present study was conducted in two phases. The first began with a look at a number of installations in Washington State with an emphasis on obtaining information on building size and use, type and size of geothermal heat pump system, reasons for selecting geothermal heat pump technology, and owner/operator satisfaction with the system. The second phase of the study expanded the geographic area to include systems in several additional parts of the country and the scope to include much more concentration on operational, maintenance, and reliability issues.

Systems were first identified through conversations with equipment sales representatives, architectural and engineering firms, well drillers, ground loop installers, HVAC contractors, and utilities. Once a substantial number of systems had been identified, the owner/operator of each system was contacted by phone and an interview conducted to determine whether or not the system should or could be further considered. The prime criteria for selection was willingness on the part of the owner/operator to participate in the study, availability of data, and age of the system. Every effort was made to include as many systems as possible with 20+ years of operating history, and as few as possible with five years or less of operating history.

Once the systems had been selected, detailed interviews were conducted with the owner/operator, maintenance staff, and, when possible, the system designer. The interviews were conducted by phone and often required discussions with several individuals. Once the interviews were completed, all of the systems were visited, additional interviews conducted, and each system gone through in as much detail as possible. Table 1 summarizes the important building and ground source heat pump (GSHP) system characteristics of the 22 buildings that serve as the basis for this paper.

As a baseline for a comparison of the results of this study, ASHRAE operation and maintenance estimates were reviewed. The ASHRAE Handbook (ASHRAE, 1995) provides a standard method for calculating maintenance cost for commercial-size HVAC systems. Based on calculations using the ASHRAE method, geothermal heat pump system maintenance can cost from $0.11 to $0.22/m^2/year in 1996

TABLE 1. BUILDING AND GSHP DESCRIPTIONS

Site	Location	Building Type	Square Footage	System Type	Number of HP Units	Heat Pump Capacity, kW_t	kWh Square Foot/Year	kWh/Square Meter/Year	Maintenance Cost $0.00US/Square Foot/Year
Beaver Lake Middle School	Issaquah, WA 1994 - New	Middle School	109,000	Ground loop - loop under athletic field - 45,062 meters in loop - 840 kW_e electric boiler	52	879	11.00	1.02	0.23 - 0.35
Bryant College	Smithfield, RI 1996 - Retrofit	2 College Dormitories	38,000	Ground loop – 36 @ 138 meters deep vertical bores - 9,963 meters total	16	281	(a)	(a)	0.01
Clark County PUD Admin.	Vancouver, WA 1957(a)- New	Administration Offices	32,000	Open loop – heat exchanger well - 116 meters deep – 12 ºC, 19 L/s possible	4	352	(a)	(a)	0.50
Exchange Building	Farmington, CT 1971 - New	Office & Commercial Complex	275,000	Open loop – four wells - 84 meters deep – 13 ºC total flow 32 L/s	495	3,848 kW_t plus an 879 kW_t chiller to provide heat to loop	17.18	1.60	0.16
Grant County Courthouse	Ephrata, WA 1982 - Retrofit	Courthouse & Courthouse Annex	52,000	Open loop – connected to 31 ºC municipal water supply system	1 x 2	1,055	(a)	(a)	0.11
Haverhill Public Library	Haverhill, MA 1994 - Retrofit	Library	44,000 including 27,000 1994 addition	Open loop – four wells - standing column – 14 ºC 4-5 L/s per well isolated with heat exchanger	19	378	16.13	1.50	0.09 - 0.14
Heritage College Library	Wapato, WA 1991 - New	College Library	18,000	Open loop 10+ºC isolated with plate and frame heat exchanger	13	169	(a)	(a)	0.64 (g)
Inn of the Seventh Mountain	Bend, OR 1992 - Retrofit	Condominium, Hotel Complex, Convention Center, Spa, and Pools	280,000+ 350 units and convention center	Open loop – 1 well - 73 L/s	2	1,759	24.47 (e)	2.27 (e)	0.16
Kittitas Middle School	Kittitas, WA 1992 - New	Middle School	39,000	Ground loop – vertical bores 70 bores, 61 meters deep Total 8,534 meters	30 (18 H_2O-to-air) (12 H_2O -to- H_2O)	295	(a)	(a)	0.20
Lane Community College	Eugene, OR 1981 - Retrofit	Downtown Comm.College - Converted Montgomery Ward Store	58,000	Open loop – 3 wells – 16 ºC Total flow 16 L/s	1 3 compressors	317	19.97	1.86	0.13 - 0.15
LDS Office Tower	Salt Lake City, UT 1972 - New	Offices & Public Rooms - 30-story tower plus 2 Wings	680,000	Open loop – 4 wells - total flow 513 L/s. two wells at 119 meters deep. two wells at 192 meters deep, 19-24ºC	3	7,913	(a)	(a)	0.12 (h)
North Bonneville City Hall	North Bonneville, WA 1995 - Retrofit	City Hall Administration and Offices	4,600	Ground loop – horizontal 1,829 linear meters	2	35	9.40	0.87	0.05
Parkview Apartments	Winchester, MA 1965 - New	Condominium Complex 318 apts.	207,400	Open loop – 2 wells 11 to 15 ºC 95 L/s total flow	2 Compressor/ units	1,407	15.35 (F)	1.43 (f)	0.12 - 0.15

Site	Location	Building Type	Square Footage	System Type	Number of HP Units	Heat Pump Capacity, kW	kWh Square Foot/Year	kWh/Square Meter/Year	Maintenance Cost $0.00US/Square Foot/Year
Squaw Valley Day Care	Squaw Valley, CA 1993 - New	Day Care Center with Snow Melt	15,000 sqm bld. – 9,000 sqm snow melt	Closed loop – horizontal ground loop - 2,880 meters	4	141	0.013 (d)	0.001 (d)	0.02 - 0.03
Sundown M Ranch	Yakima, WA 1985 - New 1990 - New 1992 - New 1995 - New	Drug & Alcohol Rehab Complex	 61,800 20,650 39,736 7,500	Open loop – 2 wells -61 meters deep - total flow 35 L/s 10+ºC	 139 50 89 19	 700 197 524 102	?????? 37.15 31.27 43.27 44.65	1.92	0.12 - 0.15 total square footage
Tacoma City Light	Tacoma, WA 1954(b)- New	Administration & Office Building	130,000	Open loop – 2 wells - 14ºC– 27 meters deep – 50 L/s 12ºC – 65 meters deep – 79 L/s - shallow well winter; deep well summer - separated by heat exchanger	2	1,231 (528 kW_t) (703 kW_t)	24	2.23	0.51
Tower Building	Yakima, WA 1980 - Retrofit	Offices with first floor Commercial	133,000	Open loop – connected to two wells via heat exchanger 37 meters and 74 meters deep 16-18ºC	152	1,055	(a)	(a)	0.11
Walla Walla Community College	Walla Walla, WA 1995 - New	Administration office, classrooms, student lounge, and cafeteria	100,000	Open loop – one production well - 11-12ºC, - 366 meters. – 63 L/s - water rejected to city water system prior to treatment	2	2,110	(a)	(a)	0.10 - 0.15
Walla Walla Corps of Engineers	Walla Walla, WA 1995 - New	Administration Office and Printing Shop	91,432	Open loop – connected to municipal water system via heat exchanger - 4-16ºC	120	943	21.50	2.00	0.57 (a)
Whitman College Science Building	Walla Walla, WA 1955 - New	Science Building	88,000	Open loop – pumped well 23ºC with intermediate heat exchanger 47 L/s		422	(a)	(a)	>0.10
Whitman College Administra-tion Building	Walla Walla, WA 1989 - Retrofit	Administration Building	30,000	Open loop – pumped well 23ºF with intermediate heat exchanger - 47 L/s	39	352	(a)	(a)	0.06 - 0.08
Yakima County Correctional Facility	Yakima, WA 1983 - New	Correction Facility	120,000 (1983) 60,000 (1991) Total 180,000	Open loop – 274 meters well 21ºC connection via heat exchanger	2	1,055	19.81	1.84	0.006- 0.007

(a) Not separately metered.
(b) Originally 2 centrifugal chillers were used; however, in 1988 one was replaced with a twin screen Dunham Bush chiller.
(c) Sized to provide conditioning to Law and Justice Center but never connected.
(d) Average daily winter HCAC system usage, facility not occupied or used year round.
(e) 1.43 *$kWh/m^2/yr$. equals total consumption. HVAC consumption equals* 0.78 *$kWh/m^2/yr$.*
(f) 2.27 *$kWh/m^2/yr$ equals total consumption; however, HVAC consumption equals* 0.94 *$kWh/m^2/yr$.*
(g) Maintenance contract.
*(h) Includes $*0.0023*/square meter/year for chemical treatment.*

dollars U.S. compared to $0.38 (medium) to $0.05/sq.ft./ year (mean) for an average conventional HVAC system. As a comparison, the Fort Polk,

Louisiana, (Pratsch, 1999) project is budgeted at $0.018/sq.ft./year while the 4,000 kW_t Galt House East Hotel in Louisville, Kentucky, has a cost of $0.12/sq.ft./year. (Geothermal Heat Pump Consortium, 1996).

GEOTHERMAL HEAT PUMP INSTALLATIONS

Selection Criteria

A number of the GSHP systems that date back to the 1950s were installed as a result of the building owners' wish to adopt a unique, quality design that would create a positive impression in the community. This was also at a time when air conditioning was becoming more and more of an issue, and a driving force in selection of many of the geothermal systems. In the mid to late 1970s and early 1980s, a number of systems were built as a direct result of the oil crises of the early 1970s. Many of those interviewed who had responsibility for the construction of these systems indicated that the availability of a secure, locally available, indigenous resource was extremely important in the decision-making process, especially in a time of rapidly escalating energy costs and concerns over fossil fuel availability. Many owners of the more recently-developed systems contributed their decisions to go with geothermal heat pumps to past experience with such systems, very high quality of the installation, energy efficiency, and cost savings. Other reasons given included:

- environmental considerations
- compatibility with building design or retrofit requirements
- utility incentives
- reputation of engineering design firm
- need for individual temperature control
- reduced space for mechanical equipment
- life cycle cost savings.

In truth, the publicity that many of the early systems received played a major role in replication of the technology in nearby areas. This can be clearly seen with the success of the Commonwealth Building in Portland, and the press that is was afforded. To a large extent, many of the systems that were built in that era were a desire on the part of building developers to capitalize on the positive publicity that the Commonwealth Building generated.

DEVELOPMENT TRENDS

Development trends can be divided into several distinct designs, including pumped wells with central or distributed heat pumps and loop systems, horizontal or vertical, relying primarily on a distributed heat pump system layout. Fortunately for the industry, all of the above seem to offer unique solutions to meet building design or retrofit requirements. Unfortunately, the industry has not yet matured to the point where all engineering design teams feel comfortable with all available technical alternatives, and thus design is often as much a factor of prior experience as it is a conscious decision to select the most appropriate technology for a given application.

Most early systems were based on pumped wells with either injection or disposal to nearby surface water. Other systems used surface water sources such as lakes, but were of essentially the same design. The heat pumps were water-to-water and two- or four-pipe systems were used to circulate water to fan coil units situated throughout the building. By the early 1970s, pumped systems were still dominating the geothermal heat pump scene, but distributed systems were becoming a major player. With the availability of polybutelene pipe in the late 1979s, the trend seems to be moving more and more toward horizontal or vertical closed loop systems, although for many large commercial applications, the open loop water source system does seem to provide some economic advantage and continues to capture a significant market share where constraints on ground or surface water use have not been adopted.

On the building side, decentralized or distributed heat pump systems seem to increasingly dominate the field primarily because of the ease of operation and localized temperature control that they provide. This seems to be an extremely attractive configuration in schools where the individual needs of each classroom can be easily met, and each teacher has total control over the system. Large, centralized systems, however, continue to play a major role and are ideally suited to many retrofit situations, especially where, because of the historical nature of buildings, major changes are very difficult or impossible. Centralized systems are also an extremely attractive choice for office parks or where low-temperature hydronic heating can be provided.

Because of the wide range of water sources and ground loop configurations that can now be used and the number of in-building systems that are possible, geothermal heat pump systems can now be tailored to fit almost any possible need. The only challenge for the design engineer is to determine the best combination of water or ground source and in-building configuration to best serve the client's needs in the most efficient, reliable, and cost-effective manner possible.

BUILDING AND GSHP SYSTEM CHARACTERISTICS

Table 1 presents information on in-building system design and energy performance. Unfortunately, because of the age of many of the installations, no actual capital cost data was available for most systems and, therefore, no attempt has been made to cover capital cost information in any detail. For the 22 systems that are covered in this paper, the installed heat pump capacity varies from a low of 1.36 tons/sq.ft. per 1,000 square feet to a high of 6.00 tons/sq.ft. (the system was designed to meet future growth at the college) per 1,000 square feet. For the water source systems, flows range from 1.30 gpm per ton of installed capacity with an average of 3.43 gpm per ton. Required flow is, of course, very dependent upon water temperature and heating and cooling requirements. For closed loop systems, the heat exchanger circuit pipe length ranged from 236 feet per ton to 600 feet per ton, with an average of 454 feet per ton. Of those with vertical bores, the range is 166 feet of bore per ton to 204 feet.

Building electrical energy use ranges from 9.40 kWh per square foot per year to 24.47 kWh per square foot per year, with an average of 18.7 kWh per square foot per year. For those systems where it was possible to determine electrical load for the mechanical system, the range was 8.43 kWh per square foot per year to 10.14 kWh per square foot per year. Electrical rates and demand charges are so utility-specific that no meaningful trend could be discerned from an analysis of available data.

EQUIPMENT AND DESIGN PROBLEMS

Due to the fairly unique differences between open and closed geothermal heat pump systems, the equipment and design problems will be treated separately as will maintenance issues and costs.

Open-Loop System

As was mentioned earlier, open systems dominated the geothermal heat pump market from 1946 until approximately 1980 when horizontal and vertical closed loop systems became readily available. A majority of open loop systems rely on one or more wells.

Water is withdrawn from the well or other source and disposed of through the use of injection wells, through surface discharge, or, in the case of standing column wells, the water is returned to the outer annulus of the production well.

There is little doubt that well problems dominate when it comes to open loop systems. The two most often encountered problems are inadequate flow in the production well and plugging that causes pressure build-up in the injection well. Production problems are most often a result of excessive draw down of the acquifer due to over use or severe drought. It can also be a result of sedimentation in the bottom of the well. In many cases, the wells are simply not drilled deep enough or completed correctly. Many such problems can be corrected by deepening the production well or by reworking. In those cases where sedimentation is a problem, correct screening can provide a relative straightforward solution. However, the vast majority of problems associated with open loop systems are caused by the injection well. The principal cause appears to be iron bacteria and, where a mature colony is established, extremely difficult to eliminate. The problem can, however, be minimized by regular maintenance including chlorination (once every 3-6 months) and back pumping of the well. In some cases, the pressure build up problem is caused by scaling (often calcium carbonate, $CaCO_3$). Again, the problem can be minimized through the use of chemical treatment, although in some severe cases, some reworking of the well on a regular basis may be required. Of course, excessive injection pressure may also be the result of poor well completion or an inadequate injection horizon.

The next most common problem associated with open loop systems is pump failure. Both open shaft, vertical down-hole pumps; and submersible pumps are regularly employed and, at least for those cases where high volume is desired, the down-hole shaft system appears to dominate. Principal problems seem to be with bearings and seals, often resulting in the need for major maintenance and, in a worse case scenario, resulting in a broken shaft. Major pump problems seem to be avoided through proper sand screening and by ensuring adequate lubrication.

Finally, the lack of a heat exchanger (shell and tube or plate and frame) to isolate the production flow from the in-building equipment can result in major system problems including excessive corrosion in the heat pump tube bundle. Most systems are now moving from shell and tube to plate and frame exchangers due to the closer approach temperature, the ease of maintenance and the flexibility they offer in terms of ease of expansion.

Closed-Loop System

Closed-loop systems began to challenge the dominance of the open-loop systems in the late 1970s/early 1980s. However, unlike open-loop systems where required flow can easily be determined based on load, source temperature, and equipment performance, loop length is much more difficult to calculate and is highly dependent upon soil characteristics including temperature, moisture content, particle size and shape, and heat transfer coefficients. Correct sizing of the ground loop continues to be a cause for continued design problems and special attention should be placed on minimizing inference between loops, whether they be horizontal or vertical.

Other problems associated with loop design and installation include improper header design, inadequate system purging, leaks associated with corrosion of fittings, or poor workmanship. All of the above problems can be minimized through proper system analysis and design, and the use of well-trained and experienced installation personnel. One of the most often encountered problems is related to the circulated heat transfer fluid. Methanol and Environol seem to be the least problematic and best heat transfer fluid choices.

Central vs Distributed Heat Pump Systems

There seems to be very few problems associated with either the choice to employ a centralized or decentralized heat pump arrangement. Both afford the capability to provide supplemental heating or cooling through the use of boilers or cooling towers. The only major design problems that seem to be somewhat common in many centralized heat pump systems is the use of a two-pipe system to circulate hot or chilled water. Because the two-pipe system does not allow for the simultaneous supply of both heating and cooling, the building owner/system operator must choose which service will be provided at any given time. Because most such systems are difficult to reverse once the decision is made to go from, for example, heating to cooling, the system can not readily be changed back should a late spring cold spell come unexpectedly. Because the provision of heating is almost always more critical than cooling, operators most often chooses to error on the side of having heat available.

OPERATION AND MAINTENANCE

Open-Loop System

Most maintenance problems associated with open-loop systems are well related. The problems include problems with pumps, including bearings and seals. Other maintenance issues include the need to clean or even rework production and injection wells and the need for chemical treatment of injected water to control scaling or bacterial growth that plugs the injection wells. Another potentially major maintenance issue is removal of sand from the heat exchanger(s) if adequate filters and/or sand traps are not used.

Closed-Loop System

Maintenance of closed-loop systems appears to be extremely minimal and restricted to circulating pumps unless the heat transfer fluid results in corrosion of fittings and other system components.

Central and Decentralized Heat Pump Systems

Central heat pump systems seem to require very limited maintenance, and because all major pieces of equipment are located in a central location, most maintenance chores can be carried out easily. Decentralized systems, on the other hand, do require considerably more routine maintenance including changing filters every three to six months. For example, when the Tower Building in Yakima, Washington, was purchased by the present owner, approximately one compressor per week required replacement; however, once a routine preventative maintenance program was put into place, only one compressor failure occurred over the entire following year. Care should be taken when installing a decentralized system to ensure that maintenance personnel have adequate access to each unit for routine maintenance and also for repairs when they become necessary.

Despite the maintenance issues mentioned, maintenance costs are relatively low in all but a few cases, averaging $0.016 per square meter per year (see Table 1). In only three of the cases evaluated was maintenance considered a major concern. In one of these, the equipment was in definite need of replacement after nearly 35 years of service, and with the others, problems with the heat transfer fluid had resulted in serious corrosion problem and leaks as well as control problems due to the leaks. Anonymously high maintenance costs were a result of, in one case, a poorly structured maintenance contract; in another, lack of local maintenance providers; and in two cases, to relatively high in-house personnel costs assigned to the HVAC system.

CONCLUSION

Geothermal heat pump systems are an increasingly attractive option for commercial buildings. Based on over 50 years of operating experience, it is safe to say that earlier concerns over long-term reliability, operation, and maintenance costs were, to a large extent, unfounded. Although some systems have had to be replaced due to problems related to production and/or injection well problems, a majority of the systems have proven to be extremely reliable, with many having been in service over 25 years, and maintenance problems and costs have been acceptably low.

Advancements in equipment, installation techniques, and control systems as well as knowledge of heat transfer continues to reduce equipment and design problems. Increasing knowledge and use of a wide variety of water sources as well as ground loop designs and configurations, together with the number of in-building systems that are now possible allow that geothermal heat pump technology can be tailored to fit almost any possible building need.

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