Commercial Geothermal Heat Pumps

Introduction

Despite the fact that commercial geothermal heat pump (often called ground source heat pump or geoexchange) 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 due, in large part, to programs by USDOE and the Geothermal Heat Pump Consortium. Due to these efforts, considerable data now exists on how such systems provide a high level of both heating and cooling comfort, while at the same time reducing both energy consumption and peak demand. 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 achieve broader acceptance, mechanical design teams must have better understanding of not only the economic, environmental, and comfort benefits that these systems can provide, but also the long-term operational, maintenance, and reliability issues that they can expect to face over the life of the system.

In order to meet this need, a number of studies have been completed to document customer satisfaction, 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. The Geothermal Heat Pump Consortium and the U.S. Department of Energy have entered into separate contracts with the Washington State University (WSU) to complete a series of case studies of commercial geothermal heat pump systems and strengthen the operation and maintenance data base.

Washington State has long been a leader in geothermal heat pump installation and use with several systems having been installed as early as the 1950s 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 24.47 kWh/sq.ft./year while HVAC-related energy use ranged from 8.43 kWh to 10.14 kWh/sq.ft./year. Maintenance costs were also found to be very attractive and averaged $0.017/sq.ft./year (Table 2). Maintenance costs were, however, somewhat skewed due to a limited number of systems where a disproportionate percentage of a facility's maintenance budget was assigned to the HVA system or where maintenance contracts were extremely poorly structured or where because of remote locations, considerable travel substantially increased the per square foot maintenance cost. 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. No attempt was made to select equal numbers of open vs closed loop systems or central vs distributed systems. 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. It is interesting to note that of all the systems that were identified, only a very few geothermal heat pump systems had been abandoned in favor of another system type, and in all such cases, the cause was related to open loop systems that had either excessive production well drawn down problems or injection well problems, and in no case due to problems with or dissatisfaction with the heat pumps.

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. Photos were taken wherever possible. If it was determined that additional information was needed, phone interviews were again conducted with system designers, well drillers, or loop installers. When energy consumption data was not readily available from the owner/operator, every attempt was made to obtain such information from the serving utility. 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 as well as findings of work sponsored by the Geothermal Heat Pump Consortium were reviewed. The ASHRAE Handbook 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/sq.ft./year in 1996 dollars U.S. compared to $0.38 (medium) to $0.50/sq.ft./year (mean) for an average conventional HVAC system. As a comparison, the Fort Polk, Louisiana, family housing project, consisting of 4,000+ family housing units, is budgeted at $0.18/sq.ft./year while the 4,000 ton Galt House East Hotel in Louisville, Kentucky, has a cost of $0.12/sq.ft./year. (Earth Comfort Update, 1996) In summary and Analysis of Maintenance and Service Costs in Commercial Buildings Geothermal Systems by Crane, Morrison, Clemens, and Ireland, completed in 1997, the authors found that maintenance costs ranged from $0.0052 to $0.31/sq.ft./year for ground source systems where maintenance was performed by in-house staff to $0.0052 to $0.381/sq.ft./year using outside contractors. Costs for water source systems were found to be significantly higher, ranging from $0.02 to $0.75. No breakdown of in-house vs contractor-provided maintenance was provided for water source systems.

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 definitely seems to have been the case with the Tacoma City Light Building and the Clark County PUD Building. This was also at a time when air conditioning was becoming more and more of an issue, and in the case of Whitman College, a driving force in selection 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. This definitely played a major role in the decision to go with geothermal heat pumps in the case of the Grant County Courthouse, the Yakima County Correctional Facility, and several systems that were built in and around Eugene, Oregon. Many of those interviewed who had 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.

Another important factor in many cases was the recommendation of the serving utility or advice provided by the state energy office.

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. Examples of such systems include the Tacoma City Light Building, Whitman College, Parkview Apartments, the LDS Office Building, and the St. Paul Energy Park. By the early 1970s, pumped systems were still dominating the geothermal heat pump scene, but distributed systems were becoming a major player. Systems such as those serving The Exchange Building, the Tower Building, and more recently, the Sundown M Ranch, are excellent examples. 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. And, in fact, a number of relatively unique water sources are now beginning to play an increasing role, including sewage effluent, secondary or re-use water systems, industrial or power generation heat rejection systems, sea water, lake water, river water, etc.

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. This was the case with the Grant County Courthouse, built in 1912 and retrofit in 1982. The 300-ton central geothermal heat pump, provided with 86ºF water from a municipal well, provides both heating and cooling to this historical building through the use of air handlers that were installed throughout the building. Centralized systems are also an extremely attractive choice for office parks or where low-temperature hydronic heating can be provided. The day care center at Squaw Valley is an extremely interesting example of a modern hydronic system. The four 10-ton, horizontal ground loop-based commercial heat pumps supply over 22,000 feet of hydronic heating coils that are arranged so as to provide zone comfort within the building and also provide over 8,000 feet of snow melt in the outside concrete playground area.

Because of the wide range of water source 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 2 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 per 1,000 square feet to a high of 6.00-tons* per 1,000 square feet. For the water source systems, flows range from 1.30 gpm per ton of installed capacity to 7.50 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. The horsepower of the well pump is totally dependent upon well construction, pumping head, and whether or not the well is equipped with a fixed or variable speed pump. Because of this, no attempt has been made to present this information as any attempt to draw any conclusions from it would be meaningless. 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 meter 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 changes 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, although some systems are based on other water sources, such as lake water, sewage effluent, or even municipal water. 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.

**The system was designed to meet future growth at the college.*

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. For example, the Yakima County Correctional Facility, the Sundown M Ranch, Lane Community College's downtown campus, and the Lane County Public works Yard all have experienced some level of difficulty with the injection well. The principal cause appears to be iron bacteria and, where a mature colony is established, extremely difficult to eliminate. It is thought that the iron bacteria are often introduced into the system by the well driller, and are a result of using contaminated tools in the drilling operation. 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. Another commonly-encountered problem associated with pumped wells is the lack of a variable speed drive. The sudden stopping and starting of the pump appears to generate excessive turbulence in the well, and often results in considerable amounts of sand being drawn into the system. This can have an adverse impact on the pump itself, often cause bearing problems and, in addition, can result in accumulation of sand in the heat exchanger(s). The use of a variable speed drive appears to minimize this problem, and the use of sand filters or traps is often a prudent safeguard for the system. The Parkview Apartments, the Yakima County Correctional Facility, and the LDS Office Building are all examples from this survey that have experienced problems related to sand being drawn into the system.

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. A majority of the systems visited had either installed plate and frame heat exchangers or commented on the desire to incorporate such equipment into their present systems or future design. For example, when the Yakima County Correctional Facility was first built, the geothermal water was allowed to flow directly from the wells through the heat pump, circulated through the building, and then injected within weeks of the start of operation, major corrosion problems forced the system to be shut down. After a plate and frame heat exchanger was installed, the system has run without any corrosion-related problems for over 15 years. Wherever there is any concern over cross contamination, a double-walled plate and frame heat exchanger provides a means to safeguard the system as well as early leak detection.

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. For example, in the case of the Benton County PUD building, the loops were stacked at intervals of three feet and, although there appears to be adequate loop length for the building load, severe swings in loop temperature (upwards of 90ºF) from winter to summer have occurred. The only satisfactory explanation appears to be that the loops are interfering with one another.

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. Major problems, including severe corrosion, have been encountered in, for example, the Benton County PUD system, with the use of potassium acetate. Some system operators also report problems with systems that use glycol, for example, Beaver Lake Middle School. On the other hand, others using glycol do not seem to have experienced such problems. Some feel that problems in glycol-based systems stem from inadequate flushing and purging. Beaver Lake replaced the glycol with water and although they have continued to experience some problems related to inadequate purging, the system is now operating in a much more satisfactory manner. Benton County PUD is still experiencing severe corrosion and multiple leaks caused by the potassium acetate and they are now seriously considering a replacement of the heat transfer fluid. In other systems, such as the day care center at Squaw Valley, methanol is used and it is well as Environol seems 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. An excellent example of a decentralized system is the one that serves The Exchange building in Farmington, Connecticut, where the in-building loop can be tempered through the use of a 220-ton chiller run in reverse to boost the temperature of the circulating loop and where the loop can be chilled during the summer by routing a portion of the water to a cooling tower. In the case of the Kittitas School system, water-to-water heat pumps are used in the place of a boiler and cooling tower to temper the loop supplying decentralized water-to-air or water-to-water heat pumps. 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. The systems that serve the Grant County Courthouse, the Parkview Apartments, and the Saint Paul Energy Park, are all examples of such systems. 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, and often as a result of bearing problems, severe shaft problems including, in at least one instance, a broken shaft. 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. In one system, the change-over of R11 to 124A in the central heat pump has, however, resulted in major maintenance concerns and at least an initial loss of system reliability. Fortunately for the installation, the manufacturer has taken full responsibility and the problems do appear to be decreasing.

Decentralized systems, on the other hand, do require considerably more routine maintenance, including changing filter 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 $0.17 per square foot per year (see Table 3). 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.

Case Studies

Bryant College, Smithfield, Rhode Island
The Exchange, Farmington, Connecticut
Haverhill Public Library, Haverhill, Massachusetts
Heritage College Library, Toppenish, Washington
Inn of the Seventh Mountain, Bend, Oregon
Lane Community College Downtown Campus, Eugene, Oregon
Latter Day Saints Office Building, Salt Lake City, Utah
Parkview Apartments, Winchester, Massachusetts
Children's world at Squaw Valley, Squaw Valley, California
Sundown M Ranch, Yakima, Washington