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Chapter 2.9

Commercial and Industrial Heat Pump Case Studies

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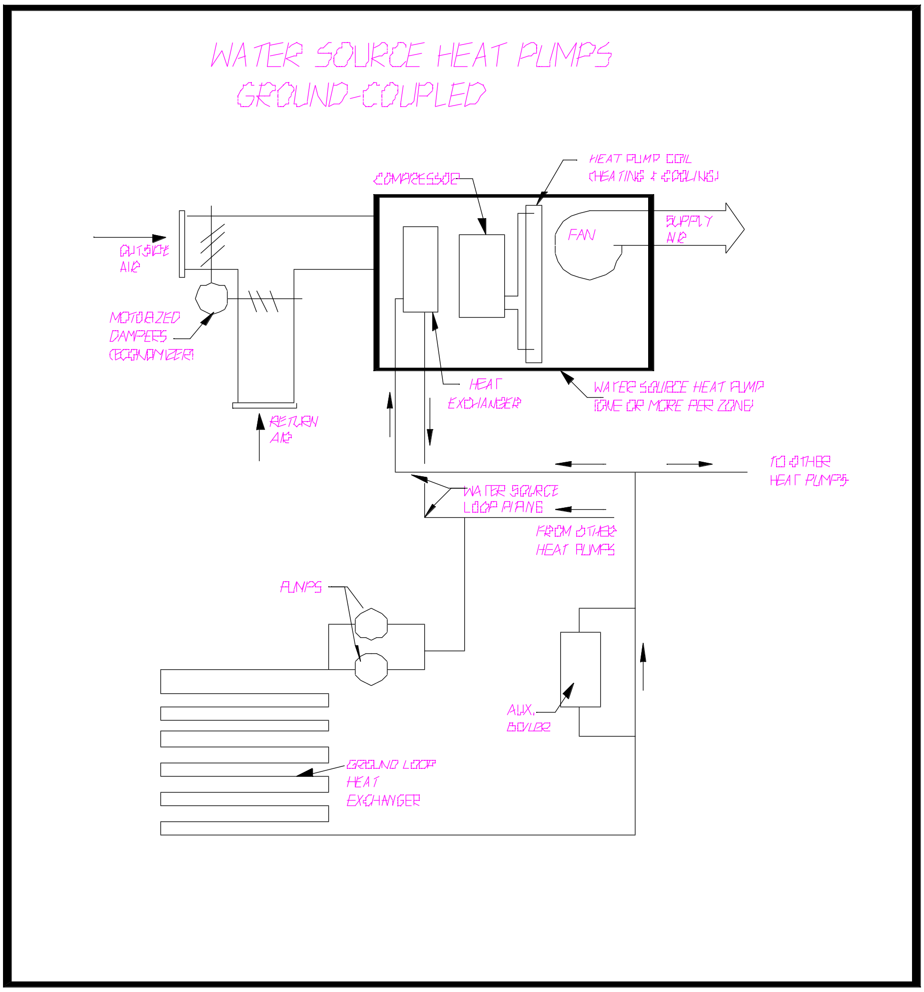


Figure 1. Geothermal Heat Pump System Schematic

The Exchange

Location: Farmington, Connecticut
Building Type: 265,000 sq.ft. commercial and office complex
System Type: Open loop, distributed water source heat pump system
Age: 28 years
Energy Use: 17.18 kWh/sq.ft./year total: 6.2 kWh for the heating and cooling system
Estimated Maintenance Cost: approximately $0.16/sq.ft./year

Building Characteristics

The Exchange is a three-story, semioctagonal commercial office building located in Farmington, Connecticut. The 265,000 square foot complex, built in 1971, is an AIA award winner. The building contains primarily office space, but a number of restaurants and commercial establishments are found on the ground and mezzanine levels. The Exchange was built as part of a Planned Unit Development that also contains 500 single-family rental and condominium units.

The construction of The Exchange is of exposed, heavy timbers without conventional wall and ceiling finishes in both retail and office areas. The sloping roof with dormer-type windows keeps the building small and low in scale for its size. The walls and ceiling are insulated with 3.5 inches of mineral wood (R-13). The roof is asphalt shingle on _ inch plywood deck. The building contains 7,500 square feet of insulated glass. Floors are a combination of concrete on grade (1st floor) and heavy planks. The building has a recently-installed energy management system (EMS). The $160,000 cost for the EMS had a one-year payback.

Geothermal Heat Pump System Characteristics

Geothermal Source Description

The 55ºF geothermal source is provided by four wells that have been used continually since 1971. The system uses a shell and tube heat exchanger between the wells and the circulating fluid that supplies the heat pumps. Well number 1, lying to the east of the building, is 350 feet deep, and provides 55 gpm. Wells 2, 3, and 4 lie to the west of the building and provide 148 gpm, 204 gpm, and 60 gpm, respectively. The wells are all at a depth of 350 feet. Wells 1 and 2 have 2-inch pipes to depth while number 3 has a 3-inch pipe and number 4 has a 4-inch pipe. Well number 1 is served by a 7.5-hp pump, well number 2 by a 15-hp pump, well number 3 by a 20-hp pump, and well number 4 by a 10-hp pump. All of the pumps are submersibles. The water is disposed of into a nearby creek at a maximum of ca 85ºF.

Heating, Ventilation, and Air-Conditioning (HVAC)

System Description

The system circulates tempered water from the tube and shell heat exchanger to each of the 495 individual water-to-air heat pumps that serve the building. The units are designed for a 20ºF _t in cooling mode and 10ºF _t in heating mode. A 220-ton screw compressor can provide supplemental heat to the loop in the winter, but since 1971, when it was installed, it has operated a total of less than 8,760 hours or less than 3 percent of the time. During the summer, when the loop temperature exceeds 100ºF, a cooling tower rejects heat to the air. The building has a design heating loss of 8,745,000 Btu/hour and a design cooling heat gain of 7,685,000 Btu/hour. Outside air ventilation is 50,000 cfm.

The building is served by a total of 495 individual heat pumps or a total of 1,094 tons. The heat pumps range in size from 1 _ tons to 4 tons. The 1 _ ton units have _ hp fans while the 2, 2 _, and 4 ton units all have _ hp fans. During periods of severe cold, the incoming well water can be boosted through the use of a Dunham Bush 220-ton screw chiller run in reverse. During the summer, the loop temperature can be moderated by sending a portion of the water to a cooling towers.

Selection of the Heat Pump System

The selection of the heat pump system was entirely consistent with the overall concept of the project and the desire of the principals to make the complex as environmentally responsible as possible. The consulting engineers, James S. Minges and Associates, Inc., also had previous experience with the use of well water for cooling.

Operating History

The system has been in operation for 28 years, and has been extremely reliable. The builder/engineer, James Minges, calculated in 1997 that the choice of the geothermal heating and cooling system had saved the "amazing amount of $5,200,000 in operation and maintenance costs over its first 27 years of existence over a conventional fossil fuel system."

James Minges was honored for his installation of the geothermal heating and cooling system in July of 1998 by the Connecticut Engineers in Private Practice when they presented him with the 1998 Engineering Excellence Participation Award. The only major change that has occurred in the building heat pump system since the original design was the addition of an energy management system in 1997.

It is interesting to note, however, that the building was designed, built, and in operation prior to the oil embargoes of the early 1970s, one of the prime driving factors behind the selection of geothermal heat pumps for many buildings selected after that time. This building was indeed before its time in not only design and construction, but also the incorporation of the geothermal heating and cooling system.

Operation and Maintenance

Maintenance has never been a major problem throughout the system's 28 years of operation and operation. Most maintenance is taken care of by in-house staff. Over 28 years, only nine of the 495 units has had to be totally replaced. Three of the down hole pumps, however, have had to be replaced. The tube bundle in the shell and tube heat exchanger was replaced at a cost of $42,000.

In 1998, for example, nine compressors had to be replaced. However, the work is done in-house and total cost per unit is $700, including parts and labor. In addition, 11 fan motors had to be replaced.

One major change in operation has been the requirement to install a monitoring system for environmental control of water that is dumped into a nearby stream. The monitoring system cost $20,000, and samples must be taken and sent in for testing 4 times per year at a cost of $400 per quarter.

Total maintenance is estimated to be approximately $0.16/sq.ft./year.

System Economics

James Minges, of The Minges Associates, performed an energy analysis on the building in 1997 and calculated that over the 26-year operating history, the building had saved approximately $5,200,000 as compared to a conventional system made up of hot water boilers and conventional chillers and cooling towers. He calculated that the 1997 maintenance cost was $0.16 per square foot/year, operating costs amounted to $0.60 per square foot/year, and replacement costs $0.05 per square foot/year for a total of $0.81 per square foot per year. The total electrical load for the building in 1997 was 4,552,560 kWh. This amounts to 17.18 kWh per square foot/year. Based on the numbers presented by Mr. Minges, the heat pump system uses ca 6.2 kWh per square foot/year.

Satisfaction with the Geothermal Heat Pump System

The present building owners and building manager are extremely pleased with the system and stated in a July 8, 1998 news article in *The Hartford Courat* "The design is really ahead of its time… has never complained or heard of any other tenant complaints regarding the temperature." The director of maintenance also expresses total satisfaction with the system and its operation and ease of maintenance.

Haverhill Public Library

Location: Haverhill, Massachusetts
Building Type: Public library, total 44,000 sq.ft.
System Type: Open loop, standing column wells, water source heat pumps
Age: 5 years
Energy Use: 16.3 kW/sq.ft/yr.
Estimated Maintenance Cost: $0.135/sq.ft./yr.

Building Characteristics

The Haverhill Public Library was built in 1967. The original building was 27,000 square feet; however, a 17,000 square foot addition was built in 1997, bringing the total to 44,000 square feet. The building is of concrete construction and, in addition to community library services, also contains an extensive historical volume section requiring precise humidity control.

Geothermal Heat Pump System Characteristics

Geothermal Source Description

The geothermal source consists of four 1,500-foot deep standing column wells (SCW). Two of the wells are drilled to serve the initial retrofit of the building to geothermal heat pumps in 1994. Two additional SCWs were drilled in 1997 to serve the building addition. Average water temperature is 55ºF. The water temperatures in the SCWs varies from a summer high of 69ºF to a winter low of 38ºF. Each of the wells may be pumped at from 70 to 80+ gpm. Each of the wells was drilled six inches in diameter; a four-inch pipe was placed in each well to depth. Pumping is via submersible pumps that draw from the bottom of the well. Discharge is to the top of the well between the standing columns and the annulus of the bore hole. In order to ensure relatively consistent water temperature, a "bleed" system is coupled to the circulation loop and allows for ca 10 percent of the water to be bled off from the system, allowing for the reestablishment of the water temperature if preset temperature parameters are exceeded. Each of the SCW submersible pumps operates on a simple pressure logic.

Heating, Ventilation, and Air Conditioning (HVAC)

System Description

The library was originally built with air-cooled chillers and electric resistance heating. Conditioned air was distributed through three large air handler units. Control was via a pneumatic control system. The retrofit that took place in 1994 included the drilling of two 1,500-foot deep standing column wells and installation of six 10-ton water-to-water heat pumps. The electric resistance elements were completely removed from the air handlers. The six heat pumps, located in the original mechanical room, were tied into the existing air handler system via a new and separate building side manifold. The heat pumps are designed to supply up to 115ºF water for heating and 45ºF for cooling. Building loop water temperature is manually set and automatically controlled by a single aquastat. Each of the six heat pump stages are sequentially called by set time delays. As each heat pump is called, an individual automatic water valve at the heat pump opens and pressurized well water flows through the heat pump. The existing pneumatic control system was retained. The heat pumps operate at a coefficient of performance (COP) of over 4.8.

In 1997, a 17,000 square foot addition to the library was built and 13 water-to-air heat pumps were installed to heat and cool this new area. The 13 heat pumps represent 47.5

tons of new, installed capacity. Water supply to these units is from two additional 1,500 foot SCWs. The decision to use distributed heat pumps instead of adding to the central system was based on the complexity of providing additional service based on the existing air distribution system and the need for more precise humidity control in the new historical volume area of the library addition. Water from the two SCWs is distributed to the heat pumps via a piping system served by two 3-hp circulating pumps. The 13 distributed heat pumps are controlled by individual thermostats.

Selection of Geothermal Heat Pump System

The decision to retrofit the library in 1994 after nearly 30 years of operation was based on a need to replace existing equipment and the availability of a Massachusetts Electric heat pump demonstration program that resulted in the system being installed at no cost to the library. However, at the time of the addition, no utility incentive program was available and the decision was based on an evaluation of geothermal heat pumps vs natural gas. The geothermal heat pumps were chosen primarily as a result of a need to provide precise humidity control.

Operating History

Since being put into operation in 1994, the system has performed very well. There have, however, been some problems with compressors with one unit failing almost immediately and a second in 1998. The first compressor was replaced under warranty. The second unit resulted in an expenditure of approximately $2,000. The only other concern is the possible need to install a sand trap or filter system to deal with sediment in the system.

Operation and Maintenance

Maintenance is taken care of primarily by in-house staff and consists of routine changing of filters and lubrication of mechanical equipment, including pumps, fans, etc. No maintenance has been required on the standing column wells or submersible pumps, but sediment in the system may necessitate the installation of sand traps or filters. Maintenance cost is ca $0.135 sq.ft./yr.

System Economics

Due to the fact that Massachusetts Electric installed the first phase of the system at no cost to the library as a demonstration of geothermal heat pump technology, the system was fully instrumented with remote monitoring data acquisition devices capable of collecting data every 15 minutes and including power usage monitor meters (kWh and kW) for both heat pumps and well pumps. In the first full year of operation, the system saved a total of $11,586, showing a reduction in total electric bills of 23 percent and a 65 percent reduction in cost for space conditioning. Of significant importance to both the library and the utility was an approximately 50 percent reduction in demand. Unfortunately, similar data is not available for phase two. However, for 1998, the entire electric load for the library was 709,800 kWh for a total of 16.13 kWh per square foot per year. Maintenance is running approximately $0.135 per square foot per year.

Satisfaction with the Geothermal Heat Pump System

Library administration and staff seem to be very satisfied with the geothermal heat pump system. The decision to use geothermal heat pump technology when the addition was built in 1997 speaks well for the satisfaction with the original system. Satisfaction with the system installed in the addition appears to exceed that of phase one, and is probably due primarily to the individual control and precise humidity control that the system provides.

LDS Church Office Building

Location: Salt Lake City, Utah
Building Type: 683,000 sq.ft. office building
System Type: Open loop water source heat pump system
Age: 27 years
Energy Use: N/A Building not individually metered
Estimated Maintenance Cost: approximately $0.13 to $0.15/sq.ft./year

Building Characteristics

The headquarters building of the Church of Jesus Christ of Latter-Day Saints (LDS) is a 28-story office tower plus penthouse and two 4-story wings to the east and west. The building was occupied in 1972. Construction is concrete. The entire complex has 683,000 net square feet of office space and houses 1,600+ employees. Three levels below ground contain the cafeteria, mail room, print shop, maintenance shop, and parking for 1,400 cars. The Genealogy Library is on the main floor of the west wing. A 335-seat auditorium is on the main floor of the tower. The interior of the building is designed on 5-foot square modules. This permits separate control of lighting and air-conditioning for each module. On the building's exterior, T-shaped columns help shade the windows to reduce the cooling load. The windows are double glazed, and rotate so that external cleaning is not necessary.

Geothermal Heat Pump System Characteristics

Geothermal Source Description

The geothermal source is provided by four wells. Two of the wells are ca 390 feet deep, and the other two approximately 635 feet deep. The two shallower wells are approximately 67ºF and the two deeper wells are ca 75ºF. During normal winter operation, water is pumped from the warmer wells and injected into the cooler wells. During the summer, the production and injection are reversed. This results in a greater than normal _t between the wells and improves operating efficiency. Well number one is equipped with a 250-hp line shaft pump with the other three wells being fitted with 200-hp line shaft pumps. Total flow during any period of operation is 4,600 gpm. The facility has permission to produce up to 6,285 gpm and inject up to 5,280 gpm. However, under normal operation, approximately 1,380 gpm is sent to the storm drains and 3,220 gpm injected. Total production capacity of the four wells is 8,130 gpm.

Heating, Ventilation, and Air-Conditioning (HVAC)

System Design

The central heat pump plant consists of three 750-ton York units connected in series. Two heat pumps can cover peak load and, in most instances, one heat pump will carry the entire building load. Each of the heat pumps consists of a turbo-compressor, condenser, cooler, and liquid intercooler, and is powered by an 800-hp General Dynamics squirrel-cage motor with geared-speed increaser. The central system is controlled through the use of a Honeywell Master Control Center. In utilizing the hot and cold water produced in the refrigeration cycle, two main air heating and cooling systems are used. The larger induction system is employed around the periphery of the building to balance heat loss and gain through the windows, while a dual duct, "high velocity" system is used in the interior to balance the net occupancy and lighting load. In the induction system, both hot and cold water is delivered to separate primary coils in a series arrangement in air streams within a common enclosure. These units, including 14 main air handlers, are located on the 13th floor of the tower and the 4th floor of the east and west wings.

Selection of the Geothermal Heat Pump System

In 1953, the church leadership expressed concerns that existing city water service was inadequate to provide necessary fire fighting capabilities for the historic buildings on Temple Square. In 1954, the church began to construct a 440,000-gallon, underground, concrete storage tank and two deep water wells and pump stations to feed fire hydrants on Temple Square. In 1957, the city proposed to meet their obligations for fire protection by constructing an 8 inch dedicated underground fire line with fire hydrants at strategic locations. In 1959, the church began to consider what should be done with the storage tank. Consulting engineers proposed the feasibility of using water from wells number one and two for air-conditioning purposes. In 1960, the feasibility study was started and submittals were sent to the state for revised use of the water. In 1962, the studies were completed and it was determined that two additional wells were needed for injection. The state water engineers gave approval and wells number 3 was completed in 1963 and well number 4 in 1964. In 1968, the construction of the new church administration building was started and it was completed in 1972. The system was also designed to provide precool assist to the HVAC system of the Relief Society building.

Operating History

Since going into operation in 1972, the system has performed very well with few major operational or maintenance problems beyond what would be anticipated during 27 years of operation. According to the maintenance staff, the average life of the York units is 25 years, and that they have now exceeded that and expect several additional years of life before major replacement is required.

Operation and Maintenance

Only one well has required extensive maintenance. Well number one, completed in May of 1955, has suffered two broken shafts, the first in 1983 and the second in 1995. The pump in well number one also has had bearings replaced in 1980 and 1994. Wells number two and three had sand separators added in 1983, but no other major changes or repairs have been required. The pump in well number 4 had to be pulled in 1981 to replace the head shaft because of leaking seals. In 1995, the entire pump in well 4 was pulled to install new bearings. Both wells number one and four have had the well brushed and cleaned.

All three of the heat pumps have had to be retubed. Chiller number 1 in 1988, chiller number 2 in 1990, and chiller number 3 in 1987. The average cost of retubing has been $80,000 to $100,000. The compressor on unit number 3 was rebuilt in 1987, and the compressor on unit number 2 was rebuilt in 1990. The cost of rebuilding a compressor is ca $15,000. Total maintenance cost is estimated to be $0.13 to $0.15 sq.ft./year.

System Economics

The system has always been extremely cost effective for the church. It was calculated that the system had a four year payback although it had cost one-third more than a more conventional system based on boilers and chiller with cooling tower. However, it should be remembered that two of the wells were drilled for other purposes and are not included in the first cost of the system. In 1982, the electrical cost for the building was estimated to be 0.03¢ per square foot, of which an estimated 50 percent was for lighting and the remainder for mechanical equipment.

Satisfaction with the Geothermal Heat Pump System

Church personnel seem to be extremely pleased with the overall operation and maintenance requirements. In fact, the head of maintenance said, “great system, would recommend again.”

Parkview Apartments

Location: Winchester, Massachusetts
Building Type: 207,400 sq.ft. apartment/ condominium complex
System Type: Open loop, central and water source heat pump system
Age: 34 years
Energy Use: 15.35 kWh/sq.ft./year – Total 8.43 kWh/sq.ft./yr for the mechanical system
Estimated Maintenance Cost: approximately $0.12 to $0.15/ sq.ft./yr.

Building Characteristics

The Parkview Apartments in Manchester, Massachusetts, was opened in 1965. The 207, 400-square foot complex is built as a perfect semi-circle and frames a two-acre landscaped courtyard. Each of the apartments opens onto a balcony overlooking the landscaped courtyard, including rock gardens bordering on a succession of ponds, bridged streams, and miniature waterfalls. The 8-floor structure and full basement contains 318 units, including studios and one- or two-bedroom units. The back wall of the complex encloses hallways and shelters the apartments from wind and reduces energy losses. The exterior is of precast concrete panels with 1 inch of urethane insulation (R-7). The roof is built-up tar and gravel on 2-inch urethane insulation (R-14) over 8-inch precast concrete deck. The gross wall area is 80,250 square feet with glass covering 39,120 square feet. The design heat loss is 5,200,000 Btuh with a ventilation requirement of 19,200 cfm. The design heat gain is 3,600,000 Btuh with a ventilation requirement of 19,200 cfm.

In April of 1980, the Parkview Apartments was converted to a condominium, and has been operated as a condominium complex since that time.

Geothermal Heat Pump System Characteristics

Geothermal Source Description

The complex was originally served by three wells; however, the system now relies on two wells. The depth is estimated to be ca 80 feet. The two wells provide approximately 1,500 gpm of ca 54ºF water. Pumping is via 30-hp, 78-foot vertical shaft pumps. Operation of the system requires the use of only one well with the second in reserve except during peak demand periods. An Alpha Laval plate and frame heat exchanger separates the well water from the in-building circulation system. Water, after passing through the heat exchanger, feeds the ponds that cascade through the courtyard and finally drains into a nearby stream.

Heating, Ventilation, and Air-conditioning (HVAC)

The original system consisted of three 200-ton Chrysler Air Temp water-to-water heat pumps. Each of the three units is equipped with two 100-ton compressors. The heat pumps operate at a COP of between three and four. Water heated or cooled by the heat pump is circulated throughout the complex via two 75-hp circulating pumps supplying a two-pipe system allowing for the supply of either heating or cooling. The system circulates up to 2,000 gpm. During the winter, water is supplied to the individual fan coil units at from 95º to 110ºF. During the summer, 52ºF water is circulated to the fan coils from the central heat pumps. During the shoulder period, the system circulates 59ºF water that can be produced by rejecting heat directly to the well water via the plate and frame heat exchanger. The system also includes a 3,000-gallon hot water accumulator and a 1,000-gallon chilled water accumulator. Water circulates to each apartment where it supplies a total of 950+ fan coil units. Temperature in the individual units is regulated by means of wall-mounted pneumatic heating/cooling thermostats and modulating valves in the fan coil units. For domestic hot water, incoming city water passes through a tube nest within the heat accumulator and then passes to a storage tank where it mixes with water from the booster heater to bring it up to desired tap temperature.

Selection of the Geothermal Heat Pump System

The apartment complex was built upon the site of a former tannery that had required very large volumes of water. The availability of water provided the developer with the possibility of using water-to-water heat pumps. The structural aspects of the building design precluded consideration of localized through-the-wall cooling equipment and mandated that a central space conditioning system would have to be adopted. The decision thus became one of economics and the first-cost differential between the costs of an oil-fired boiler plant with its housing, stack, fuel storage facilities and chillers and cooling tower, etc., and the cost of the heat pump system. The differential turned out to be small. The final selection would therefore be based on operating cost and, after extensive analyses, it was determined that the heat pump system would have substantially lower operation and maintenance cost.

Operating History

The system is now over 30 years old and is definitely showing its age. One of the Chrysler Air Temp heat pumps failed several years ago and, because replacement parts are no long available, had to be taken out of operation. The other two units continue to operate, although the condominium association is now looking at other heat pumps to replace those that are now in use. Several years ago, the association installed the Alpha Laval plate and frame heat exchanger and they are very pleased with its performance. The two-pipe system does require a certain amount of crystal balling as the system has to be changed manually from heating to cooling mode and vise versa. Once the change is made in the fall and spring, they are reluctant to change back. This can result in some days where air-conditioning would be desirable but they feel it is better to error on the side of being able to provide heating. This does not appear to have been a major source of complaint, but it appears that a four-pipe system would be the preference if retrofitting the complex were feasible.

Operation and Maintenance

The system has operated very successfully for over 30 years, and has served the tenants well. At this point, maintenance is, however, becoming a problem and system reliability is coming more and more into question. At this point, maintenance and repair is running as high as $80,000 per year; however, the expected range is ca $25,000 to $30,000. The wells and especially the pumps appear to be requiring much more maintenance than would normally be required. They have to pull the pumps every other year. One potential cause for this is that the pumps are not fitted with variable-speed drives, and it appears that a considerable amount of sand is drawn into the system, most likely when the pumps are started. Normal operation is taken care of by the condominium association, and maintenance is also coordinated by one of the association board members who has a very good understanding of the system and its maintenance and operational requirements.

System Economics

When the system was first built (1965), the owner, Edward Brendt, calculated that heating and cooling was costing an average of only $6.10 per apartment per month, or approximately $0.11 per square foot per year. At this time (1998), heating and cooling requires 8.43 kWh/square foot/year, while total electrical consumption is 15.35 kWh/square foot/year (1997). Maintenance costs are calculated to run approximately $0.12 to $0.15/square foot/year. The condominium association is, however, expecting to incur a major expense in the near future as the heat pumps are definitely at a point where they need to be replaced to ensure reliability. Continued tracking of this facility through the change out and over the next several years of operation would appear to provide an excellent opportunity.

Satisfaction with the Geothermal Heat Pump System

There seems to have been a high level of satisfaction with the system over the years, and only recently has the system deteriorated to the point where maintenance and repair costs are rising and major replacement deemed to be a necessity. The one single item that would appear to be a source of dissatisfaction is the two-pipe system allowing for only the supply of either hot or chilled water but not both. This appears to be an almost universal problem, and two-pipe systems should be avoided in favor of four-pipe system whenever possible.

Benton PUD

Location:	Kennewick, Washington
Key Contact:	Nancy Philipp, Energy Advisor
Geothermal Source:	Ground source, horizontal loop
System Type:	closed loop,water-to-air heat pumps
Age of System:	3 years
Building Type:	31,000 ft^2 office building
Energy Use:	18 kWh/ft^2
System Designer:	SCM Engineering

Building Characteristics

The new headquarters for Benton PUD was occupied in January 1994. The building primarily consists of office space, but also includes a customer service area and an auditorium that is regularly used for public meetings and events. Construction is stick frame with a masonry facade. This is an energy-efficient-building featuring efficient lighting, occupancy sensors, an efficient building envelope, and variable speed drives on pumps.

Geothermal Heat Pump System Characteristics

Ground Source Description:

There is a horizontal ground loop under the parking lot and grass area east of the building. There are three sets of loops in three layers for a total of nine overall loops that feed into a header in the mechanical room. Within each set of loops there are seven to eight individual loops. The first layer of pipes was put in six inches of sand covered by three feet of fill followed by the second layer of pipes in six inches of sand covered by three feet of fill, then the third layer of pipes in six inches of sand and topped off by six feet of fill. The loops cover an area that is approximately 160 feet by 166 feet. There are two 5-hp pumps that pump a potassium acetate (GS-4) heat transfer solution through the ground source loop. The pumps are equipped with variable speed drives. Only one pump operates at a time.

Heating, Ventilating and Air Conditioning (HVAC) System

Description:

The HVAC system consists of nine water-to-air heat pumps for space conditioning and one water-to-water heat pump for domestic hot water. The heat pumps use the ground source potassium acetate loop as a heat source when heating and a heat sink when cooling. There are valves at each heat pump to allow the ground loop to bypass the heat pump when it is not heating or cooling. The total design heat pump capacity is 77 tons.

Each heat pump serves a zone in the building. They are constant volume units. They have 2-stage compressors with economizers. A thermostat in each room controls a damper to allow some individual room control within each zone.

Selection of the Geothermal Heat Pump System

The PUD wanted an attractive building that showcased energy efficiency for the community. An energy study was performed that compared air-to-air heat pumps and the geothermal heat pumps to a baseline system with electric resistance heating and DX cooling. The payback for the geothermal heat pump system was relatively long, even with a $44,700 rebate from the Bonneville Power Administration (22 year payback). However, the geothermal heat pump system was clearly the most efficient, using less than half the energy of the other options. They also expected it to have lower maintenance than an air-to-air heat pump system which is exposed to greater temperature extremes.

The commissioners were favorably disposed toward a geothermal system. One commissioner had a water source heat pump system for his residence and others were familiar with residential systems. They also visited several other non-residential buildings with similar geothermal heat pumps.

Operating History

The PUD has had some difficulty achieving stable operation from the geothermal heat pump system. When they first occupied the building in January 1994, the ground loop temperatures got down to 18°F. They were concerned about the potassium acetate freezing solid in the loop as this temperature was very close to its low end temperature range. To reduce the load on the ground loop and to prevent the loop from freezing they used electric space heaters to aid in heating the building. The first summer the loop temperature leaving the building reached 126°F and the return was 119°F. The heat pump units were tripping off because of high head pressure. They could not bring the heat pumps back on until the head pressure dropped. Since the first year there has been some improvement as the ground loop has “settled in.” Now in the winter the loop temperature gets down to the low 40’s and last summer it got up to the high 90’s. They hope this improvement continues.

They have been told since the installation that it can take up to five years for a ground loop to “settle in.” The process of settling in involves the elimination of air pockets in the soil and the rehydration of the soil which dried out during the construction process. This process improves heat transfer between the ground loop and the soil.

They believe some of the problems maintaining and controlling the ground loop temperature are related to a lack of moisture in the ground. Moisture in the ground is important for heat transfer. They have clay like soil that looses moisture rapidly. Having some kind of leach line that would allow them to introduce water and control the moisture content in the soil would improve heat transfer.

The original design strategy was to oversize the loop capacity. They were supposed to need only seven of the nine loops so that there would be extra capacity for additions to the building. However, because the ground loop temperatures have been worse than expected, they have been using all nine loops. The factors affecting heat transfer with the soil noted above effectively reduce the heat transfer capacity of the loop. Another contributing factor could be the three-layer ground loop design. The three ground loops are stacked relatively close together which would tend to reduce the capacity of the ground loop.

They are also trying to reduce system run time by shutting the system off at 6 p.m. Extended hours of operation don’t allow the ground loop to recover, reducing the capacity of the system. Some of the problems when the building was first occupied may have been due to a bake out of the building to remove volatile chemicals.

Heating the building to 90°F for the bake out took a lot of heat out of the ground and it did not recover before occupancy. Another strategy they have used during the hottest part of the summer is to heat the building at night and on weekends to help cool the ground loop. They remove any excess heat in the building using the ventilation system in the cool of the morning.

They have had some problems with temperature control across the zones in the building. Some zones include perimeter areas with different orientations as well as interior areas. They plan on splitting some of these zones by adding another heat pump and converting the domestic hot water heat pump to a space conditioning unit for some of the core spaces.

There are also some control problems. One of the most baffling occurs only occasionally when the system is in air conditioning mode. As the need for cooling increases, the central direct digital control system calls for 2nd-stage cooling. The heat pump has not been responding to the control signal. They manually have to trick the heat pump into going to 2nd-stage cooling by creating an emergency situation. The challenge in solving this problem is that one vendor claims it is a central control system problem and the other vendor claims it is a problem with the heat pump controls.

Operation and Maintenance Issues

On the heat pump side, the maintenance is no different than what you would expect for a typical system. They have a preventive maintenance program that includes changing the filters, checking the belts, inspections, etc. Two compressors have failed on one of the heat pumps. Both were replaced under warranty.

The biggest maintenance headache has to do with the potassium acetate heat transfer fluid that is in the geothermal loop. They selected this heat transfer fluid because it is very environmentally benign. It is not hazardous and does not require any special handling if it spills or leaks. However, there have been extensive problems with leaking. The original installation used teflon tape on the fittings in the geothermal loop. For potassium acetate, plumbers putty needs to be used. When the system goes from winter to summer operation and the heat transfer fluid expands, there are lots of leaks. This makes a mess. They have had leaks in the ceiling in a number of places in the building. The leaks are very disruptive and are not easy to repair. Even though the potassium acetate is environmentally benign, it has an acidic smell and feel and really isn't that pleasant. It is also corrosive when exposed to air. Some of the plumbing fittings on the system look they are 20 years old. Their black moly fittings are not lasting. They also believe that the failure of all the bypass valves to the heat pumps is due to this heat transfer fluid.

Because the valves to the heat pumps have failed, the heat transfer fluid continually flows through each heat pump. As a result, the pumps on the ground loop always run at full load and have not been able to take advantage of their variable speed capability.

Both motors on the ground loop pumps have been reconditioned and they replaced both shafts. It is not clear what the problem is, but they believe it may be due to negative pressure on the pump due to leaks. There was a lot of cavitation damage on the shafts and pumps and the unstable load may be stressing the motors.

System Economics

An energy study was completed prior to the design of the Benton PUD Headquarters Building. The study compared a geothermal heat pump system and air-to-air heat pump system to a baseline electric resistance heat and direct expansion cooling system. Table 1 summarizes the results relative to the baseline.

The Bonneville Power Administration provided a $44,700 rebate for the geothermal heat pump system, which reduced the payback to 22 years. A package of efficiency measures including increased wall and roof insulation, high efficiency windows, reduced glazing area, high efficiency lighting, and occupancy sensors was installed. A rebate of $62,850 was provided for all these measures, which were estimated to reduce energy consumption by 39 percent (229,320 kWh/yr). The simple payback of all the efficiency measures without the rebate was 13.8 years. The rebate reduced the payback for the utility to 4.7 years.

Table 1.**Comparison of HVAC System Incremental Costs and Savings**

	Incremental Cost ($)	**Incremental Energy Savings (kWh/yr)**	**Incremental Energy Savings (%)**	**Incremental Energy Cost Savings ($/yr)**	**Simple Payback (yrs.)**
Air-to-Air Heat Pump	12,345	35,991	6.1	1.080	11.4
Geothermal Heat Pump	124,560	122,011	20.8	3,660	34.0

Clearly, the selection of the geothermal heat pump system was not based purely on economics. When the interactive effects of the other measures are considered, the actual payback would be longer than 22 years. The geothermal heat pump is clearly the most energy-efficient choice and the desire of the utility to demonstrate this technology was the overriding factor in its selection.

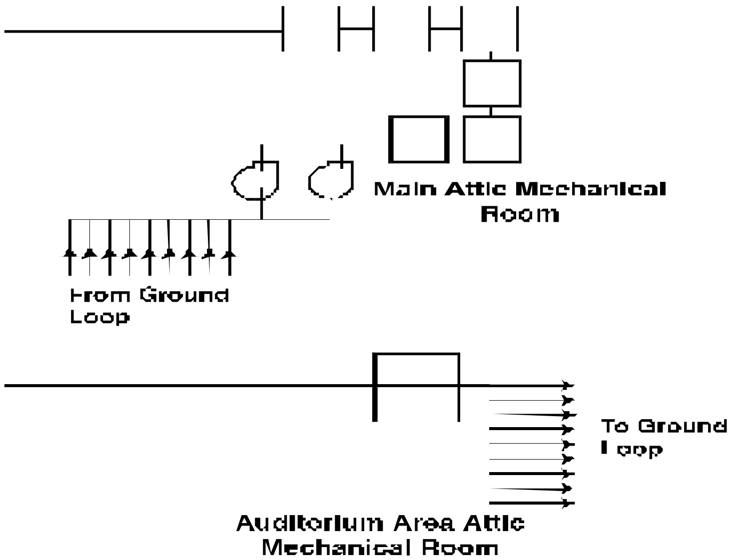
Actual energy use in the building has been greater than estimated in the energy study. For the year ending in March 1997, building energy use was 559,920 kWh (18 kWh/sq.ft.-yr). This is 56 percent higher than the energy study estimate. The PUD has a meter on the building HVAC equipment. Energy use by the HVAC equipment was 236,930 kWh for the year ending on March 1997. This compares to 34,724 kWh estimated in the energy model. This dramatic of a difference draws into question the validity of the energy model. It appears the model significantly underestimated fan and pump energy. The geothermal system is also operating less efficiently than expected due to the extreme ground loop temperatures, longer hours of operation to maintain temperatures, pumps not unloading due to failed valves, and other control problems. These results suggest the geothermal heat pump system is not meeting performance expectations and is saving very little, if any, energy. However, as the ground loop continues to settle in and the problems with the failed valves are addressed, the geothermal heat pump system will begin to produce savings.

Satisfaction with the Geothermal Heat Pump System

Benton PUD was not satisfied with the initial performance of their geothermal heat pump system. If the first year problems would have continued, they would have had to find a solution like adding a cooling tower or boiler. Fortunately, some of the problems seem to be correcting themselves as they make adjustments and the system settles in. They still have the issue of the potassium acetate and whether to keep dealing with the leaks or go to the expense of replacing it.

One of their concerns is the amount of time and money they have put into this new system to deal with a number of operation and maintenance problems. The average building owner might not have access to the resources the PUD has to deal with these maintenance problems. The PUD expected many years of trouble free operation after the initial shakedown period.

They still believe in the geothermal heat pump concept. They realize most of the problems they are experiencing are due to



design decisions. Their advice to others considering a geothermal system is to make sure the designer is experienced with geothermal systems.

Figure 1. **Schematic of Geothermal Heat Pump System**

Yakima County Jail Geothermal Heat Pump Study
Yakima, Washington

Contact Names: Regie Goforth
Phone Number: (509) 574-2300
Geothermal Source: Groundwater
System Type: Open loop, two 150-ton water to water heat pump
Age of System: 14 years
Building Type: 180,000 ft^2 County Correctional Facility, including court rooms, and inmate quarters and support facilities.
Energy Usage: 20.69 kwh/ft^2/year
$0.917/$ft^2$/year

Building Characteristics
Yakima County Correctional Facility

The main building containing court rooms, jury rooms, inmate quarters, and support facilities was completed in 1983, and is a four-story, concrete block structure. A 60,000 ft^2 annex of similar construction was added in 1991.

Geothermal Heat Pump System Characteristics

Groundwater Source Description

The facility is served by one 900 foot deep, 8 inch diameter well capable of producing 600 gallons per minute of 70+°F water. The 30-horsepower pump is driven via a variable speed drive, and is set at 260 feet. The water is pumped to two plate and frame heat exchanger where a delta T of six to eight degrees is removed. The geothermal water is then pumped to an injection well where the water is returned back to the producing aquifer.

Heating, Ventilation, and Air Conditioning (HVAC) System Description

The mechanical room contains two plate and frame heat exchangers, two 150-ton Trane heat pump and a 600 kW, 1,588 amp, 4,620

MBtuh electric boiler. In addition, the system uses a cooling tower for heat rejection. A four-pipe system circulates the heated or cooled water to air handlers that are located throughout the building. Two 15-horsepower pumps circulate water for heating and two 10-horsepower pumps are used for circulating chilled water.

Selection Criteria

Selection of the Geothermal Heat Pump System

At the time the Yakima County Correctional Facility was being planned, the country had just experienced the second major oil crisis in a decade, and oil and natural gas prices were escalating rapidly. The Yakima County Commissioners were intent on finding the most cost-effective, energy-efficient, and secure energy alternate for the planned 265-bed correctional facility.

Technical studies were provided to the County by the Washington State Energy Office, the Oregon Institute of Technology Geo-Heat Center, and Pacific Power. These studies evaluated the opportunity for and the risk of obtaining adequate supplies of geothermal fluids, the technical feasibility of using heat pumps to meet the heating and cooling needs of the proposed facility, and the economics of the heat pump option relative to the use of natural gas and/or electricity. These studies plus the existence of a 85°F flowing artesian geothermal well drilled in the early 1900s, only a few blocks from the planned construction site, and information concerning the economical feasibility of installing a geothermal heat pump system were all the Commissioners needed to choose the heat pump system over other alternatives.

Operating History

The Yakima County correctional facility was commissioned in 1983. Within weeks of commissioning, the geothermal heat pump system began experiencing extremely high and totally unacceptable levels off corrosion. The system had to be shut down and the County contacted the Washington State Energy Office (WSEO) and requested help in determining causes of the problems and measures that could be taken to minimize or eliminate these problems. WSEO, in turn, brought in the Oregon Institute of Technology Geo-Heat Center (OIT) to undertake the engineering studies. Although the water had been tested prior to selecting the heat pump system and found to be potable, a number of poor engineering decisions led to the problem encountered. The primary causes of the corrosion were the use of an open to the atmosphere holding tank, and a decision to circulate the geothermal water directly throughout the building, i.e., no heat exchangers were used to separate the geothermal fluids from the piping and air handlers found throughout the facility. Another major problem involved the use of a fixed speed pump. The production well pump which, upon start up, caused considerable turbulence in the well and resulted in large amounts of sand being introduced into the system.

OIT engineers recommended several design and operational changes to the system. First was to eliminate the open holding tank that was allowing oxygen to enter the system, and second was to isolate the geothermal fluid loop from the inbuilding distribution loop. This was done through the addition of plate and frame heat exchangers. The third major design change was to add a variable speed controller to the production pump that would minimize turbulence at start up and eliminate the problem of brining sand up from the production zone. These changes completely eliminated the operational and corrosion problems that had been encountered but at a significant cost to the County. These costs included engineering, purchasing new equipment, construction, and possibly most significant, the County was forced to use an electric boiler throughout the reconstruction period. Unfortunately, these costs resulted in lengthy legal proceedings with the County finally prevailing.

Operation and Maintenance Issues

The system has operated very satisfactorily from a mechanical standpoint, with the only major problem being one compressor that has been rebuilt on a number of occasions. The other three compressors have required little maintenance.

The system has, however, experienced two problems with the geothermal supply and disposal system. The Yakima area has experienced a significant lowering of the groundwater table over the past several years due to several years of draught conditions and increased groundwater usage. The lowering of the static water level in the production well required that the production pump be reset and nine sections of pipe added. The system has also experienced some problems with the injection well being able to accept no more than 250 gpm of spent geothermal fluid without increasing pump pressure. The exact cause of the injection problem has not been determined. If the situation worsens, the County will be forced to increase pumping pressure, work over the existing injection well, or drill a second injection well.

Satisfaction With the Geothermal Heat Pump System

The County has been very satisfied with the system despite the initial problem that resulted in lengthy legal proceedings. The system has proven to be very easy to maintain, and has met the demands of the increased load without major system expansion or modification.

Problems that have been related to one of the four heat pump compressors is not in anyway directly related to the geothermal system.

Problems with the declining acquifer, the requirement to reset the production pump, and what appears to be an increasing problem of pressure building up in the injection well have been and continue to be of major concern. The County may be forced to work on the injection well or drill a second injection well.

If acquifer draw down or injection problems worsen, operation and maintenance personnel have indicated that they may be forced to look at alternative operational strategies and/or system options. To date, however, the system has continued to provide reliable service is a cost-effective manner, and county officials have experienced strong support for and confidence in the system.

Beaver Lake Middle School

Location:	Issaquah, Washington
System Type:	Closed Loop, Water Source Heat Pump System
Age of System:	3 years
Building Type:	109,000 ft^2 middle school
Estimated Energy Use:	11 kWh/ft^2
Estimated Maintenance Cost:	n/a
System Designer:	Tres West Engineers, Inc.

Building Characteristics

Beaver Lake Middle School was occupied beginning with fall classes in 1994 (note that during design the school was called Plateau Middle School). The building is a two-story 109,000 square foot structure serving 570 students. A track and grass sports field is located to the southeast of the building. The building layout is a cross shape and includes music rooms, stage and commons area, library, main gymnasium, and auxiliary gym. Two-story classroom wings extend out each side with shop areas and a kitchen included in the west wing. Administrative offices are located at the junction of the east wing.

Construction is primarily CMU with metal stud framing and metal deck roofing with asphalt shingles. The floors are concrete and glazing is double-pane with thermal break in aluminum frames. There is a large quantity of skylights over the gyms, library, and commons area. The building has an energy-efficient envelope, efficient lighting system with occupancy sensors, energy management system with digital controls, and variable speed drives on pumps.

Geothermal Heat Pump System Characteristics

Ground Source Description:

The ground-coupled water source heat pumps utilize a horizontal ground loop heat exchanger for a heat sink in lieu of a cooling tower and supplemental boiler. The horizontal loop consist of 162,500 linear feet (650 ft. per ton) of 1" diameter polybutylene piping in two layers (4 ft. and 6 ft. deep) spaced 2 feet apart. The piping is buried below the football and baseball fields southeast of the building. There are three (3) circulation pumps equipped with variable speed drives.

Heating, Ventilating and Air Conditioning (HVAC) System

Description:

The system consists of 52 Water Source Heat Pumps located in ceiling spaces. Each heat pump serves a zone in the building, either one room or a portion of a larger room. The total design heat pump capacity is 250 tons. An 840 kW electric boiler provides auxiliary backup heating.

The system is constant volume with a thermostat controlling each zone. System controls modulate the pumps as required to meet the loads. Piping and valves at each heat pump provide bypass flexibility for maintenance and repair. The heat pump water loop is sized to provide requirements for the whole building (520 gallons per minute) if all heat pumps were working simultaneously.

Selection Criteria

Issaquah School District wanted a modern, efficient middle school that would provide a great learning environment. The District has had success with water source heat pumps and had a larger site where ground coupling could be implemented. An energy study was provided by Puget Sound Power and Light.

The geothermal system was clearly the most efficient showing $33,622 in yearly energy savings relative to the baseline system. Financial incentives provided by Puget Sound Power and Light covered the incremental costs of the geothermal system and convinced the District to try the new technology.

Operating History

Issaquah School District has had difficulty achieving stable operations from the geothermal heat pump system. During the first year of occupancy they began to experience leaks throughout the system. These leaks occurred at all of the valves and connections at the heat pumps. The recommended solution was to replace the non-toxic gylcol refrigerant with water.

Many adjustments were required in the operations because of the change. The replacement of the refrigerant created many air pockets in the lines which caused the lack of proper flow to the heat pumps. This resulted in the units tripping off because of high head pressure. The second year of operation required a lot of maintenance staff hours to adjust the operation to use water as the heat transfer fluid and removing air pockets.

The system now seems to be operating properly with loop temperatures being maintained at 50°F. The electric boiler automatically comes on when temperatures from the ground loop drop below 50°F. The system is sufficiently able to maintain comfortable conditions in all zones according to maintenance staff.

Operation and Maintenance Issues

General maintenance for the system has been no different than expected for a typical heat pump system. The biggest maintenance problems have been caused by the glycol heat transfer fluid in the geothermal loop.

The system leaked due to brass fitting corrosion during the first year. Many different Teflon tapes were tried unsuccessfully to stop the leaking. The leaks persisted during the first year necessitating the replacement of many ceiling tiles. Some valves have been replaced but the corrosion is still evident throughout the system.

The glycol fluid was removed and the system was cleaned and replaced with water the second year. Unfortunately air was trapped in lines causing problems the second year. Air vacuum causes an interruption in the flow of water and the heat pumps shut off due to high head pressure. The heat pumps then are taken out of service using the bypass valves and maintenance is performed to remove air from the lines.

Adjustments also had to be made by trial and error to modify flows and temperatures because of the different heat transfer fluid characteristics. The system now appears to be working with routine maintenance requirements. There are still concerns about future maintenance requirements such as damaged valve and fitting replacement.

System Economics

An Energy Smart Design Assistance Report was completed prior to the design of Beaver Lake Middle School. The study considered several system options. The baseline system was water source heat pumps with electric boilers and constant speed pumps. Options included variable pumping, water source heat pumps with gas boilers, and the geothermal heat pump system. Table 1 summarizes the results relative to the baseline.

Table 1. Summary of HVAC Analysis

SYSTEM	SYSTEM COST($)	ENERGY USE (kBtu/YR)	ENERGY COSTS($)	ENERGY SAVINGS ($)	SIMPLE PAYBACK (YRS)
WSHP- Elec Boiler Const Spd Pumps	BASELINE $1,015,303	6,933,197	$93,322	BASELINE	
WSHP-Elec Boiler VFD Pumps	+ $27,230	6,542,555	$88,065	$5,257	5.18
WSHP- Gas Boiler Const Spd Pumps	- $ 7,450	7,620,264	$92,530	$ 792	
WSHP- Gas Boiler VFD Pumps	+ $19,780	7,229,622	$87,293	$7,584	2.61
WSHP-Grnd Source Elec Boiler	+ $84,563	4,686,927	$65,802	$27,520	3.07
WSHP-Grnd Source Elec Boiler- VFD	+ $112,908	4,252,159	$59,700	$33,622	3.36

Puget Sound Power and Light provided a $112,908 rebate for the geothermal heat pump system, which reduced the payback to 0 years. The system was estimated to reduce energy consumption and save Beaver Lake School District $33,622 yearly. The simple payback without the rebate would have been 3.36 years.

The selection of the geothermal heat pump system was based primarily on the economics and the desire of the District to build a modern efficient facility for its students and staff.

The District has no comparable school facilities and therefore is not aware of whether this school is saving money relative to similar schools. The actual energy cost in 1996 was $15,000 greater than the estimate from the Energy Smart Design Report. However, this was mostly due to an increase in electric rates. Actual energy use for the facility was 4,179,099 kBtu, several percent less than the study estimate. Adjusting original baseline energy costs for the current electric rates results in an annual baseline energy cost of $121,884. Relative to this new baseline, the District is saving over $45,000 annually, which is more than the original savings estimate.

Satisfaction with System

Issaquah School District is not satisfied with the geothermal heat pump system. The first year they spent a lot of time dealing with leaks and the second year adjusting the system to use water as the heat transfer liquid. They also had to contend with many disruptions due to air trapped in the lines as a result of the switch in heat transfer fluids. Although the maintenance problems now seem minimal, there are still concerns about the possible long-term maintenance cost of replacing valves and fittings corroded by the glycol heat transfer fluid.

Because of the problems they have had, the District believes the system has not realized the energy savings they were promised. They also believe new technologies should not be tested in public schools where resources are not available to handle operation and maintenance problems.

They still believe the geothermal concept is sound, but have no faith in the ability of engineering to deliver the technology. They believe the engineer must have more knowledge and experience before the system can be installed successfully.