ELECTRIC POWER RESEARCH INSTITUTE

Hybrid Geothermal Heat Pump Systems

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Technical Update, December 2009

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PRODUCT DESCRIPTION

Hybrid geothermal heat pump systems offer many of the benefits of full geothermal systems but at lower installed costs. A hybrid geothermal system combines elements of a conventional water loop heat pump system in order to reduce the geothermal loop heat exchanger costs, which are probably the largest cost element of a geothermal system. These hybrid systems have been used successfully where sufficient ground space to install large heat exchangers for full geothermal options was unavailable, or where the costs of installing such heat exchangers were prohibitively high. Hybrid systems are most suitable where a large mismatch exists between seasonal heating and cooling needs, such as in commercial buildings that require much more seasonal cooling than seasonal heating even in cold climates. This report reviews the state of the art in hybrid geothermal heat pump systems and provides a rationale as to why such systems are in the best interest of utilities and their customers.

Results and Findings

Hybrid systems are cost-effective where full geothermal systems are too expensive to install, offering customers and utilities nearly the same benefits as full geothermal systems. Such hybrid systems provide more energy-efficient heating than air source heat pumps because of the warmer source water temperature as compared to ambient air. In addition, hybrid systems do not create sharp winter peak demand on the electric power system as compared to air source heat pumps, and they provide both winter heating and summer cooling that improve utility load factors. Some of the benefits of full geothermal systems—such as low maintenance costs and long service life of buried external equipment—are compromised in exchange for much lower initial costs of hybrid systems. In fact, hybrid systems can significantly cut down the initial cost of a full geothermal loop—the largest cost element of a geothermal system—sometimes by 50% or more. Such cost reductions will promote larger penetration of hybrid systems for space cooling and heating. This report traces development of water source heat pumps, water loop heat pumps, and geothermal heat pump systems for space heating and cooling.

Challenges and Objective(s)

Utilities have promoted and continue to promote the use of full geothermal systems with incentives and rebates. However, utilities could provide similar support and incentives for hybrid geothermal systems, which would increase the deployment of hybrid systems and help reduce carbon footprint. The goal of this report is to help utility marketing and customer relations representatives understand not only how hybrid geothermal heat pump systems can be as attractive to utilities as full geothermal systems, but also how customers can benefit from the lower initial costs of hybrid systems.

Applications, Values, and Use

Hybrid systems are well suited where quantities of seasonal heating and cooling loads are very different, since the full geothermal loop heat exchanger must be sized to deliver the larger of the two loads. Despite such benefits and the clear potential for reducing costs, utilities have not promoted hybrid geothermal systems as actively as full geothermal systems. What is needed now to enhance market penetration are methods backed by demonstrated solutions and technology transfer, leading to better design, implementation, and operational control of hybrid geothermal systems.

EPRI Perspective

EPRI has supported research, development, demonstration, and technology transfer of geothermal and water loop heat pump systems from the early days of emergence of these systems. EPRI sees an opportunity to combine the best features of full geothermal systems and energy efficiency features of water loop systems to create hybrid systems that are cost-effective and economical for end users, while greatly benefitting utilities.

Approach

Researchers reviewed the seasonal heating and cooling loads mismatch from performance of several geothermal systems, where loop temperatures continued to increase after the first year of operation even in very cold climates. They found large differences between requirements for the two types of loads. In cooling dominated buildings—and most commercial buildings are cooling dominated even in cold climates—the loop size must be larger than what it would be if it were sized for heating. The extra size and cost of the loop to provide cooling can be very high. Two factors contribute to system operational shortfall: first, the lack of industry knowledge of variations in thermal performance of ground heat exchangers over the long term and second, changes in use patterns that would vary seasonal accumulated heating and cooling loads, also over the long term. While the design software for full geothermal systems has improved significantly with experience, hybrid systems offer alternative solutions to eliminate increased loop size and costs. Hybrid systems also offer a retrofit option to full geothermal systems for preventing long-term heat buildup in existing systems. Researchers examined case studies that clearly demonstrated the initial cost savings from applying hybrid systems that used a cooling tower with a geothermal loop heat exchanger. These case studies showed that hybrid systems provided all the benefits of geothermal heating and cooling to customers and utilities.

Keywords

Geothermal Systems
Hybrid Geothermal Heat Pump Systems
Ground Source Heat Pumps
Water Loop Heat Pumps
Water Source Heat Pumps
Heating and Cooling Loads

ACKNOWLEDGMENTS

The author acknowledges prior work of many individuals and companies who have greatly contributed to the development of geothermal systems. Their reports and data on operating performance of systems have helped shape this product.

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HYBRID GEOTHERMAL HEAT PUMP SYSTEMS

Hybrid geothermal systems provide lower installed cost heating and cooling solutions while preserving many of the features of the geothermal systems for the utilities and its customers. These features include more efficient heating and cooling that reduces carbon footprint; reduced peak demand on the utility infrastructure; and more efficient asset utilization with a larger load factor. The customer benefits include a much lower and affordable installed costs, high energy efficiency, smaller equipment footprint, better zone control, and efficient transfer of heat from one zone to another such as from core areas that require year around cooling to perimeter areas that require winter heating.

The primary driver for a hybrid system is lower initial costs. In conventional, commonly used closed loop geothermal systems, the loop costs can be very high; it has been reported to exceed 50% or more of the total system's costs in some systems. This is a major barrier in faster adoption of this highly energy efficient technology.

The closed loop geothermal size and costs can be reduced in many cases by supplementing the loop with heat rejection equipment where excess heat from the loop is rejected to keep its temperature cool or by heat addition equipment where heat is to be added to keep the loop warm. The excess heat rejection is more common in commercial buildings even in cold climates. The reduction in loop costs can make hybrid geothermal systems viable and cost effective in many cases where a geothermal only system would be impractical due to high costs.

Despite lower installed costs of hybrid systems and nearly all of the practical benefits of geothermal systems, there is very limited penetration of such systems in the market. Some of the current hybrid systems in service were accidental where poor ground conditions could not support a full geothermal system. This update reviews recent state of the art and provides rationale why these are in the best interest of the utilities and its customers.

2
EVOLUTION OF GEOTHERMAL HEAT PUMP SYSTEMS

Open Water Loop Cooling and Heating

Water-cooled air conditioning units evolved almost at the same time as the air-cooled air conditioning units. The water-cooled air conditioning units gained market acceptance especially in rural and less populated areas where water was easily available from sources such as pond, river or ground water aquifers. The warm water from the condenser was either dumped into drain or returned back to the pond, river or aquifers. The practice of 'pump and dump' or 'open loop' was later prohibited in many places. The return of water back to the water source, even putting it back into aquifers, still continues in some places, although more and more local jurisdictions are creating restrictions in its use.

As heat pump systems evolved, customers were able to use the same equipment to provide heating also without any additional furnace. The heat pump provided more efficient heating as compared to simple resistance heating and made it economical to use electric heating in many places for users. The utilities also benefited from better utilization of its assets by supplying additional electricity in winter.

However, air source heat pumps had problems in supplying heat at low temperatures; its efficiencies and heating capacities declined precipitously at very low ambient air temperatures, which resulted in larger energy use and high electric peak demands at lower temperatures. In addition, resistance heat is needed during defrost cycles in air source heat pumps at low ambient temperatures, further reducing its efficiencies. These limitations made air source heat pumps less attractive in colder climates.

The water-source heat pumps, however, could still supply heat efficiently even at low ambient temperatures as long as the water temperature were not too cold. It also did not need defrost cycles as needed by air-source heat pumps at low ambient temperatures. These features made the system very energy efficient and economical to operate and a system of choice.

The first commercial building to be fully sealed and completely air conditioned in 1946 in Portland, OR, featured a water loop heat pump system for heating and cooling. (Wikipedia-1). The American Society of Mechanical Engineers (ASME) designated this Commonwealth Building, a 13-story office tower in Portland, OR, as a National Historic Mechanical Engineering Landmark in 1980 for the specific feature of heat pumps for heating and cooling. (Wikipedia-2). The warm water was supplied from wells in the Commonwealth building, and the system is still in operation. Several buildings built in 1950s and 1960s with open loop systems are still performing well. (Bloomquist, R. 1999).

However, access to warm water temperature in winter remained a challenge for widespread use of water source heat pumps.

Closed Water-loop Heat Pump Systems

The access to warm water became possible in a closed water loop heat pump system with the addition of a boiler in the water loop. In a water loop heat pump system (Figure 2-1), individual heat pumps are connected to a common water loop, and heat rejection equipment such as cooling tower or a fluid cooler as well as heat addition equipment such as boiler are also connected to the same water loop. The heat rejection and heat addition equipment moderate the loop water temperature within a certain temperature range, typically 60 to 90 degrees Fahrenheit. If the water temperature rises above the upper limit, the cooling tower or fluid cooler will turn on and bring the temperature below the upper limit. Similarly if the water temperature falls below the lower limit, a boiler will turn on and heat the water to above the lower limit. The individual heat pumps connected to the water loop provide heating or cooling of the space as needed.

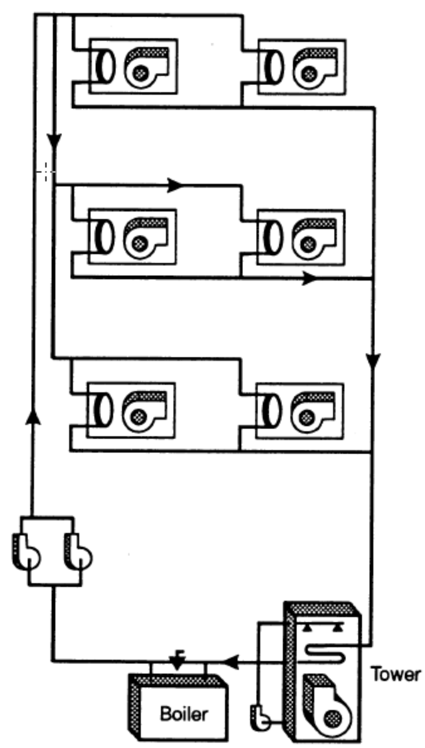

Figure 2-1
Schematic of a Water Loop Heat Pump System

With many distributed heat pumps on a common water loop, these systems also offered some other benefits such as:

- Individual zone temperature control; it provides greater occupant comfort and satisfaction
- Ability to transfer heat from one area to another within a building through the common water loop; this feature is particularly helpful in buildings where simultaneous heating and cooling is required for many hours such as core area or IT equipment room cooling and perimeter area heating
- Deferred incremental initial cost; the central water loop can be installed with taps for connection of heat pumps, but the heat pump installation can be delayed until just before occupancy
- Flexibility in design and operation; the heat pump units can be changed to different sizes if the load changes in the future
- Less space requirement; it neither needs large equipment room nor large ductwork for air distribution. The floor-to-floor airshaft size and floor-to-ceiling height can be reduced.
- Very long service life for the heat pump equipment (A 1990 EPRI study revealed that median service life of heat pumps —time between replacement or retirement of a half of the units— to be 47 years.) These systems compete well with commonly used roof top air conditioning systems.

These advantages, coupled with high energy efficiency, helped these systems to compete effectively against alternatives despite slight cost premiums. These systems gained popularity in certain areas such as Oregon/Washington in the Northwest, Minnesota in Midwest and Connecticut in Northeast.

While cooling tower and boilers could be used with large water loop heat pump systems, these were not practical with smaller air conditioning systems. Providing efficient cooling in summer was not an issue; air source or air cooled air conditioning systems performed well in summer. But the air source heat pumps could not provide efficient heating in winter. The electric utility industry directly and through its associations (National Rural Electric Cooperative Association, NRECA and Electric Power Research Institute, EPRI) along with the U.S. Department of Energy and the air conditioning industry continued to look for cost effective solutions for providing both summer cooling and winter heating.

Ground Source Heat Pump Systems

The ground temperature a few feet below the surface is relatively stable and does not vary as much as the ambient air temperature with time of day and season. This is a good source of warmth in winter but challenge to economically and efficiently tap it remains. The thermal performance of the ground depends upon moisture content in the soil as well as the seasonal heat extraction and rejection to the ground among other factors.

When heat is extracted from the warm ground in winter through a heat exchanger, it becomes colder. The amount of heat conduction depends upon the surrounding ground temperature and thermal properties. The thermal properties depend upon moisture content in soil, and moisture migrates within the ground towards cold surfaces. In winter the heat exchanger surface is cold and moisture migration towards it increases ground thermal conductance. If heat continues to be extracted, the fluid temperature in heat exchangers may fall below the water freezing point, and moisture surrounding the heat exchanger may freeze. Though the fluid temperature in the heat exchanger falls below freezing by a few degrees, it is still much warmer than the ambient air temperature and the water source heat pump still operates efficiently. The phase change of the surrounding moisture in to ice releases latent heat and provides heating to the circulating fluid and does not let its temperature fall too fast.

On the other hand, when a heat pump is working in an air conditioning mode, it will be rejecting heat to the ground. The ground immediately close to the heat exchanger will warm up as heat is dissipated to the ground through conduction. The moisture around the heat exchanger will also migrate away from a hot heat exchanger, which would reduce the heat transfer effectiveness of the soil surrounding the heat exchanger. Therefore, as the fluid temperature in a heat exchanger rises, the effectiveness of the ground coupling reduces, and the fluid temperature rises even faster. The cumulative seasonal heating and cooling loads, therefore, are also important to thermal heat transfer and sizing of the heat exchanger loop for efficient operation in geothermal systems.

Direct Coupled Geothermal Systems

Initial ground source heat pumps buried the refrigerant's copper heat exchangers directly in the ground. These systems worked efficiently, but the heat exchangers did not last very long as even a small pinhole leak in the piping would lose all refrigerant. These were suitable for smaller heat pumps but were not practical for large systems. Though these systems proved the concept of ground coupling and geo exchange, but did not find a wider market.

Ground Coupled Water Source Heat Pump Systems

The availability of high density polybutylene (HDPE) pipe in late 1970's and early 1980's made it economical to build close loop ground coupled systems. This addressed the major issue of open loop system's pump and dump approach. The working fluid simply remained in a closed loop and did not come in direct contact with ground or aquifer water; the heat from the circulating fluid in the heat exchanger simply conducted in and out to the ground or aquifer water.

The design of closed loop heat pump systems brought a new set of challenges. It was straightforward and simple to design open loop systems; a water flow rate was determined based on load and the water temperature. But design of the closed loop was anything but simple—one needed to know far more information not only about the peak loads as is needed for sizing conventional equipment and open loop system's water flow rates, but also knowledge of seasonal cumulative heating and cooling loads as well as heat conduction properties of the ground. The seasonal cooling and heating loads changed not only on seasonal variation in weather, but also on changes in building use patterns. This in itself created a certain level of uncertainty. In addition, the ground loop heat transfer characteristics needed to be known for determination of the loop size. The heat transfer characteristics would vary with many parameters such as the soil type, e.g., rocky, clay, sandy, etc.; moisture content in soil that would change with season, and whether and how much heat is being extracted from or rejected to the ground; depth of the heat exchanger in the ground, time of the year, etc. The electric utility industry and the geothermal heat pump industry has been actively engaged in research, development and technology transfer in design and sizing of closed loop heat exchangers. Several different types of heat exchangers and geo exchange designs have been developed to meet the needs of different end uses efficiently and economically.

Horizontal Ground Loop

Some of the initial applications of ground coupled heat pump systems buried the heat exchanger pipe horizontally about six feet below the ground. These were for smaller systems mostly in rural areas where sufficient ground lot was also available. An artist's rendering of a horizontally buried ground loop is shown in Figure 2-2.

Figure 2-2
Schematic of a Horizontal Ground Loop Heat Exchanger

The horizontal pipe layout was later improved with a slinky design as shown in Figure 2-3. The slinky design required less physical space and lower cost.

Figure 2-3
Slinky Ground Loop Heat Exchanger for a Small 3-ton Heat Pump System

(Source: Wikipedia; Mark Johnson photo)

Vertical Ground Loop

In vertical closed loop field, pipes that run vertically in the ground. Holes are bored in the ground to a depth of about 75 to 400 ft as shown in Figure 2-4 and Figure 2-5. A pair of pipe with a U bend connector at the bottom is inserted in each hole. The working fluid travels through one end of the pipe and returns on the other. For providing better thermal conductivity, the hole around the pipe is filled with bentonite grout. Grout seals area around the pipe and protects the ground water from contamination as well as seals artesian wells. The bores are spaced around 15-20 feet apart and the depth is determined based on ground soil characteristics. A single 300 feet vertical borehole may provide about 1-3 tons of heating capacity. There has been a lot of research done in proper sizing of ground loops and sophisticated software is now available.

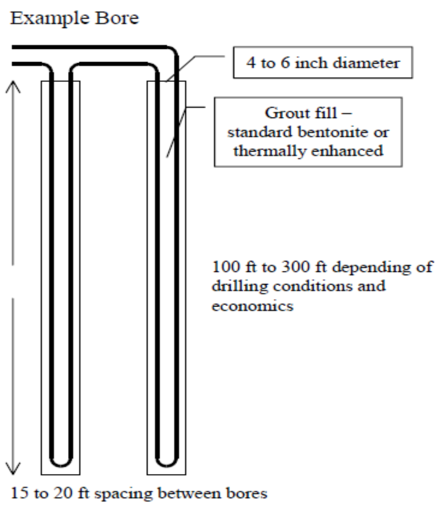

Figure 2-4
Schematic of a Vertical Bore Ground Loop Heat Exchanger

Figure 2-5
Schematic of a Vertical Bore Heat Exchanger in a Building

Pond Loop Heat Exchangers

If surface water is available from pond or water body but it is not suitable or not allowed to be used directly for heat exchangers, bundled coil of pipes can be anchored at the bottom of the pond as shown in Figure 2-6. The loosely coiled pipes allow water to move across the coil bundles due to natural temperature difference between the fluid within and water outside the tubes. Pond systems provide warmth source because the water at the bottom of the pond is at its highest density, which is at 39 F even if the top of the pond is freezing. In proper size ponds, the water at the bottom of the ponds would not freeze.

Figure 2-6
Picture of a 12-ton Pond Loop Heat Exchanger Before it is Sunk to the Bottom of the Pond

(Source: Wikipedia, Mark Johnson photo)

Standing Column Well

A standing column well is a hybrid of a closed loop and open loop well as shown in Figure 2-7. It consists of a very deep well where water is pumped from the bottom of the well to the heat pumps and the return water from the heat pumps is injected back into the top of the well. As the water moves along the depth of the well, it exchanges heat with the surrounding ground and often mixes with the ground water. If the return water temperature becomes too hot in summer or too cold in winter, a certain quantity of the water from the standing column well is not returned but bled off. This causes the underground aquifer water to be drawn and increases the thermal capacity of the standing column well.

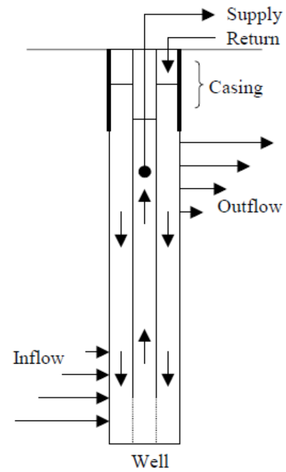

Figure 2-7
Schematic of a Standing Column Well

The bleed feature of the standing column wells offers the flexibility to deal with the heat build up unlike closed loop systems. ASHRAE research project (TRP-1119, Standing Column Well Model Validation and Design Guide) evaluated the impact of bleed on well temperatures. Their results showed that increasing the bleed rate had a considerable impact on design summer maximum and winter minimum temperatures and should be entertained in case of unexpected loads.

The closed loop geothermal systems evolved rapidly in several different configurations. A 1993 EPA report, which determined the GHP system as the most energy efficient and environmentally benign option among major residential heating and cooling options, provided further boost the industry. These systems were extended to many commercial applications. Many large geothermal systems with total capacities in several hundreds to thousands of tons were installed. However, several commercial systems ran into problems of heat buildup in the ground loop over time with loop temperatures exceeding 110°F in summer. At these temperatures, the heat pump efficiencies declined sharply and projected energy savings failed to materialize. The reliability and credibility of such systems suffered.

It is worth noting that these systems performed very well in winter eliminating winter peak demand on the utilities. But these failed to perform efficiently for cooling in summer. From customer perspectives, however, a failure is a failure. The utilities and customers need a better solution so it can retain the benefits of the closed loop heat pump systems for winter heating and do not incur penalty for summer cooling.

3
CAUSES OF HEAT BUILDUP IN COMMERCIAL GEOTHERMAL HEAT PUMP SYSTEMS

Most geothermal systems are designed well and operating trouble free and providing efficiency benefits to customers and utilities. However, heat build has been observed in some large commercial geothermal systems. The heat build up could be linked to several reasons and their compounding effects. Some of these are discussed below.

Lack of Soil Thermal Heat Transfer Characteristics Knowledge

A good knowledge of the ground thermal properties is needed for proper design of the geothermal loop. However, it is very hard to get this information. Soil samples are generally collected on large projects by drilling test bores to measure its conductivity, but these are limited for small projects due to costs. The moisture content in soil has significant impact on its thermal properties. Moisture content changes with time and samples collected at a certain time may not reflect its conductivity at other times. Moisture content could also change with the amount of heat extracted or rejected to the ground. If higher heat transfer conductivity is assumed than present, or if the moisture is driven away from the heat exchanger if the heat rejected to the ground loop is higher than estimated, the loop field will overheat. Once the loop field overheats, even more moisture migrates away from the heat exchanger, thus reducing thermal conductivity, which causes the loop temperature to rise even faster. This may not be an issue in soils where moisture presence is small such as in rocks.

Location of Ground Loop

Finding sufficient space to drill vertical bores could be difficult at many sites and boreholes fields may be covered with impermeable surfaces such as parking lots. If heat rejection into the ground is more than heat extraction, the soil around heat exchangers will dry out. With no rainwater percolating from the impermeable top surface and re-moisturizing the soil, the heat in the ground will continue to build up.

Changes in Building Use Patterns

The sizing of geothermal heat exchanger loop is unlike sizing of heating and cooling equipment. While most heating and cooling equipment is sized to meet the design hourly peak loads, the geothermal loops must be sized to dissipate heat generated by the cooling equipment over the entire season as well as heat removed from the ground over the entire heating season. This requires a good knowledge of the heating and cooling use patterns and load profile. If use patterns change over time and the actual heating and cooling loads are different than the estimates used in design of a geothermal loop heat exchanger, it can impact its performance.

Cooling and Heating Loads Mismatch

Perhaps the single most important factor is the mismatch between the actual winter heating and summer cooling loads. In an ideal design, the accumulated heat rejected in to the geothermal loop in summer should be nearly equal to the heat extracted from the loop in winter. In reality, however, a large mismatch between seasonal heating and seasonal cooling loads exists especially in commercial buildings. Or to be more accurate, large mismatch between heat extracted from and heat rejected to the ground heat exchangers exists. Heat rejected to the ground is more than the cooling loads since compressor heat is also added to it. On the other hand, the heat extracted from the ground is less than the seasonal heating loads since the compressor heat is added to the extracted heat before it is delivered to the space.

Generally if the seasonal cooling loads are more than 50-70% of the seasonal heating loads, there will be mismatch, and if the geothermal loop is not designed to account for this mismatch, heat will eventually build in the geothermal loop. On the other hand, if the cooling loads are less, and it can happen in extreme cold climates, the ground will become cooler over a time. In case of a mismatch between heating and cooling loads, the loop should be sized for the larger load. In most commercial buildings, accumulated summer cooling loads are much higher than the accumulated heating loads even in colder climates, and a much larger size of ground loop heat exchanger would be needed. As discussed earlier, once the mismatch causes the loop field temperatures to rise, it gets into spiral of temperature rise.

The ground loop cost is perhaps the single largest cost component of geothermal heat pump systems; loop costs more than 50% of the total system costs have been reported. In small systems, however, the geothermal loop cost is still relatively small in absolute terms and geothermal systems are often practical and cost effective. This explains why most of the geothermal applications are of small size.

The following geothermal case studies show measured data of mismatch between heat extraction from and heat rejection into the loop. These examples are selected to show the quantity of mismatch between seasonal summer cooling and seasonal heating loads since measured data is available. This is not a reflection of the abilities of geothermal systems; in fact there are thousands of full geothermal systems that are operating efficiently for many years. These are selected merely to show large differences between seasonal heating and cooling loads; a large difference between the two is conducive to a more cost effective hybrid system. Although many commercial systems show larger seasonal cooling than heating and benefit from cooling towers/fluid coolers, as one of the case study below would show that the hybrid systems can also benefit from boiler or heat addition devices if heating loads are higher.

The Richard Stockton College, Pomona, New Jersey

This community college system was the World's largest closed loop heat pump system when it was built in 1993 with 1740 tons of air conditioning capacity. (Taylor, et al, 1998) The ground loop heat exchanger consists of four hundred 4-inch boreholes up to 425 feet deep, with a single 1¼-inch diameter closed loop HDPE U tube in each borehole. The boreholes are 15 feet apart and cover 3.5 acres of land, and a parking lot is paved over much of the borehole field. The boreholes were back filled with bentonite clay slurry for increased thermal conductance to the ground as well as for preventing exchange of water between aquifers and with the surface water. The borehole field comprises 64 miles of heat exchange piping with a volume of 1.2 million cubic meters. The heat pump units on the entire campus are on a common water loop that is connected to the ground loop heat exchanger.

The climate of Pomona, NJ, is cold with about 5300 heating and 1100 cooling degrees days. Despite cold weather, the seasonal cooling loads are much higher than the seasonal heating loads. Figure 3-1 shows the amounts of heat rejected into and heat extracted from the ground loop over twelve months of 1996. Total heat added to the ground was 2770 MWh while heat extracted from the ground was only 785 MWh adding net 2238 MWh into the ground as heat build up. Table in Figure 3-2 summarizes heat rejected in to and heat extracted from the ground over the initial 4 years of operation. The heat rejection into the ground is 3 to 8 times more than heat extracted. For proper load balance in closed loop heat pump systems, the heat rejected and extracted should be nearly equal; if the heat rejected in the ground is more than the heat extracted and the heat exchanger is not designed to account for the same, the ground temperature would increase. The average lowest and highest heat loop temperature returning from the ground and supplied to the heat pumps saw an increase of about 2°F each year as shown in Figure 3-1. Though, this increase in temperature increases winter heating efficiency, it reduces summer cooling efficiency where the equipment operates most of the time. With predominant cooling load in this building, the loss in cooling efficiency penalizes energy use. The cooling capacities of a heat pump also reduces with higher loop water temperatures and after a few years of heat build up, the heat pump equipment may struggle to provide sufficient cooling.

The heating worked well over the years with sufficient capacity and high efficiency. In fact even during a severe cold wave, there was sufficient heating available from the heat pumps and no backup resistance heating was needed.

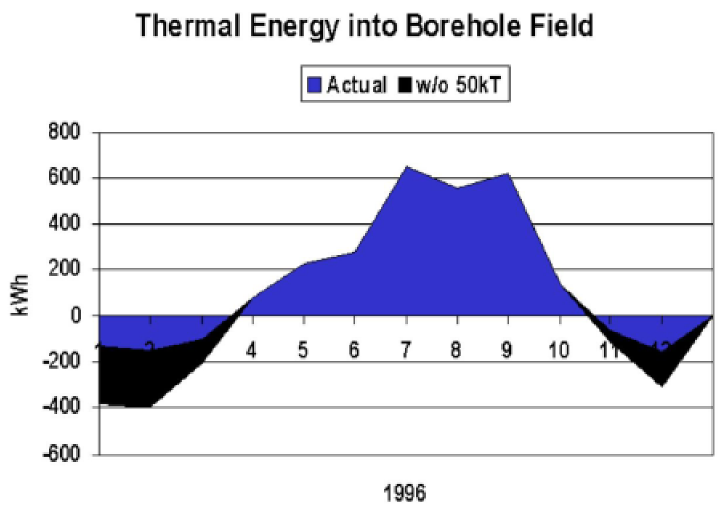

Figure 3-1
Heat Rejection and Extraction for the Geothermal at the Richard Stockton College in Pomona, NJ in 1996

Year	Net Heat Rejection: E_{NET} (MWh)	Heat Added to the Ground: E_{IN} (MWh)	Heat Extracted from the Ground: E_{OUT} (MWh)
1994	2253	2752	656
1995	3032	3306	453
1996	2238	2770	785
1997	2750	3403	1209
Total	10272	12231	3103

Figure 3-2
Summary of Annual Heat Rejection and Heat Extraction from GeoExchange Loop

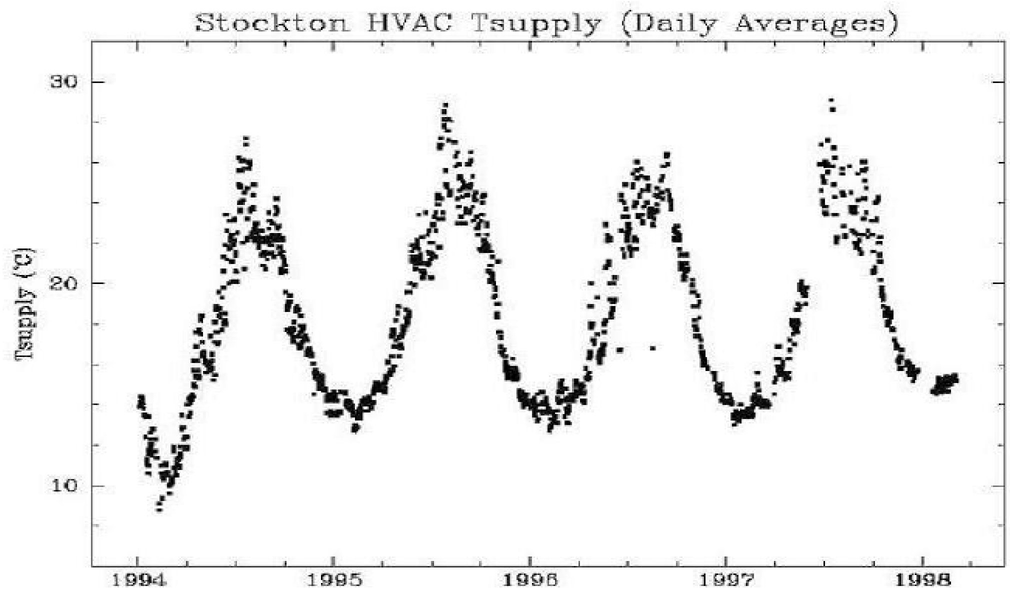

Figure 3-3
Loop Return Temperature History at Richard Stockton College, Pomona, NJ

A Quick Service Restaurant Near Detroit, MI

EPRI monitored the thermal performance of a newly installed geothermal heat pump system in McDonalds, a quick service restaurant, in Westland, MI, which is a cold climate with about 6200 heating and only 1000 cooling degree days (EPRI 1999). The geothermal loop was designed for 33 tons of cooling with 32 vertical boreholes of 196 ft deep and 14 feet apart, or about 190 feet per ton. The loop performed well as designed in the first year with loop return water temperature exceeding 90^0F for only 16 hours, which is well within the 95^0F design limit. However, during the following year, the loop return temperatures exceeded 105^0F for 57 hours, which greatly impacted the heat pump cooling efficiency and capacity. Figure 3-4 shows the amounts of heat rejected into and heat extracted from the ground loop. There is a large mismatch between the seasonal cooling and heating loads, with cooling loads far exceeding the heating loads even in this cold climate. Figure 3-5 shows daily average loop supply and return temperatures. The loop return temperature increased from 51.2^0F in April 1998 at the inauguration of the restaurant to 72.4^0F in April 2002, or an increase of 5.3^0F per year just after four years of heating and cooling. A similar trend was observed at the end of the cooling season; it increased from 80.3^0F in 1998 to 101.5^0F in 2002, an average of 5.3^0F per year.

A reevaluation of the actual seasonal heating and cooling loads revealed that the cooling loads were much higher than estimated. The actual heat rejected into the ground was 6 to 10 times larger than extracted for heating even in this cold climate. For most commercial buildings even in the cold climates, the seasonal cooling loads tend to be much larger than the seasonal heating loads. A redesign of the loop based on actual loads indicated that the ground loop should have been 63% larger, or at 310 feet versus the 190 feet per ton that was installed, to achieve a design temperature of less than 95°F over the life of the system.

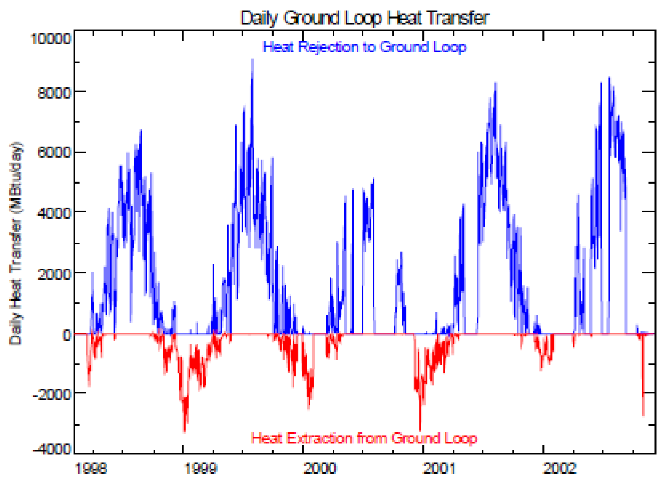

Figure 3-4
Heat Rejection into and Heat Extraction from the Closed Ground Loop at McDonalds in MI

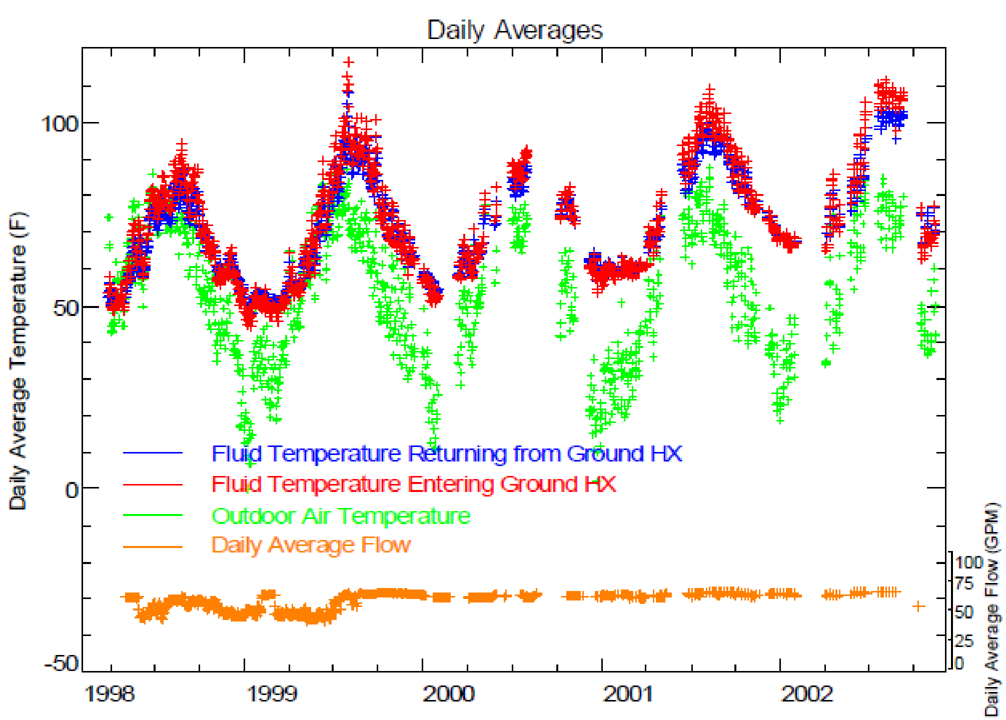

Figure 3-5
Daily Average Fluid Supply and Return Temperatures from the Geothermal Heat Exchanger at McDonalds in MI

4

HYBRID GEOTHERMAL SYSTEMS

The previous two and many more similar studies have clearly established that in most commercial buildings, the accumulated summer cooling loads are much higher than the accumulated winter heating loads. This is particularly true of commercial buildings not only in moderate climates but also for buildings in cold climates. Therefore, the ground loop size is dictated by the cooling needs, which causes the loop size to be much larger than if it was designed for meeting the heating needs. Compared to a geothermal loop designed primarily for heating needs, a geothermal loop designed for cooling needs can be 50-300%, or even more, larger for such buildings. Since, the geothermal loop costs are often the single largest component of a geothermal system costs, it is under intense scrutiny for cost control.

However, the main driver for use of geothermal system is for heating and not cooling. It provides efficient heating and avoids peak demands associated with inefficient heating. Efficient cooling is available without the use of geothermal systems. A simple use of heat rejection equipment such as cooling tower or a fluid cooler in a geothermal loop would allow heat to be rejected to the ambient effectively and efficiently, which would reduce overall system costs. The cost of a conventional cooling tower or a fluid cooler could as low as a tenth of the cost of a geothermal loop for the same heat rejection capacity. The geothermal loop costs depend on many factors and have been reported in the range of $6-16 per feet in muddy soils and $10-26 in rocks. With 100 to 300 ft per ton of loop length requirement, the typical loop costs may range from $1500-5000 per ton. On the contrary, the cost of conventional cooling towers is about $120-180 per ton and fluid coolers are $350-500 per ton.

A hybrid geothermal system uses geothermal loop along with elements of ‘conventional’ water loop systems to reduce overall system costs and make it affordable for end users, which in turn provides benefits of lower peak demands, greater load factors and carbon footprint reduction to utilities.

In some applications, the seasonal heating loads can be larger than the cooling loads where loop size may be governed by the heating loads. In such cases a hybrid solution would reduce the ground loop size by providing supplemental heating to the loop to avoid long term build up of excess cooling in the ground. Such heat can be provided from a conventional boiler, a solar water heater, or heat from any waste heat stream.

A geothermal only system is often preferred because there is no exposed equipment to weather elements, which reduces maintenance costs. The buried HDPE loop piping also has a very long life that is estimated to be 25 to 50 years. Full geothermal is obviously preferred when seasonal heating and cooling are matched, i.e., seasonal heat rejection in the ground matches with the seasonal heat extraction, or when the full geothermal loop costs are relatively small. This may be true for some envelope load dominated buildings in cold climates, such as residential or small buildings, or schools even in moderate climates that are in operation for academic year with no operation in summer months.

Hybrid systems are most cost effective where a large mismatch between seasonal cooling and seasonal heating loads exists and where geothermal loop costs are high. This is likely true with many commercial buildings even in northern climates.

Hybrid System Configurations

A hybrid system integrates a cooling tower or fluid cooler if it is cooling dominated, or a boiler or other heating device if it is heating dominated, into the water loop. An open cooling tower can be placed directly in line with the geothermal loop if the fluid in the loop is water as shown schematically in Figure 4-1, or through a heat exchanger if it is different than water as shown in Figure 4-2. A directly connected cooling tower provides more efficient cooling of the water, but it can be used in geothermal loops where loop temperatures are not expected to go below about 45^0F in winter. If the fluid temperatures in the loop are likely to fall below about 45^0F, an antifreeze solution is used in the loop and the open cooling tower will need to exchange heat with the loop through a heat exchanger as shown in Figure 4-2. With a closed loop cooling tower or fluid cooler, no intermediary heat exchanger is needed.

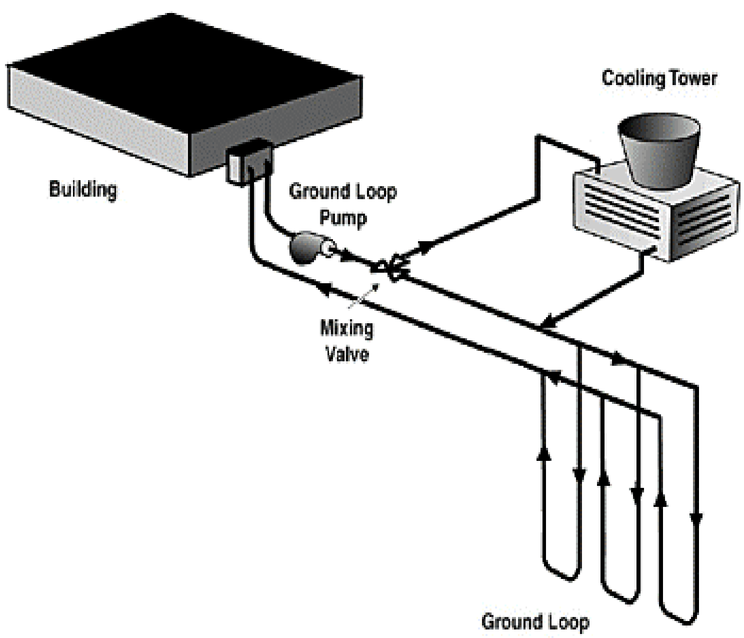

Figure 4-1
Schematic of a Hybrid Geothermal Heat Pump System

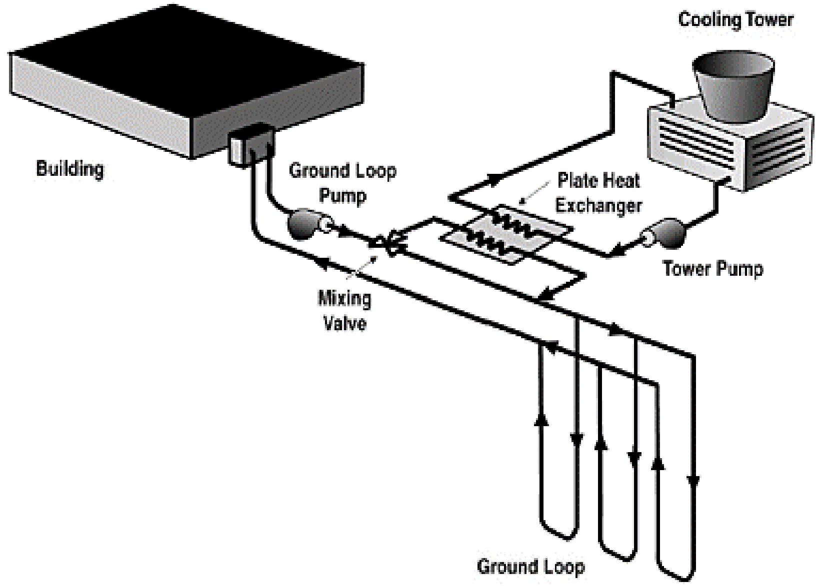

Figure 4-2
Schematic of a Hybrid Geothermal System with an Intermediary Heat Exchanger

Hybrid Systems Examples

The earlier hybrid systems were accidental and not planned. These resulted from unforeseen site geological conditions after the start of construction that would significantly increase costs and, coupled with unavailability of additional space for increased loop size, prevented full geothermal systems. However, these did provide valuable data and confirmation on the commercial viability and attractiveness of hybrid systems.

A number of hybrid systems have since been reported, and research papers have been published that deal with design, controls, operations and proposed design methodology for hybrid systems.

Paragon Center, Allentown, PA

The hybrid concept saved a geothermal project at an 80,000 sq ft office building in Pennsylvania in 1995 when site geological conditions limited the well depth to just 110 feet although the initial two test bores indicated no problems with 500 ft deep boreholes for a 200 ton system. (Singh and Foster, 1998). The design had called for 55 boreholes with depth of 500 ft. Due to newfound site conditions, the alternative full geothermal design would have required 240 boreholes of 110 feet depth at much higher costs. A hybrid geothermal was considered that only required 88 boreholes of 110 ft along with a closed circuit cooling tower. The total cost of the hybrid systems' boreholes and cooling tower was about half of the total cost of the loop field of the 'revised' full geothermal design. In fact the total cost of hybrid system's boreholes and cooling tower came in about the same as the boreholes of the original design of the full geothermal system and it saved the project.

A conventional closed loop cooling tower was added to assist in heat rejection in summer. The cooling tower was put in operation in summer only whenever the loop temperature exceeded 75°F and used only 3% of the total annual HVAC energy. The loop temperatures did not exceed 90°F providing efficient cooling, and did not fall below 42°F and provided sufficient and efficient heating without requiring resistance backup heating.

Fond du Lac High School, Fond du Lac, Wisconsin

Fond du Lac built a new 390,000 sq ft high school in 2001 and used a closed loop geothermal system for air conditioning. The geothermal loop consists of bundles of tubes immersed at the bottom of two large ponds that were built as storm water retention ponds. The climate at Fond du Lac is cold with about 7200 heating and 900 cooling degree days. The gym and theatre are also on the common water loop and being heated and cooled with heat pumps. Since these facilities require large heating capacities and the loads are heating dominated, a hybrid system with a boiler, instead of a cooling tower, is used here. The school officials expected the system to pay back in 8-9 years. (Winter, 2000)

Springhill Suites Hotel, Pensacola, FL

Barfield reported a 2008 ASHRAE Technology Award winning hybrid geothermal heat pump system for Springhill Suites Hotel in Pensacola, Fl. (Barfield 2008) The 80,145 sq. ft. hotel guest rooms and offices are cooled with 300 tons of heat pumps. In addition, domestic water heating heat pumps, pool heating heat pumps and ice machines are also connected to the common water loop. The climate is warm with about 1500 annual heating and 3000 cooling degree days. The air conditioning loads are obviously high. The water-cooled ice machines are also connected to the water loop and rejecting heat in to it year around. However, water source domestic water heat pumps and swimming pool heat pumps are continually removing heat from the common water loop. The creative use of water source heat pumps for domestic water and swimming pool heating provides very efficient heating as well as extracts heat from the loop. Though the ice machines add heat to the loop, it not only operates more efficiently but also does not add heat to the air within the hotel. The ground loop has 98 boreholes, maximum possible on this property, providing about 100 tons capacity. It is supplemented with a 150 tons closed loop evaporative cooling tower. The system can meet all heating requirement for the space as well as domestic and swimming pool water heating very efficiently without requiring backup resistance heat and meet the cooling requirements in summer with the help of cooling tower.

Hebrew SeniorLife, New Bridge on the Charles, MA

Ramkumar (2008) presented a case study of hybrid geothermal system for nearly 1 million sq ft senior living community center in MA at the IGHSPA meeting in 2008. The climate is cold with about 5600 heating and 900 cooling degree days, but the seasonal cooling load is higher as in many commercial facilities. The consulting engineers, Alderson Engineering Inc., evaluated a full geothermal and a hybrid system with a cooling tower. The results are presented in Figure 4-3. The hybrid system's loop field and cooling tower costs are only about a half of the costs of a full geothermal system loop field, and the annual maintenance and operating energy costs of the cooling tower are estimated at less than 2.5% of the loop field cost savings. The hybrid system is obviously the most cost effective choice.

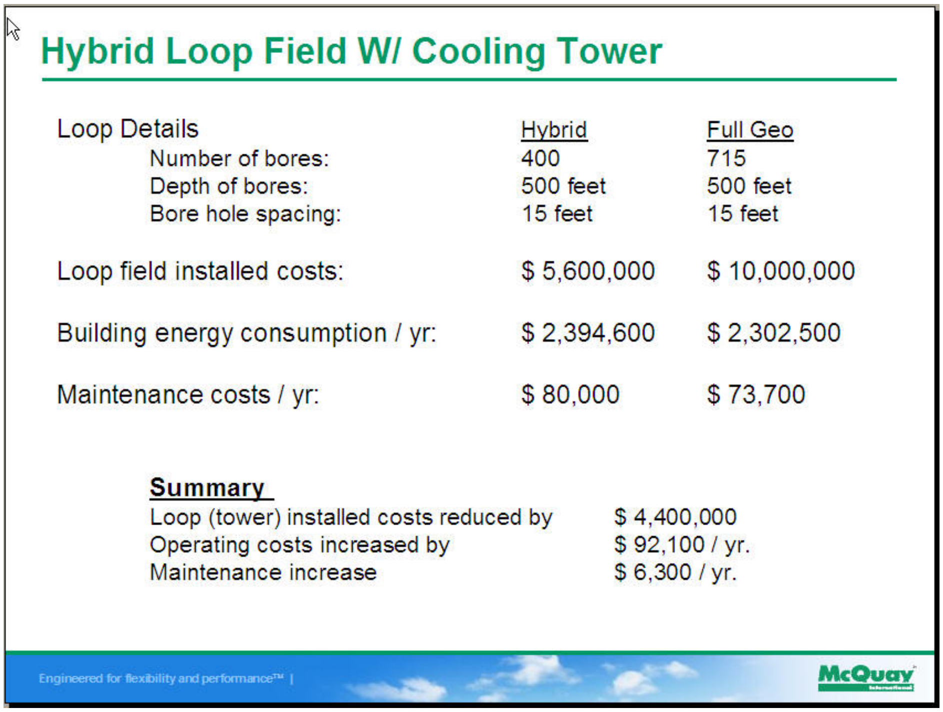

Figure 4-3
Comparison of Hybrid and Full Geothermal System at Hebrew SeniorLife in MA

Hybrid Systems Developments

Hybrid systems are attracting attention from researchers, designers and users for its obvious benefits. ASHARE recently sponsored research project (ASHRAE TRP-1384) on 'Development of Design Guidelines for Hybrid Ground-Coupled Heat Pump Systems'. The study was led by Scott Hackel at University of Wisconsin and is largely academic using computer model simulations. It concludes that in most moderate and southern climates, hybrid geothermal systems have a lower life cycle costs than full geothermal system.

The existing full geothermal systems can be easily converted to hybrid by addition of a cooling tower or fluid cooler if long term loop temperatures are rising, or with an addition of boiler, solar or other supplementary heat equipment, if long term temperature are dropping or if sufficient heating is unavailable. Hybrid systems are also more tolerant and can accommodate some changes in load patterns and some uncertainty of geothermal heat exchange design.

There are still many challenges such as how to correctly and optimally size the supplementary cooling or heating equipment, where these should be placed in the geothermal loop (e.g., before or after the heat exchanger loop in the water flow), how should it be operated and controlled (e.g., should these devices be in operation all the time or bypassed during certain times based on some criteria such as the loop temperature) or how to take advantage of cool nights to reject heat to the ground.

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CONCLUSIONS

The hybrid system is often the most cost effective and energy efficient choice for the customers. It provides nearly all of the benefits of full geothermal systems to utilities but at a much lower initial cost, which also makes it affordable for the end users. These are particularly attractive where a large mismatch between seasonal heating and cooling loads exist as in many commercial buildings. In cooling dominated applications, the winter heating is provided efficiently with heat recovered from the ground and cooling is provided efficiently with lower temperature water in summer through conventional heat rejection equipment. The customers benefits from higher efficiency heating and cooling. But the utilities benefit the most from reduced peak demands and higher load factors in winter as well as lower peak demands in summer.

The utility industry has made a significant commitment to geothermal systems and supported research, development, demonstration and technology transfer. The utilities have promoted full geothermal systems with incentives and rebates.

The utilities may also want to actively support further technology development, demonstration, and technology transfer of hybrid systems. It is in the best interest of the utilities to support these systems since these are as efficient as full geothermal systems but cost less to customers, and provide reduced peak demands and higher load factors to utilities.

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