Highlights of the California GeoExchange Project

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ABSTRACT

A two year project sponsored by the Pacific Gas & Electric Company, the California Energy Commission, and the National Geothermal Heat Pump Consortium was initiated in 1997 to increase public awareness, identify California-specific cost-effective technologies, and reduce market barriers for ground-coupled heat pumps. Major activities included demonstration projects, research and development of system and loop designs, and market evaluations. Four commercial projects, and seven single and multifamily residential projects consisting of 326 units, were initiated. Five of these sites were monitored for up to 16 months. Monitoring data were used to calibrate DOE-2 models, which were in turn used to develop performance data for technical evaluations and market studies. Technical evaluations were completed on sizing methods, flow optimization, loop design options, water heating options, hybrid systems, and loop irrigation. Vertical helix loop designs were developed, installed and tested. The project developed 600 pages of reports, including a business plan for GeoExchange in California, and a GeoExchange Handbook. Project recommendations were to distribute key project findings, continue R&D on near term technologies, continue support for R&D to reduce loop costs, and to expand DOE-2 modeling capabilities to accommodate a larger number of system design options.

Introduction

GeoExchange or ground-coupled heat pumps (GHP) space conditioning systems utilize the relatively stable heat transfer environment of the ground to provide highly efficient operation, cutting energy consumption for heating, cooling and water heating uses by 30% or more and significantly reducing peak demand. In addition, GeoExchange eliminates outdoor condensing units and their attendant noise, and it reduces maintenance costs. Despite this, the California GeoExchange market penetration is significantly less than in other regions of the country. GeoExchange faces a number of market barriers in California, including lack of consumer awareness, undeveloped infrastructure, and long payback periods. As experience with GeoExchange grows in the state and the number of GeoExchange designers and installers increases, awareness will increase and first costs will decline.

The Geothermal Heat Pump (GHP) Model Utility Program Demonstration Project was initiated in 1997 to evaluate the technology and potential for market growth of GeoExchange systems. The two-year project was the major component of a statewide commercialization effort by the California Geothermal Heat Pump Collaborative, and was supported by Pacific Gas & Electric, the California Energy Commission, and the National Geothermal Heat Pump Consortium. Overall project goals were to (1) significantly increase public awareness of GHP through demonstration and education initiatives; (2) identify and optimize, cost-effective GHP technologies which respond to California conditions; and (3) reduce market barriers constraining commercialization.

This paper summarizes the work completed for the California GeoExchange Project. Due to the many tasks in this project, each key area is presented in an overview format to make it easier for the reader.

Project Implementation

One of the tasks of the program was to demonstrate GeoExchange technology in the residential and commercial building sectors in the service territory of a major northern California utility. The goal was to prime the market in the service territory by increasing ground-coupled heat pump installations by 100,000 square feet in the commercial sector, and 150 units in the residential sector. The initial goal was to solicit production builders along with institutional and commercial sites, but a lack of interest from volume builders led to targeting custom home builders and multifamily housing. To encourage participation, incentive money was used to offset the higher first costs for the demonstration sites.

The posture adopted early in the project was to support project design professionals and decision-makers with feasibility studies, sizing analysis, the latest design information, and general technical assistance. This approach was founded in the belief that owners would gain confidence in the technology, and design professionals would more quickly adopt GHP design practices if supported in their design efforts rather than force-fed designs as part of an incentive arrangement.

Potential candidates were screened to insure the projects had economic potential and were good GHP prospects. Design drawings were obtained and reviewed for each site. Once promising candidates were identified, feasibility analyses were performed. Computer simulations, using Version 2 of the DOE-2 hourly building simulation program, were completed for all commercial and most residential sites to generate annual performance projections. Cost estimating and DOE-2 analysis were used to identify cost savings relative to competing conventional systems. Analysis results and project information were combined into preliminary feasibility reports that were presented to demonstration site candidates.

Table 1 lists the final outcome of demonstration project recruitment efforts. Including non-residential components of multifamily buildings, the commercial goal of 100,000 ft^2 was met. The residential goal of 150 units was exceeded by more than double, though primarily with multifamily units rather than single family production homes. A third success of the demonstration project was the identification of sectors most receptive to GHP marketing efforts.

Table 1. Summary of Demonstration Sites

	Number of Sites	Total Sq. Ft.	Total Units	Total Tons
Single Family	22	47,988	22	61
Multifamily	2	267,508	304	512
Commercial	2	94,128	n/a	198
Total	26	409,624	326	771

Upon completion of construction, feasibility studies for each demonstration site were completed. Neither of the multifamily sites and only one of the commercial sites were completed at the end of the program. Economic analysis based upon the calibrated DOE-2 models and contractor's reported costs indicate that GHP for the non-residential site is clearly economically favorable, while the residential sites rely upon the program incentives for economic feasibility.

Technical Support

The overall strategy of this technical support effort was to:

1. Assemble necessary tools for analyzing GHP system options.
2. Apply those tools to evaluate the technology options available.
3. Use performance and cost data to evaluate and improve GHP prospects in the region.

The most significant analytical tool was the recently developed DOE-2 GHP hourly simulation used in previous studies by project researchers. In this project, Version 2 of the DOE-2 model was calibrated with California GHP monitoring data to evaluate GHP technology options. Technical support work included evaluation of GHP markets, monitoring of existing GHP installations, calibration of the DOE-2 GHP model using monitoring data, and analysis of technology options and "hybrid" GHP systems for improving GHP cost-effectiveness.

Monitoring of Existing GHP Installations

Nine residential and two commercial GHP sites were selected for detailed performance monitoring, including five of the demonstration sites (one commercial and four residential). The goal of monitoring was to observe operation, verify that the performance of the heat pump systems was consistent with assumptions used in the computer models, and to evaluate cost effectiveness. Monitoring data were later used to calibrate the DOE-2 model and assess alternative ground loops.

Results from the monitoring data showed that the average monitored seasonal GHP heating COP was approximately equivalent to the ARI-330 rating, while the average monitored seasonal cooling EER was 23% less than the corresponding ARI-330 rating. Two factors account for these results. First, cycling degradation reduces system performance, not accounted for in the ARI ratings. Second, the average seasonal loop temperatures were higher than the ARI-330 rated points for both heating and cooling, resulting in better heating performance and poorer cooling performance than rated conditions.

Calibration of the DOE-2 GHP Model

Data collected from existing monitored projects were used to calibrate the DOE-2 computerized ground loop performance model. Monitored data collected from previous monitoring work in northern California valley and mountain regions (Rainer et al, 1998) were used. The heat pump and ground loop models from DOE-2 were coupled to form a "proxy" program that was validated against DOE-2 and used to test its accuracy. A test apparatus was constructed to allow *in situ* testing of soil conductivity and deep ground temperature to improve confidence in ground loop calibration work. DOE-2 performance curves were generated based on monitored heat pump performance, and revised part load curves, developed by research sponsored by the Florida Solar Energy Center (CDH Energy Corp., 1998), were used to better approximate equipment cycling degradation.

Calibration of the ground loop model resulted in coefficients of variance between measured and simulated return water temperatures ranging from 3.4% to 9.2%. The proxy model with calibrated heat pump curves predicted annual energy use within 5% to 7% of monitored values. The DOE-2 GHP model was found to be a reliable predictor of building energy use and its accuracy at predicting ground loop temperatures was found to be extremely valuable for verifying design information. Manufacturer's heat pump performance curves were generally consistent with field test data. On the sites evaluated, manufacturer's curves did not introduce more than a 10-20% error when predicting energy use using DOE-2.

GHP Sizing Guidelines

Several computer ground loop sizing tools and recommended manual sizing methods are commercially available, but none have been verified with California conditions. Current loop sizing recommendations may not be optimal for California, where GHP installation costs are higher compared to more mature GHP markets, and where mild climates may justify designing for higher loop temperatures. The goals of this task were to verify common GHP sizing methods and to determine optimal loop sizing parameters. Loop sizings were completed using the calibrated DOE-2 model for four building types (one residential and three commercial), three soil types, and eight California climate zones. Results were compared to corresponding results from available residential and commercial GHP sizing programs.

Full-year DOE-2 runs were also used to determine a cost-optimized relationship between heat pump capacity and ground loop size, and to determine the optimal entering water temperatures to be used for sizing systems. Net present values were calculated for each analysis case.

Sizing optimization runs showed without exception, that entering ground loop water temperatures of 105ºF (cooling) and 45ºF (heating) should be used for sizing unless otherwise dictated by heat pump specifications. A 32ºF minimum may be used if antifreeze is employed. When sizing ground loops, care should be taken to select accurate soil properties and weather data, both of which have significant impact on loop sizing and performance. Horizontal loops in cooling-dominated climates should be sized assuming dry soil conditions unless site-specific conditions dictate otherwise. Test bores and *in situ* conductivity testing are recommended for larger systems to verify site soil conditions. Hourly simulations are recommended to verify sizing in multifamily and commercial projects.

The residential sizing tool evaluated generally oversized ground loops, but given the uncertainty of specific soil conditions for most residential applications, the program provides an adequate safety factor. The commercial ground loop sizing tool evaluated was found to be accurate, but thermal conductivity analysis of the soils and careful building load analysis using appropriate sizing software are essential in optimizing loop length.

Ground-Coupled Heat Pump Flow Optimization Study

The major goal of the flow optimization study was to develop guidelines for optimizing water flow in GHP systems, encompassing "reverse-return" header design, optimal header pipe designs for parallel loops, and optimal flow rate. Methods used to develop the guidelines included analyzing heat transfer to assess ground heat transfer dependence on flow rate, estimating installed costs for all header components, computing varying pump energy use, and completing economic evaluations by combining performance and installed cost parameters. Most GHP installations are designed with loop flows of approximately 3 gpm per ton of block load and "reverse-return" headers to balance flow rates among multiple flow circuits connected in parallel.

Results showed that reverse-return header design provides little performance benefit, while increasing installation costs by $25 to $33 per bore hole. Lower costs and improved economics are possible through optimal header design. Economics favor more, shorter headers in parallel over fewer, longer headers, and simple headers on the bore hole line should be used rather than shared headers with bore holes on both sides of the header.

An optimal loop flow rate could not be identified in the analyses, but results suggest there is little economic sensitivity to flow rate over the typical flow range. Valuable future activities include preparation of a design manual, optimization of large vertical GHP fields, determining flow rate effects on ground loop performance, and development of design optimization computer software for GHP systems.

Water Heating Options

Ground-coupled heat pump water heating offers the potential for improving GHP cost-effectiveness in California by efficiently heating, or pre-heating, residential domestic hot water. Three technology options were evaluated in this study: desuperheaters, dedicated or stand-alone geothermal water heaters, and three-function integrated GHP systems that combine both desuperheating and dedicated water heating.

Results indicated that if natural gas is available, GHP water heating options will not generally be cost-effective under residential rates in the northern California utility's service territory. In areas where natural gas is unavailable, economics improve significantly. Since non-natural gas areas are key market sectors for GHP in California, the additional water heating benefits should prove valuable in promoting GHP technology. GHP water heating was shown to be cost effective with natural gas in multifamily applications where water heating can be centralized and the loop shared with the space conditioning heat pumps. In cooling-dominated climates the loop size can often be reduced due to better seasonal balancing of the ground, significantly reducing installed costs.

Hybrid Cooling Tower Systems

Ground-coupled heat pumps applied to commercial and institutional buildings typically reject more heat to the ground than they absorb seasonally, creating an annual heat imbalance. This imbalance can gradually increase soil temperatures, resulting in decreasing heat pump performance and, in extreme cases, system failure. Cooling towers can be used to supplement ground loops to maintain temperatures within preferred operating ranges. The goal of this project task was to determine optimal cooling tower piping configuration, water temperatures, sizing, flow rates, and operating periods, for a typical commercial building hybrid system. This analysis required development of two computer simulation tools. The DOE-2 program was modified to incorporate a simulation routine for parallel-piped hybrid systems, and a DOE-2 “proxy” model was developed to simulate series-piped cooling towers, ground loops, and heat pumps.

For the cases studied, using a cooling tower to supplement cooling load reduced GHP heat rejection system costs as much as 48% (including the cost of the tower), due to ground loop reduction. This study concluded that commercial ground loops for hybrid systems should be sized for the heating load. The use of relatively small cooling towers operated at an 80°F threshold temperature result in the lowest initial costs. Using a larger tower operating at the same threshold temperature yields the lowest net present value by keeping the loop cooler on average, decreasing operating hours and increasing heat pump efficiency. Further research is needed to verify design methods and computer models using monitored performance data, and to develop guidelines for designers.

Ground Loop Irrigation

A literature review, field test, and computer analyses were completed to determine the potential for using loop irrigation to reduce horizontal ground loop costs. Field tests were conducted using a horizontal ground loop consisting of two 500’ long trenches with six buried pipes in each. One trench was lined with plastic to contain moisture and the other was unlined. Both trenches were equipped with drip irrigation lines and moisture and temperature sensors. A DOE-2 computer model was used to size horizontal ground loops for three typical soil types, and to compute heat pump energy use for irrigated and non-irrigated loops. Actual costs for installing the irrigation system, estimated ground loop installation costs, increased energy costs, and water utility costs were used to estimate the economic feasibility of loop irrigation for three soil types.

Monitored soil moisture levels were 5% prior to irrigation and ranged from 14-37% after irrigation was initiated. Soil thermal conductivity estimated after irrigation was commenced increased to approximately 1.0 Btu/hr-ºF-ft, or more than double the dry value. The DOE-2 model showed loop size for the three soil types could be reduced by 26 to 54% resulting in net present cost savings of $146 for light-damp soils to $3706 for light-dry soils. Results showed that in low conductivity soils (0.50 Btu/hr-°F-ft or less), it is less expensive to install loop irrigation than to install a loop sized for the dry soil conditions.

New California Ground Loop Concepts

Funding was provided through the project to assist in the development of lower cost ground loop technologies. Two proposals from outside entities were accepted to develop shallow vertical helix loop designs. Both projects successfully demonstrated new, lower-cost vertical loop designs that can potentially reduce installed loop costs by 50% or more, compared to conventional deep bore vertical ground loops. Both concepts were shown to perform well in shallow bores 20’ to 35’ deep. Also, both have manufacturer involvement that could facilitate advancement from the “proof of-concept” stage to volume production systems. The most promising of the two utilizes pre-fabricated ½” vertical spiral helix coils that can be dropped directly into a 36” diameter 20’ deep hole. A diagram of the helix coil in place is shown in Figure 1. Thermal testing of this configuration showed bore hole thermal performance equivalent to 87 feet of deep vertical bore with ¾” tubing.

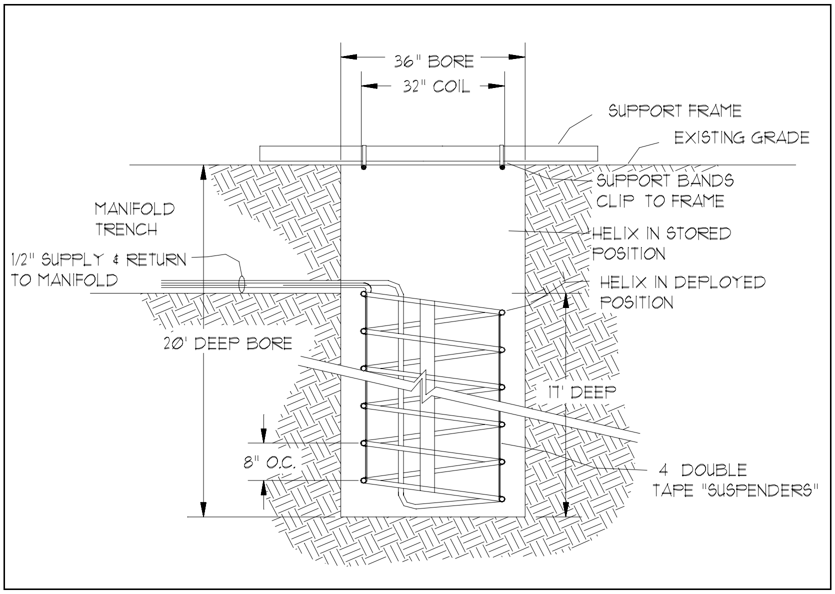

Figure 1: Helix Loop Design

GHP Field Options

The major challenge for the GeoExchange industry in California is cost-reduction. This challenge reflects the widespread availability of low-cost natural gas, combined with modest space conditioning loads due to mild climates and relatively energy-efficient Title-24 buildings. The project set out to identify and evaluate alternate, cost-effective GHP technologies that respond to California conditions, comparing both conventional and conceptual horizontal and vertical ground exchanger techniques, and ranking the most promising alternatives.

The conventional vertical and horizontal base case systems used for the study were vertical U-tube bores and 6-pipe horizontal loops, respectively. Seven deep vertical options, five shallow vertical options, and ten horizontal options were evaluated. For each alternative, costs were estimated for excavation, exchanger placement, backfilling, and manifolding. Results were developed on a cost per ton basis. To compare all conceptual alternatives equally, “mature market” costing was used, assuming that each technology was well established in the marketplace.

The best “near-term combination” option was found to be directional drilling with high-conductivity grout and improved manifold layout, offering 37% installed cost savings. The shallow helical coil offers more than 50% near-term cost reduction over deep vertical options. For horizontal options, slinky loops are currently only slightly more cost-effective than the 6-pipe base case, but additional near-term cost reductions are possible with trench irrigation and pre-fabricated serpentine arrays.

Home run manifold design offers significant near-term savings for all loop options by eliminating field fusion joints while providing connection access and loop isolation valves for faster purging. Further RD&D funding and continued support of the most promising near-term measures could result in over 50% installed loop cost reductions.

Evaluation of GHP Markets

Cost information gathered from demonstration site results and contractor pricing was used with performance monitoring data to evaluate GeoExchange economics by sub-market and climate zone in California. The goal was to complete a detailed evaluation of California residential and non-residential market potential for the GHP technology in the utility service territory. Extensive research, parametric thermal performance modeling, and economic analyses were completed to assess market viability under a range of conditions in eight targeted central and northern California climate zones. The DOE-2 hourly energy simulation program was the primary modeling tool used. Residential models assumed building and occupancy characteristics consistent with the California Title-24 energy standards. Non-residential models were typical for the markets analyzed and included multi-family, office, retail, motel and school buildings.

Both residential and non-residential analyses included low, medium and high load cases. Residential analyses compared three GHP ground loop options (vertical, horizontal, and vertical helix) and installed cost scenarios to four commonly applied conventional fuel and system combinations for all three load ranges and eight climate zones. Non-residential analyses compared two ground loop options (vertical and vertical helix) and installed cost scenarios to commonly applied competing fuel and system combinations varying with application, for all three load ranges and eight climate zones.

Results show substantial current GHP market potential using the shallow “vertical helix” ground exchanger. Best markets include areas where natural gas is unavailable, including custom homes, multi-family housing, office buildings, and schools. Markets are available but somewhat more limited for horizontal and deep vertical ground exchanger types, with GHP not being cost effective if natural gas is available under typical residential rates in northern California. Market size might grow dramatically in all sectors with installed cost reductions. Such reductions appear attainable with adequate market research and development support.

Conclusions

Taken as a whole, the results of these project activities should have a substantial and favorable impact on the future of GHP technology in California. The work completed under the California GeoExchange Project led to a better understanding of where GeoExchange technology fits into the California market and its future potential. It can be concluded that GeoExchange is best applied to specific market niches in California, with the best applications being areas where heating and cooling loads are high and where natural gas is unavailable, such as the foothills and the mountain regions. It also appears well suited for all-electric custom homes, schools, multi-family and low-income housing and office buildings throughout the region. For all these markets, paybacks are most favorable when natural gas is unavailable.

The work done for the project implementation section of the project has contributed significantly toward the achievement of the national GeoExchange industry goal of 2,000,000 units by 2005. Prior to the commencement of the program, approximately 1,000 GeoExchange units were installed in California. As part of the program, more than 400 additional units were installed. A number of these installations are high profile projects using innovative designs, such as the water-to-water heat exchanger system utilizing an open loop on an existing de-watering trench and the vertical helix loop system at one building of a student housing complex. As a result of these projects and the increased level of awareness and experience they are generating among contractors, designers and developers, the market for GeoExchange in California has gained significant momentum. GeoExchange systems are now more readily available in Northern and Central California, and the market for them has grown. As an example, one HVAC contractor reported that the GeoExchange portion of their business had grown from 3% to 30% of total business in the last three years.

The availability of an hourly ground loop simulation model calibrated with data from existing California projects allows fair and accurate performance comparisons between GHP and traditional heating/cooling systems. A wide range of promising ground exchanger concepts were evaluated using the calibrated model, with other available and customized analytical tools. The model was also used to develop improved sizing guidelines aimed at reducing installed costs.

The following design guidelines were developed to assist designers and installers design optimized GHP systems for California conditions:

- Use design loop temperatures of 105°F and 45°F for cooling and heating respectively, unless cooler climates dictate using antifreeze in the loop. Improvements in heat pump performance by designing at lower cooling temperatures do not provide enough benefit to offset the increase in loop costs.
- Accurate loop modeling relies on knowledge of “bore” conductivity and soil properties, which are inputs to the loop model. Variations in soil characteristics, moisture, and depth and movement of aquifers favor field tests in installed ground loops or in-situ tests, especially for large projects.
- Reverse return piping of the ground loop is not cost-effective. Shorter headers, using smaller diameter pipe is more cost-effective than longer headers using larger diameter pipe.
- Using cooling towers to supplement ground loops can significantly reduce installed system costs in commercial and institutional applications where cooling-dominated loads create a heat imbalance in the ground exchanger.
- Loop irrigation in areas where dry summer soil conditions exist can significantly reduce installed loop costs.

Significant work was completed in developing the vertical helix loop concept, which promises to provide significant loop cost reductions. Because of high first costs, mild climates, and inexpensive natural gas, cost reductions are critical in expanding the future GHP market. Based upon project results, helix loops, along with home-run manifold designs, show the most promise in achieving the necessary cost reductions.

Recommendations

Non-Technical Programs

GeoExchange systems are particularly applicable to a number of well-defined markets in California, but are not in wide use in those markets. These include custom homes, multi-family housing, schools and possibly offices. Portions of California with high heating and cooling loads, as well as areas without natural gas service and areas with high water tables, are especially suited for GeoExchange. Yet this is not widely recognized. Market research, development, demonstration and outreach programs are needed to encourage growth of the use of GeoExchange in these niche markets.

A program for schools is a high priority. California has recently passed a number of multi-billion dollar bond measures to fund the construction and renovation of schools. GeoExchange systems offer individual classroom controls, low maintenance costs and the elimination of outdoor units subject to vandalism – all important features for schools. To foster the use of GeoExchange technology in California schools, it is recommended that a market transformation program be implemented. Suggested program elements include market research designed to identify the best approach to this unique market; customized promotional materials; outreach through mailings, presentations and meetings; installation incentives; design assistance and the monitoring and publication of results.

Another program recommendation is for the renewal of a California GeoExchange industry collaborative. The California Energy Commission previously ran the collaborative, helping to bring GeoExchange technology to the state. As of this writing, the Geothermal Heat Pump Consortium had funded the initiation of such an organization for a limited term.

To broaden the availability of GeoExchange technology in California, a designer outreach and training program is recommended. This program would target the architects and engineers that specify heating and cooling systems. Meeting presentations, all day seminars, and on-site training would be offered to enable building designers to offer GeoExchange as an option and to respond when clients request that they include GeoExchange in a building design.

To overcome first cost barriers, a loop leasing program is recommended. Existing loop leasing programs, such as that offered by a rural northern California electric cooperative, expand utilities' service offerings and their dealings with customers. Loop leasing programs also enable the cost of a geothermal loop installation to be amortized over its useful life, making GeoExchange systems affordable to a larger market.

Technical R&D Programs

The research results gained in this project verify substantial opportunities for GHP market growth in California. Significant recommendations for continuing technical work include:

- Side-by-side performance monitoring of both deep bore and helix loops, and the central GHP water heating systems, at a student housing project.
- Implementation of at least one demonstration project using deep "directional drilling" vertical bores with a high conductivity thermal grout and home run manifolds.
- Preparation and dissemination of a "California GHP Design Manual" that conveys key design guidelines derived from research in this program.
- Development of a "motorized manual" backfill device to further increase the cost advantage of shallow vertical GHP field options.
- Implementation of "field test" demonstration programs for shallow vertical field options, pre-fabricated horizontal arrays with loop irrigation, and home run manifolds.
- Solicitation of R & D proposals to develop the "gravity hydraulic drilling" and "slot excavation" concepts described in the field options report (Davis Energy Group, 1999b).

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