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# GEO-HEAT CENTER Quarterly Bulletin

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## Geo-Heat Center's

## 30th Anniversary

**Vol. 26, No. 1** **March 2005**

# GEO-HEAT CENTER QUARTERLY BULLETIN

**ISSN 0276-1084**

## A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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**Cover:** Oregon Institute of Technology's geothermally-heated fountain (photo courtsey of Mary Smohters)

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# GEO-HEAT CENTER'S 30$^{TH}$ ANNIVERSARY

***The current Geo-Heat Center Staff, from left to right:***
***John Lund, Donna Gibson, Gene Culver, Toni Boyd and Andrew Chiasson.***

The Geo-Heat Center can trace its beginning to an international conference held on the Oregon Institute of Technology campus during October of 1974. This conference on the "Multipurpose Use of Geothermal Energy" which included papers on the uses for industrial, agricultural and commercial-residential of geothermal energy, generated an interest in exchanging and disseminating information on the direct-uses of this renewable and domestic energy source. In addition, since the campus was heated with 192ºF (89ºC) geothermal water, it was a natural location for a geothermal research and technical assistance center. The Geo-Heat Utilization Center was established in 1975 and later changed to the present Geo-Heat Center. The primary focus of the Center was, and still is, to disseminate information and provide technical assistance to potential and existing users of geothermal resources, to publish technical papers and a quarterly newsletter on the progress and development of direct-use geothermal energy in the U.S. and other countries, and to undertake applied research. Initially, this was accomplished through the mail and by phone, but now most is done via the Internet and Emails. Our emphasis was originally on low-to-moderate direct-uses of geothermal energy, but has been expanded over the years, based on customer requests, to include low-temperature power generation and geothermal (ground-source) heat pumps.

The original founders of the Geo-Heat Center, Paul Lienau, Gene Culver and John Lund with assistance from Lars Svanevik, were all faculty members at OIT, and have since retired. However, some of us have difficulty completely retiring. Paul, is living on Camano Island north of Seattle, but is actively involved in the local water district; Gene is again working for the Center on a part-time basis; John is the Director of the Center on a part-time basis, and Lars is still teaching chemistry on a part-time basis. We have also had 23 other researchers along with eight international visitors work for the Center over the years. Kevin Rafferty, Charles Higbee and Gene Ryan are best known for their extended contributions to the Center, and Toni Boyd and Andrew Chiasson rounding out our present staff. Other former employees, such as Gordon Bloomquist, David McClain and Mark Dellinger are still active in the geothermal field.

As an indication of our successful activities over the past 30 years, we have published 94 issues of the *Quarterly Bulletin*, which includes approximately 450 articles. Issues from Vol. 16, No. 4 (October 1995) to present are available on our website: http://geoheat.oit.edu. In addition, we respond to approximately 1,000 technical assistance requests annually, and our website has 9,000 hits, 1,350 users and 2,000 PDF files downloaded per day. We have come a long way since our modest start in 1975.

**- The Editor**

# GREENHOUSE HEATING WITH GEOTHERMAL HEAT PUMP SYSTEMS

**Andrew Chiasson, P.E.**
**Geo-Heat Center**

## ABSTRACT

The objective of this study is to examine the feasibility of greenhouse heating with geothermal heat pump (GHP) systems. Both closed- and open-loop systems are examined at four locations across the U.S. and a net present value analysis is conducted for a 20-year life-cycle for various GHP base-load fractions.

Results show that it would only be under situations of relatively low ground-loop installation costs and/or relatively high natural gas costs that some portion of a greenhouse could be economically heated with a closed-loop GHP system. At natural gas costs of about \$0.60/therm (\$0.21/m$^3$), no fraction of a closed-loop GHP system is economically feasible for the cases examined. At natural gas costs from \$0.60/therm to \$1.00/therm (\$0.21/m$^3$ to \$0.35m$^3$), closed-loop GHP systems begin to emerge as economically viable, but only at low loop installation costs, on the order of \$5.50/ft (\$18/m). At these rates, the feasible ground loop size would only be capable of handling 15-30% of the total annual heating demands of the greenhouse. At ground-loop installation costs of \$10/ft (\$33/m), natural gas costs would have to exceed \$1.50/therm (\$0.53/m$^3$) for closed-loop GHP systems to be considered economically viable.

Open-loop GHP systems show considerably more favorable economics than closed-loop systems. At natural gas costs of about \$0.60/therm (\$0.21/m$^3$), an open-loop system could feasibily be installed to handle 25-30% of annual greenhouse heating demands. At \$0.75/therm (\$0.26/m$^3$) natural gas cost, the feasible annual base-load handled by an open-loop system would increase to 60% and then again to about 85% at \$1.00/therm (\$0.35m$^3$) natural gas cost. Of course, open-loop systems would need to be sited at locations with sufficient groundwater supply.

## INTRODUCTION

The success and economic benefits of heating greenhouses with low-temperature geothermal resources (i.e., groundwater temperatures >140ºF (60ºC)) has lead to the question of whether or not lower temperature resources could be exploited with the aid of geothermal heat pumps (GHPs). This study seeks to answer that question, and therefore, the objective is to determine the feasibility of heating greenhouses with GHP systems. Both closed- and open-loop systems are examined at four locations across the United States: Boston, MA; Dallas, TX; Denver, CO and Seattle, WA. A number of GHP base-load combinations are examined for the four locations to find the lowest 20-year life-cycle cost at various natural gas rates and GHP installation costs.

## GREENHOUSE HEATING SYSTEMS

Of the many types of greenhouse heating systems, the two most common types are fan-coil systems and bare-tube systems. The particular system chosen by a grower depends on many factors such as economics, type of crop, and preference.

In a comparison study of this type, assumptions need to be made about the greenhouse heating system that is being displaced by the GHP system. GHPs are of two types: water-to-water and water-to-air. Water-to-water heat pumps would displace a low-temperature fossil-fuel fired boiler system. Water-to-air heat pumps would displace fan systems; where, the conventional heat source could either be a boiler with unitary hot water fan coil system or a direct gas-fired air-handling type system. Therefore, for comparison purposes in this study, the greenhouse heating system considered is a simple bare-tube system; where, the base-load heat demand is supplied by a water-to water GHP system and the remaining heat demands are supplied by a natural gas-fired, low-temperature boiler.

## GREENHOUSE HEATING LOADS

Hourly heating loads were calculated for a **1-acre (4047-m$^2$) greenhouse** using typical meteorological year (TMY) data for Boston, MA; Dallas, TX; Denver, CO and Seattle, WA. Heat transfer processes included in the calculations were: *solar heat gain, conduction through the structure, convection, infiltration, and ground conduction*. Greenhouse construction was assumed to be fiberglass with a set-point temperature of 65ºF (18.3ºC) and infiltration losses of 1 air-change per hour. Greenhouse cooling was assumed to be accomplished by another means, such as natural ventilation or evaporative cooling.

Hourly heating loads for the year are shown in Figure 1. As might be expected, Denver and Boston show the most extreme heating loads. An interesting and important result is shown in Figure 2, which is a plot of the fraction of total annual heating demands versus the fraction of the peak load that a base-load system would be designed to handle. This is significant since a base-load system (the GHP system in this case) sized at 50% of the peak load could meet about 92% of the total annual heating requirements.

## ECONOMIC ANALYSIS

### Closed-Loop GHP System

The hourly loads shown in Figure 1 were converted to monthly total and peak loads, and using a software program, ground loops were sized for each city for several

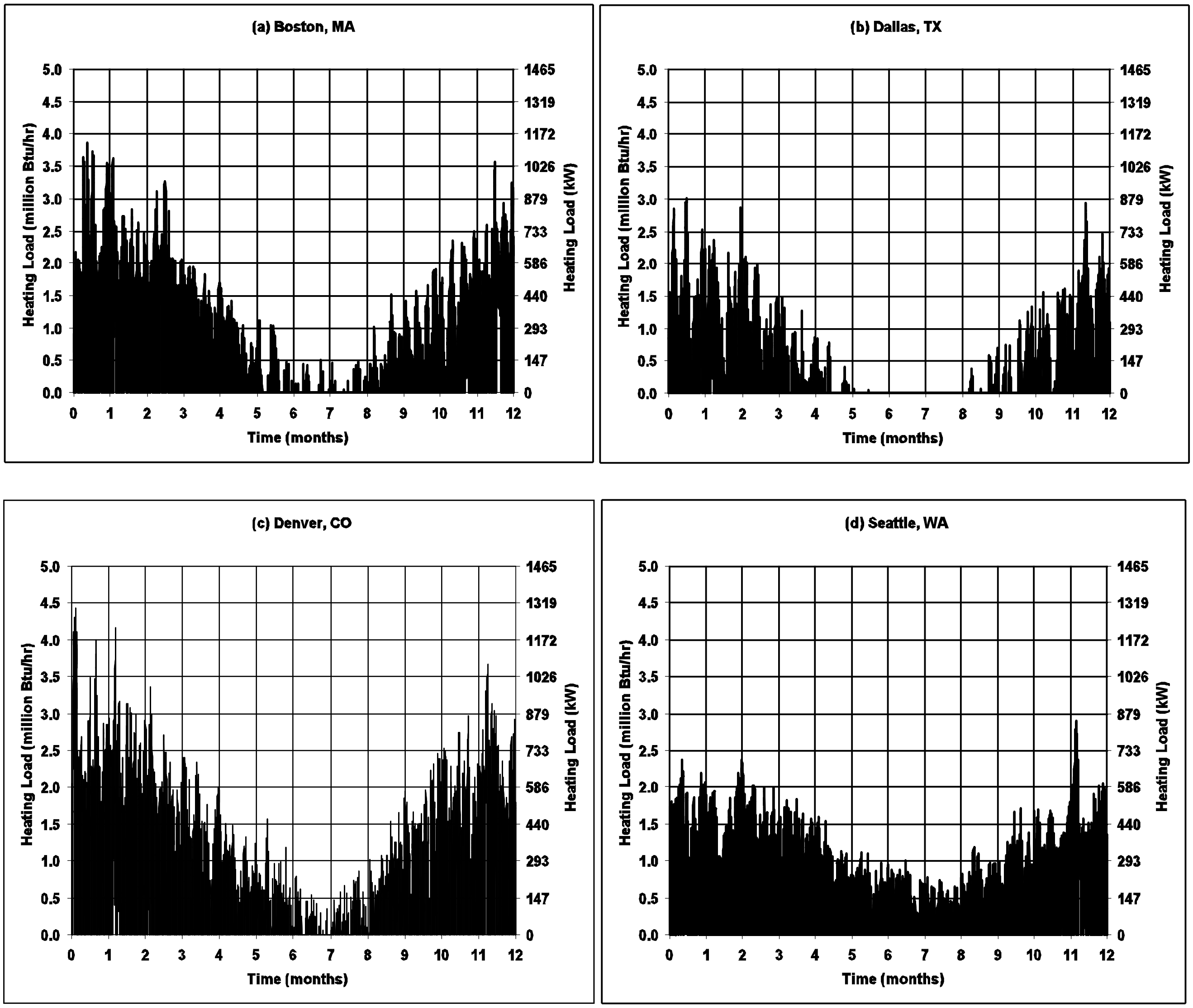


*Figure 1. Hourly heating loads on an annual basis.*

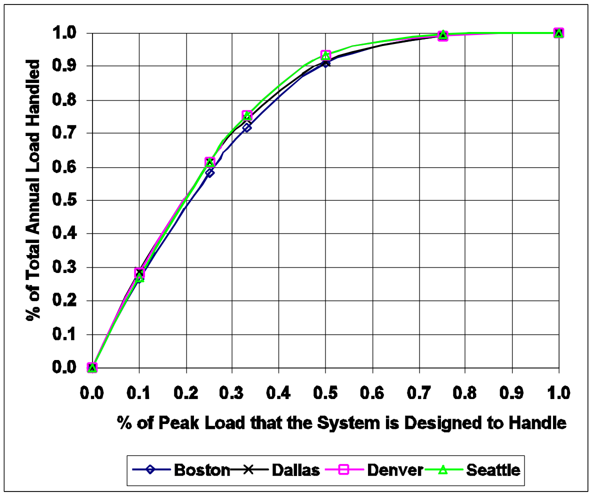


*Figure 2. Fraction of total annual heating load actually handled versus design fraction of peak load for a base-load system.*

GHP part load cases (100%, 75%, 50%, 33%, 25%, 10% and 0%). The loop-sizing software also computes heat pump power consumption.

A net present value (NPV) analysis of a 20-year life-cycle was used to compare alternatives for the various part load cases. Equipment costs for natural gas-fired boiler systems were taken from R.S. Means Mechanical Cost Data, and water-to-water heat pump material and installation costs were assumed at \$1000/ton (\$284/kW) of heat pump capacity. Ground-loop installation costs are commonly reported per foot of vertical bore, and for this study, a range of \$4/ft to \$12/ft (\$13/m to \$39/m) was examined, which is representative of the widely varying values observed across the U.S.

Annual operating costs included fuel and maintenance costs. A range of natural gas costs from \$0.50 to \$2.00 per therm (\$0.18/m$^3$ to \$0.70/m$^3$) was examined. Electricity cost was fixed at \$0.10/kW-hr. Annual boiler maintenance costs were assumed at 2% of capital cost. A discount rate of 6% was assumed.

Results of the closed-loop economic analysis are presented in Figure 3 in the form of a contour plot. Results were similar for all cities examined. The plot shows contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and ground-loop installation costs. A review of Figure 3 reveals that at natural gas prices of about $0.80/therm ($0.25/m$^3$), it would not be justifiable to heat any portion of a greenhouse with a closed-loop GHP system; unless, the ground loop could be installed at very low cost of about $5/ft ($16.40/m). At these rates, it would only be feasible to install a ground loop capable of handling 15-30% of the total annual heating requirements. At a loop installation cost of $10/ft ($33/m), natural gas prices would have to exceed $1.50/therm ($0.53/m$^3$) to justify installing a ground loop to handle 15-30% of the total annual heating requirements.

## Open-Loop GHP System

The same overall approach was taken in the economic analysis of the open-loop systems as for the closed-loop systems with the following differences. The capital cost range of the open loop systems were taken from *Outside the Loop Newsletter* (Vol. 1, No.1, 1998). These costs, shown in Figure 4, are expressed per ton (and kW) of delivered capacity for various well configurations and include costs of production and injection wells, well tests, pumps, piping to the building, heat exchangers, controls, and 15% contingency. For the operating costs, additional electrical loads were included to account for a submersible pump operating under an assumed vertical head of 100 ft (30.48 m).

Results of the open-loop economic analysis are presented in Figure 5. The plot shows contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and open loop installation costs. A review of Figure 5 shows much greater feasibility of greenhouse heating with open-loop GHP systems over closed-loop systems. At natural gas prices of about $0.80/therm ($0.25/m$^3$), it would be economically feasible to install an open-loop GHP system up to a cost of about $600/ton ($170/kW). This open loop cost covers most of the well configurations shown in Figure 4. For this cost, an approximate 40% open-loop system (relative to the peak load) could feasibily be installed and would be capable of handling about 80% of the total annual heating demands (see Figure 2).

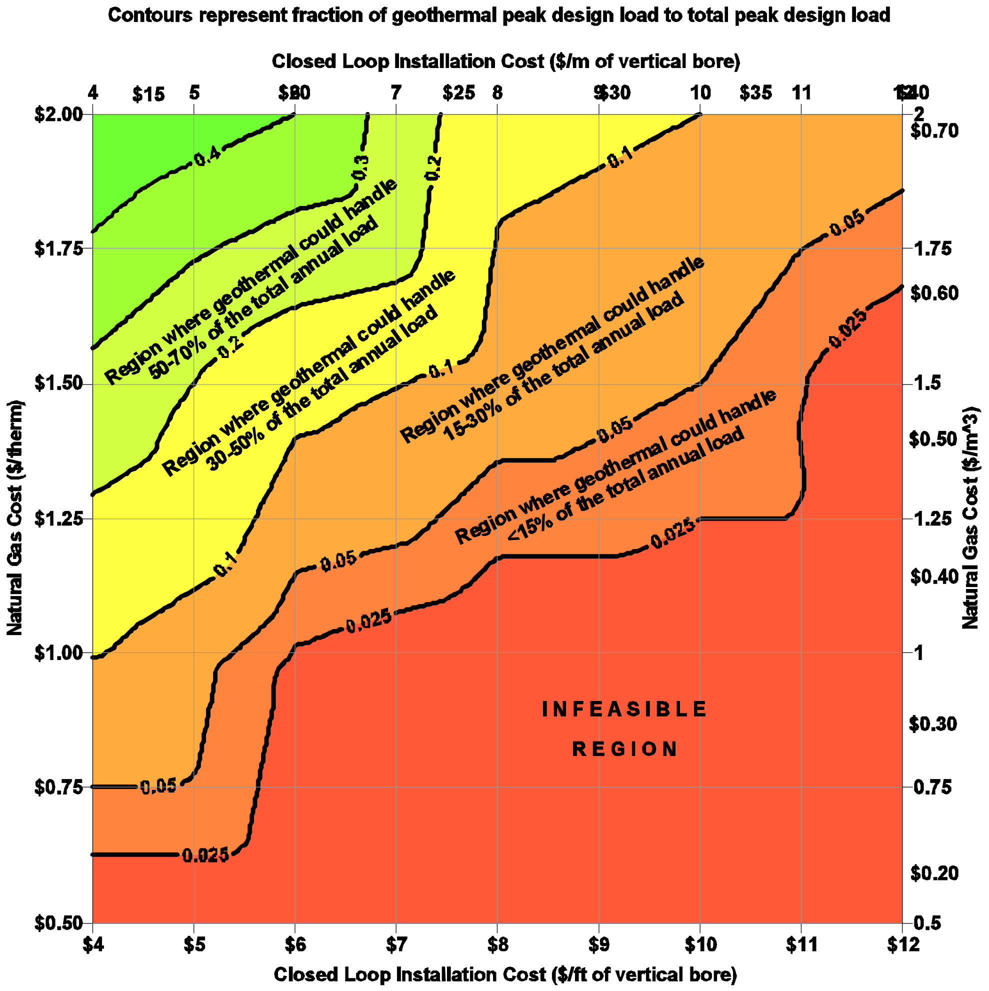


*Figure 3.* ***Closed loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs (Results derived from Boston, Dallas, Denver and Seattle climate data).***

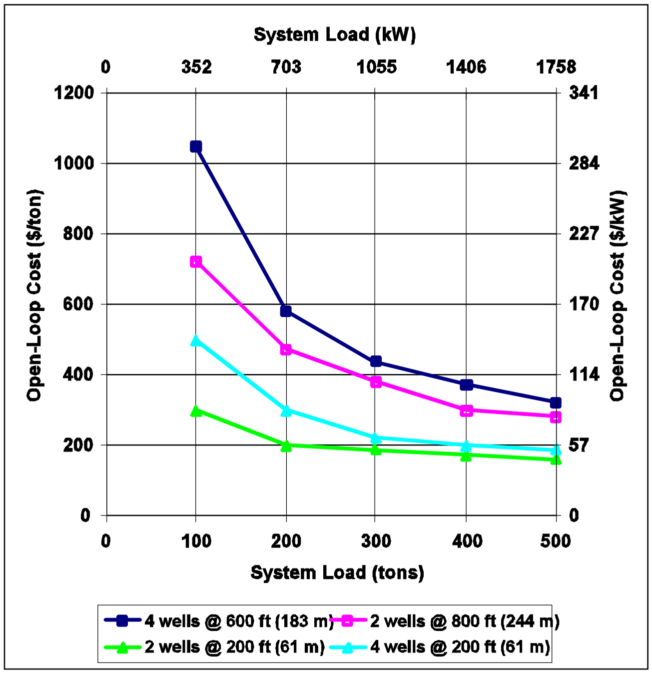


*Figure 4. Open-loop system costs for 60°F groundwater (Source: Outside the Loop Newsletter, Vol. 1, No. 1, 1998).*

Note also the relative "flatness" of the 0.1 to 0.4 curves in Figure 5 from about $200/ton to $600/ton ($57/kW to $170 /kW). This reflects the economies of scale with open loop systems; only two to four wells are needed if enough ground water is present. Thus, a greenhouse would need to be sited at a location; where, there is sufficient groundwater supply.

## CONCLUDING SUMMARY

This study has examined the feasibility of greenhouse heating with closed- and open-loop GHP systems. Heating loads were computed for four climates across the U.S. The net present value of a 20-year life-cycle was determined for various GHP base-load fractions.

The results of this study show that the feasibility of heating greenhouses with closed-loop GHP systems is strongly dependent on the natural gas cost and the ground-loop installation cost. It would not be economically justifiable to heat any portion of a greenhouse using a closed-loop GHP system; unless, loop installation costs were as low as $4/ft to $5/ft ($13/m to $16.40/m) and natural gas prices exceeded $0.75/therm ($0.26/m$^3$). This represents a very marginal situation at 2005 rates. On the contrary, for the cases examined, open loop systems appear to be quite economically feasible above natural gas rates of about $0.60/therm ($0.21/m$^3$).

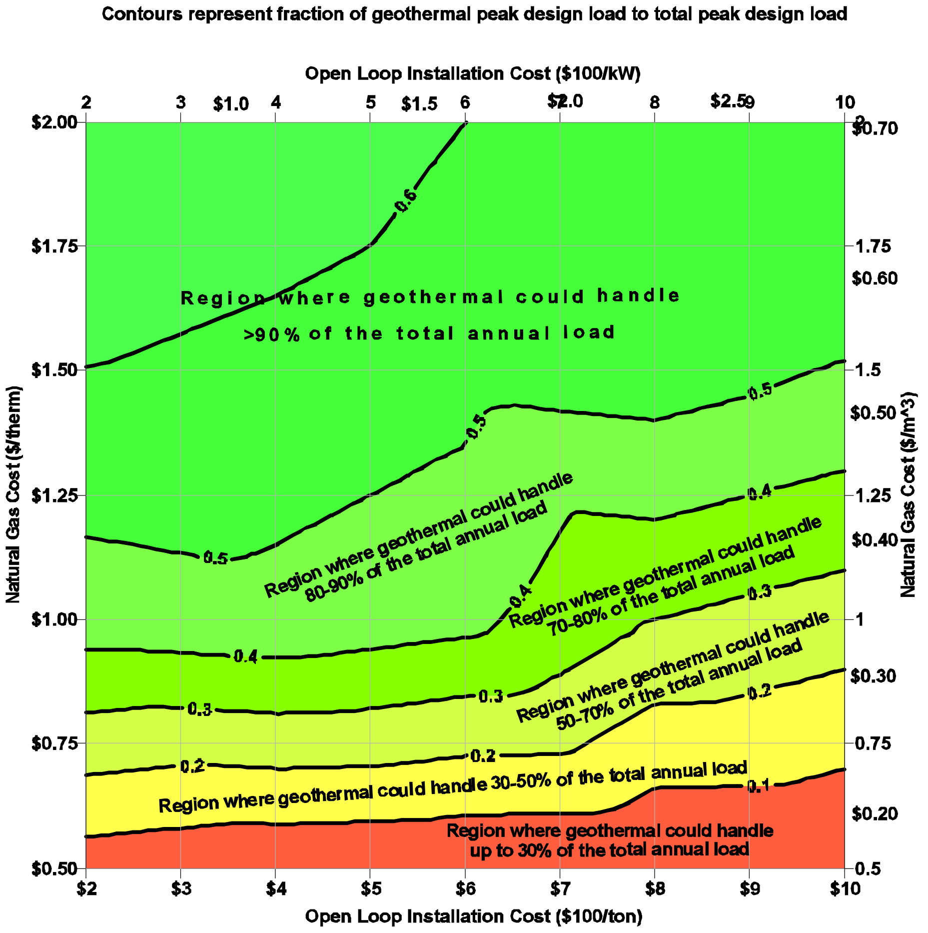


*Figure 5. Open-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and open-loop installation costs (Results derived from Boston, Dallas, Denver and Seattle climate data).*

# AQUACULTURE AND GEOTHERMAL HEAP PUMP SYSTEMS

**Andrew Chiasson, P.E.**
**Geo-Heat Center**

## ABSTRACT

The objective of this study is to examine the feasibility of aquaculture tank heating with geothermal heat pump (GHP) systems. Both closed- and open-loop GHP systems are examined for heating uncovered and greenhouse-covered tanks at three locations across the U.S. A net present value analysis is conducted for a 20-year life-cycle for various GHP base-load fractions with natural gas-fired boiler peaking. The fraction of GHP capacity to the peak load yielding the lowest life-cycle cost is plotted at various GHP installation costs and natural gas rates.

Heating load calculations show that covering aquaculture tanks with a greenhouse-type structure reduces the heating requirements by over 50%. Economic analyses for closed-loop GHP systems show that, the lowest life-cycle cost at natural gas rates of \$1.00/therm (\$0.35/m$^3$) is observed when the GHP system is sized for 10-20% of the peak load. At that fraction, 30-55% of the total annual heating load could be handled. At low loop installation costs of \$4/ft-\$6/ft (\$13/m-\$20/m), approximately 55-70% of the annual heating load could be handled.

Open-loop GHP systems show considerably more favorable economics than closed-loop systems. In all situations examined, at natural gas prices of \$1.00/therm (\$0.35/m$^3$), the lowest life-cycle cost is observed when the open-loop system is sized for about 40% of the peak load. At that size, the GHP system can handle over 80% of the annual heating requirements. At low-to-moderate installation costs of \$200-\$700/ton (\$57/kW-\$200/kW), over 90% of the annual heating load could be handled. Of course, open-loop systems would need to be sited at locations with sufficient groundwater supply.

## INTRODUCTION

The success and economic benefits of aquaculture operations with low-temperature geothermal resources (i.e., groundwater temperatures >140ºF (60ºC) has lead to the question of whether or not lower temperature resources could be exploited with the aid of geothermal heat pumps (GHPs). This study seeks to answer that question, and therefore, the objective is to determine the feasibility of heating fish tanks with GHP systems. Both closed- and open-loop systems are examined at three locations across the United States: Boston, MA; Dallas, TX, and Denver, CO. A number of GHP base-load combinations are examined for the three locations to find the lowest 20-year life-cycle cost at various natural gas rates and GHP installation costs.

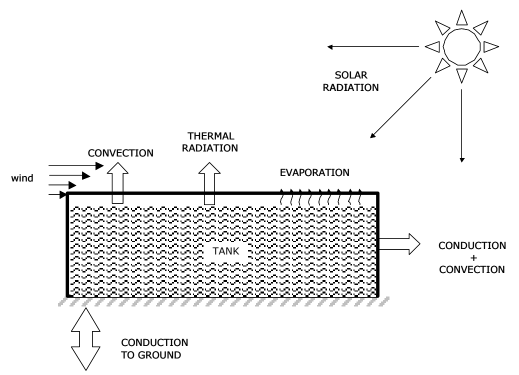
## AQUACULTURE TANK HEATING SYSTEMS

In a comparison study of this type, assumptions need to be made about the fish tank heating system that is being displaced by the GHP system. It was assumed that a conventional system would consist of a number of above-ground tanks; where, water is heated by a natural gas-fired boiler system. The alternative is a water-to-water GHP system.

## AQUACULTURE TANK HEATING LOADS

Hourly heating loads were calculated for above-ground aquaculture tanks with a total surface area of 10,000 ft$^2$ (930 m$^2$) and a depth of 5 ft (1.5 m). Typical meteorological year (TMY) data for Boston, MA; Dallas, TX, and Denver, CO, were used to compute loads for two scenarios: (1) tanks uncovered and (2) tanks covered by a greenhouse structure. Heat transfer processes included in the calculations are shown in Figure 1. The tank set point temperature was 80ºF (27ºC).

**(a) uncovered tank**



**(b) covered tank**

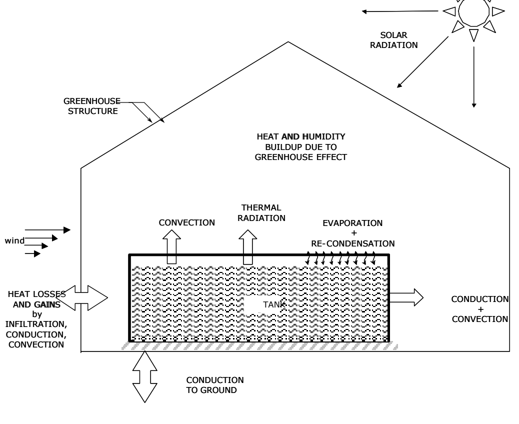
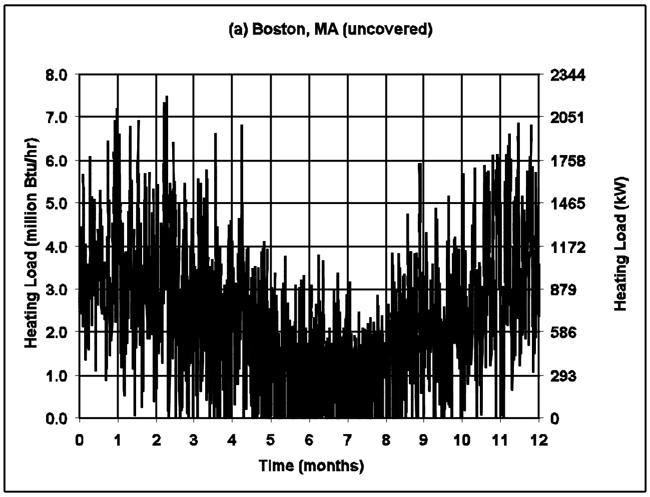
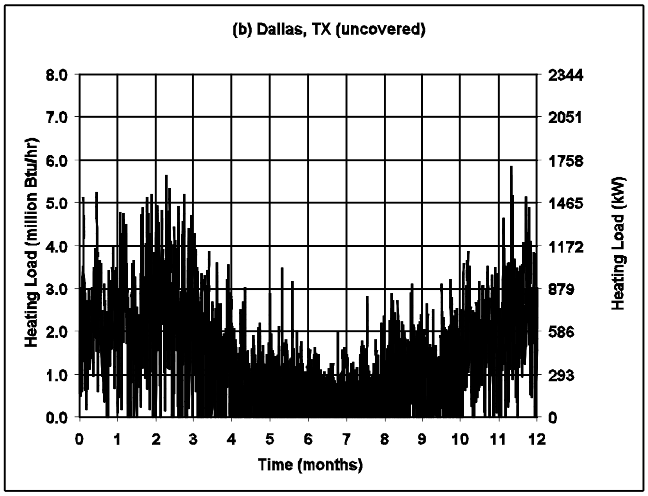


***Figure 1.*** ***Heat transfer processes in covered and uncovered aquaculture tanks.***

Hourly heating loads for the year are shown in Figures 2 and 3. As might be expected, Boston and Denver show more extreme heating loads than Dallas. In all cases, covering the tanks with a greenhouse structure results in approximately a 50% reduction in heating load. An interesting and important result is shown in Figure 4, which is a plot of the fraction of total annual heating demands versus the fraction of the peak load that a base-load system would be designed to handle. This is significant since a base-load system (the GHP system in this case) sized at 50% of the peak load could meet about 92% of the total annual heating requirements.





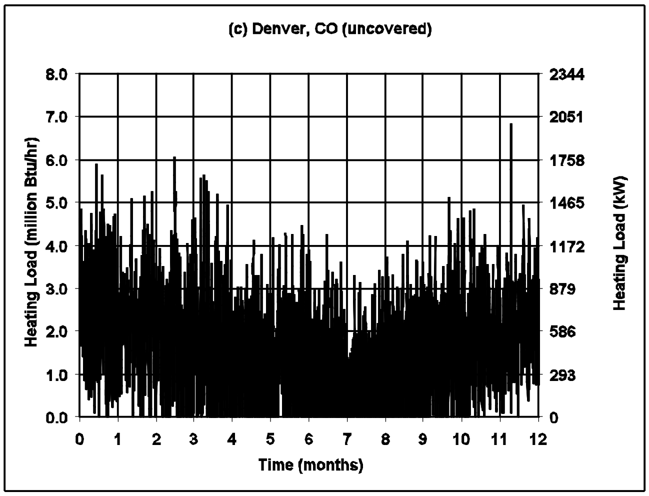
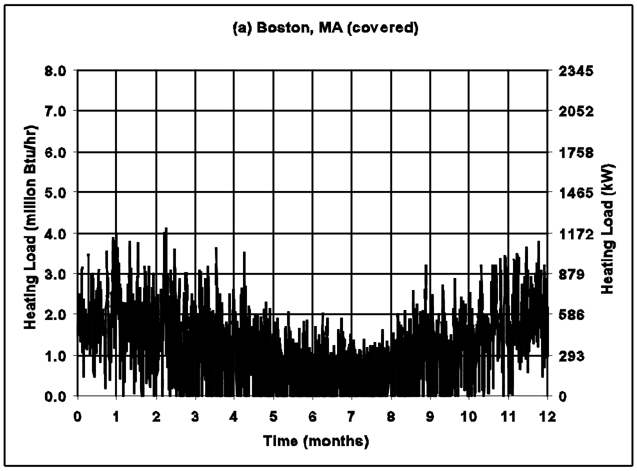
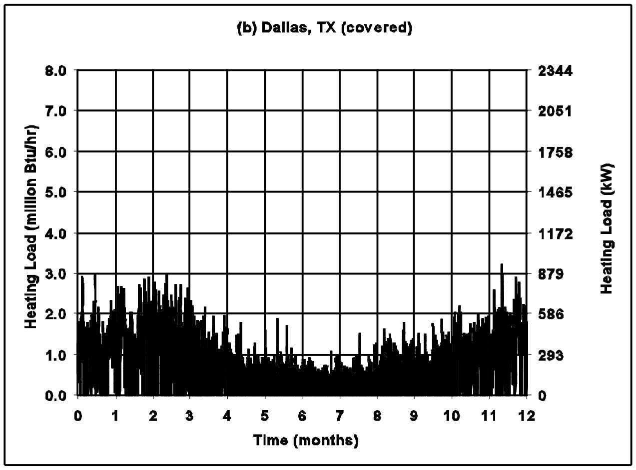


*Figure 2.* ***Hourly heating loads on an annual basis for uncovered aquaculture tanks.***





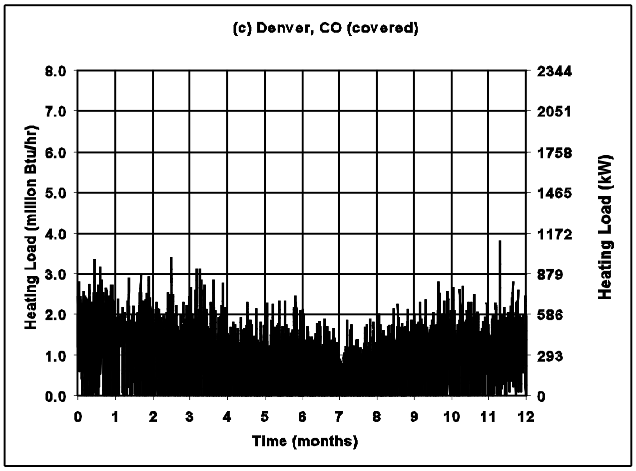
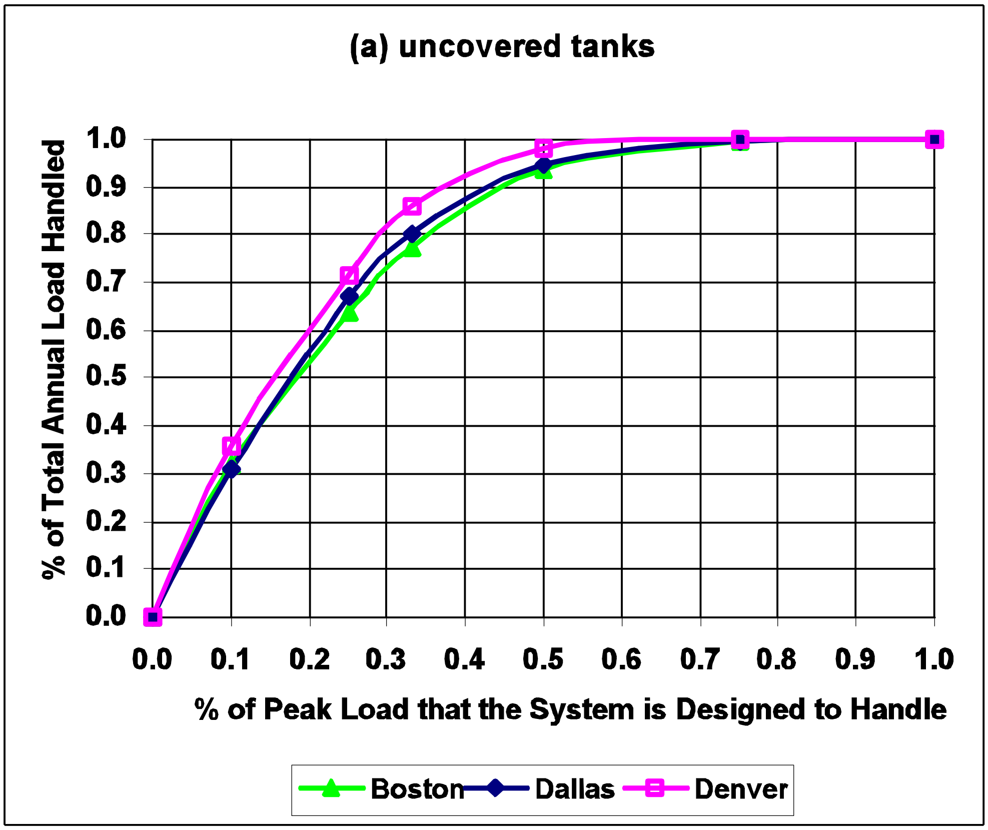


*Figure 3.* ***Hourly heating loads on an annual basis for covered aquaculture tanks.***



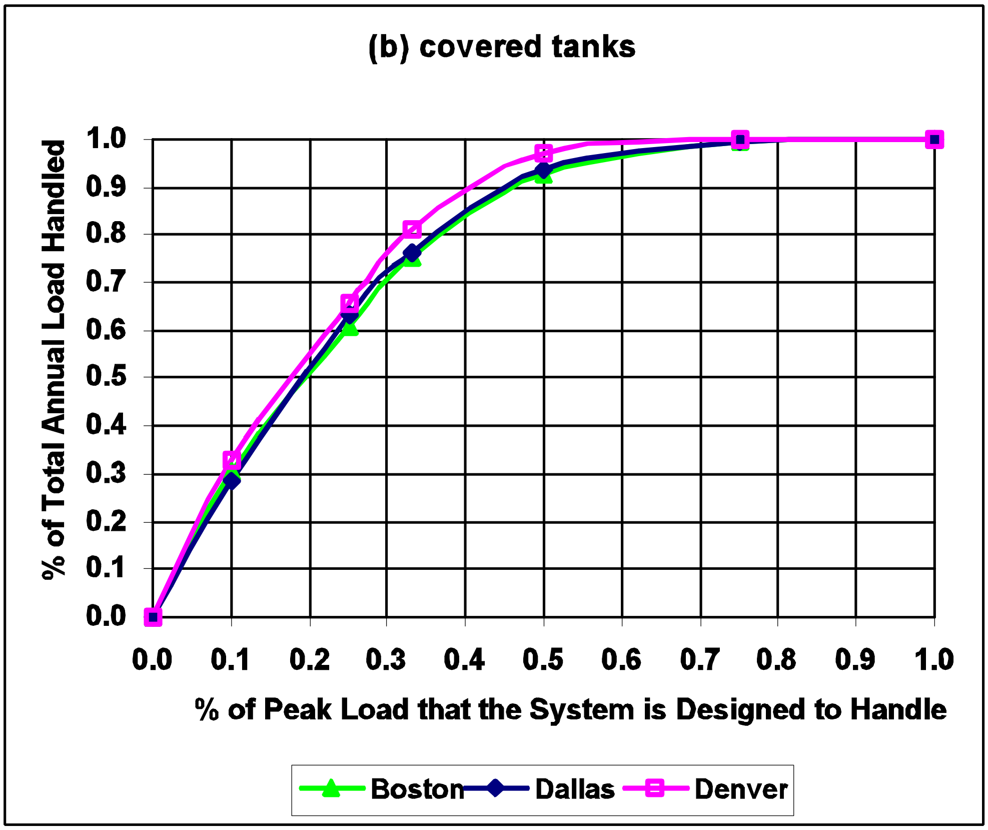


*Figure 4.* ***Fraction of total annual heating load actually handled versus design fraction of peak load for a base-load system.***

## ECONOMIC ANALYSIS

### Closed-Loop GHP System

The hourly loads shown in Figures 2 and 3 were converted to monthly total and peak loads, and using a software program, ground loops were sized for each location for several GHP part load cases (100%, 75%, 50%, 33%, 25%, 10%, and 0%). The remainder of the load is handled by a natural gas-fired-boiler system. The loop-sizing software also computes heat pump power consumption.

A net present value (NPV) analysis of a 20-year life-cycle was used to compare alternatives for the various part load cases. Equipment costs for natural gas-fired boiler systems were taken from R.S. Means Mechanical Cost Data and water-to-water heat pump material and installation costs were assumed at $1000/ton ($284/kW) of heat pump capacity. Ground-loop installation costs are commonly reported per foot of vertical bore, and for this study, a range of $4/ft to $12/ft ($13/m to $39/m) was examined, which is representative of the widely varying values observed across the U.S.

Annual operating costs included fuel and maintenance costs. A range of natural gas costs from $0.50 to $2.00 per therm ($0.18/m$^3$ to $0.70/m$^3$) was examined. Electricity cost was fixed at $0.10/kW-hr. Annual boiler maintenance costs were assumed at 2% of capital cost. A discount rate of 6% was assumed.

Results of the closed-loop economic analysis are presented in the form of contour plots in Figure 5 for uncovered tanks and in Figure 6 for greenhouse-covered tanks. Results were similar for all three cities examined. The plot shows contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and ground-loop installation costs.

A review of Figures 5 and 6 reveals that at natural gas prices above about $0.50-$0.60/therm ($0.18/m$^3$-$0.21/m$^3$), it would be economically justifiable to heat a portion of aquaculture tanks with a closed-loop GHP system, depending on the installation costs. For **uncovered** tanks at natural gas costs of $1.00/therm ($0.35/m$^3$), for example, the lowest life-cycle cost is seen to range from a GHP sized at about 7% of the peak load at installation costs of $12/ft ($39/m) to about 22% of the peak load at installation costs of $4/ft ($13/m). At these sizes, the GHP system could handle from about 25% to about 65% of the total annual load, respectively. For **covered** tanks under the same conditions, the lowest life cycle cost is seen to range from a GHP sized at about 12% of the peak load at installation costs of $12/ft ($39/m) to about 25% of the peak load at installation costs of $4/ft ($13/m).

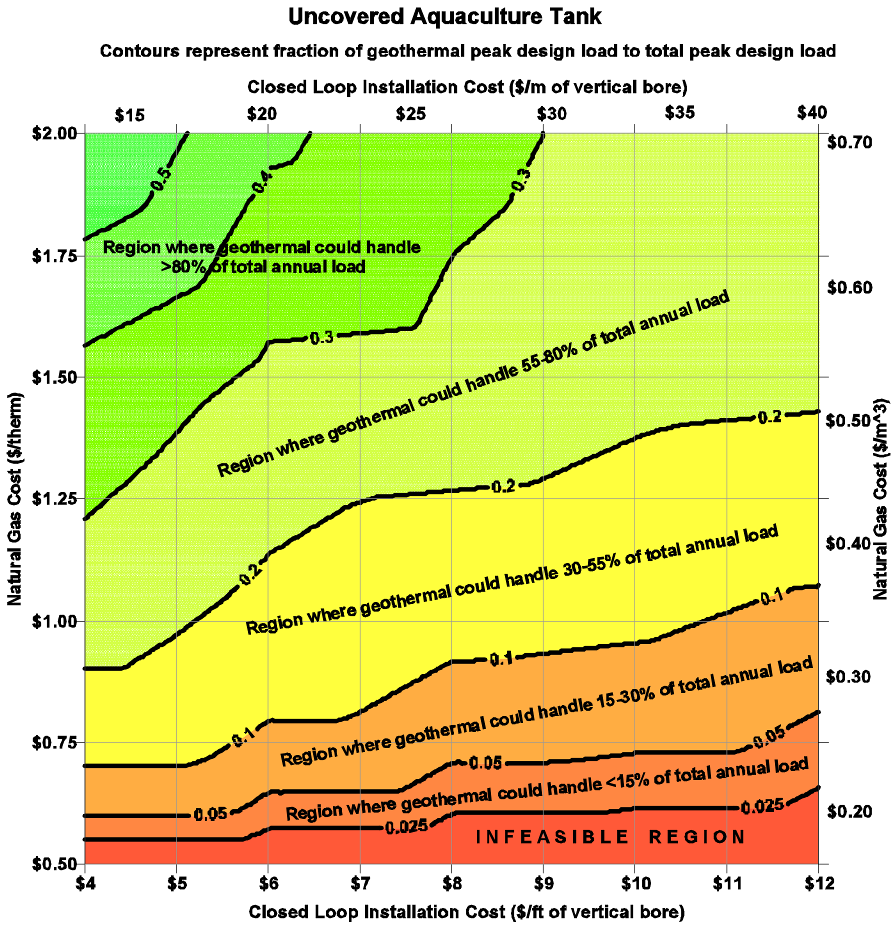


*Figure 5. Closed-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat uncovered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).*

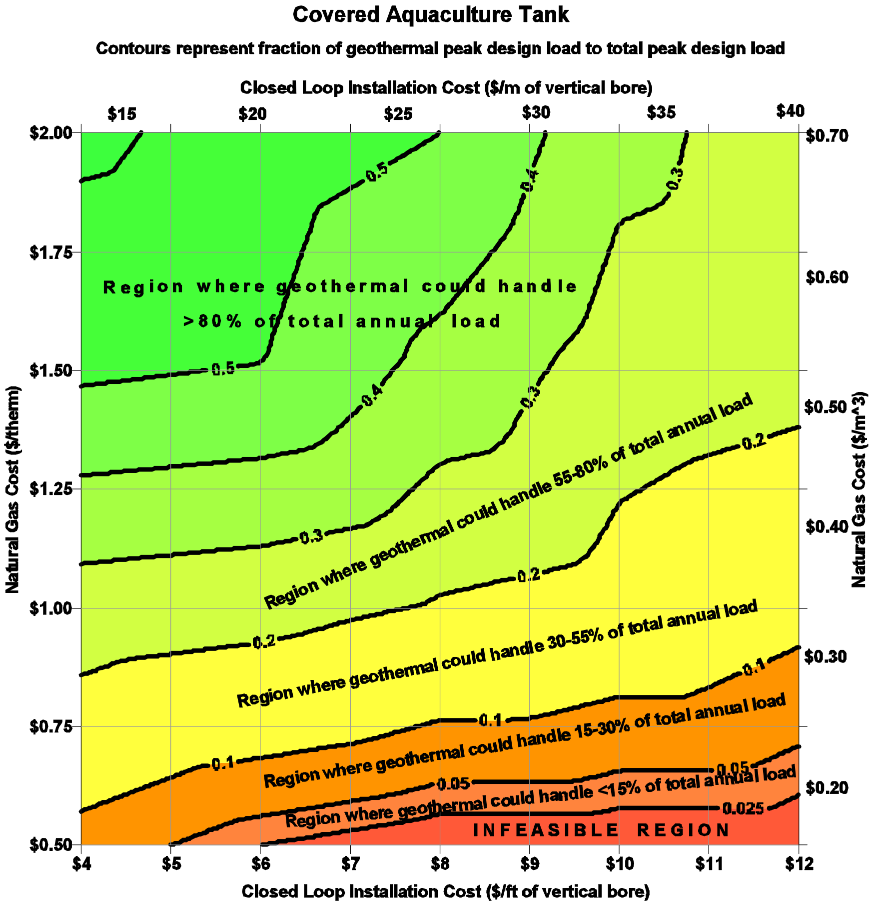


*Figure 6.* *Closed-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat covered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).*

## Open-Loop GHP System

The same overall approach was taken in the economic analysis of the open-loop systems as for the closed-loop systems with the following differences. The capital cost range of the open-loop systems were taken from *Outside the Loop Newsletter* (Vol. 1, No.1, 1998). These costs, shown in Figure 7, are expressed per ton (and kW) of delivered capacity for various well configurations and include costs of production and injection wells, well tests, pumps, piping to the building, heat exchangers, controls, and 15% contingency.

For the operating costs, additional electrical loads were included to account for a submersible pump operating under an assumed vertical head of 100 ft (30.48 m).

Results of the open-loop economic analysis are presented in Figure 8 for uncovered tanks and in Figure 9 for greenhouse-covered tanks. The plots show contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and open loop installation costs. A review of Figures 8 and 9 shows greater feasibility of aquaculture tank heating with open-loop GHP systems over closed-loop systems. The lowest life-cycle cost at natural gas rates of $1.00/therm ($0.35/m$^3$), is seen for the GHP system sized at about 40% of the peak load, being capable of handling over 90% of the annual heating load, at installation costs up to

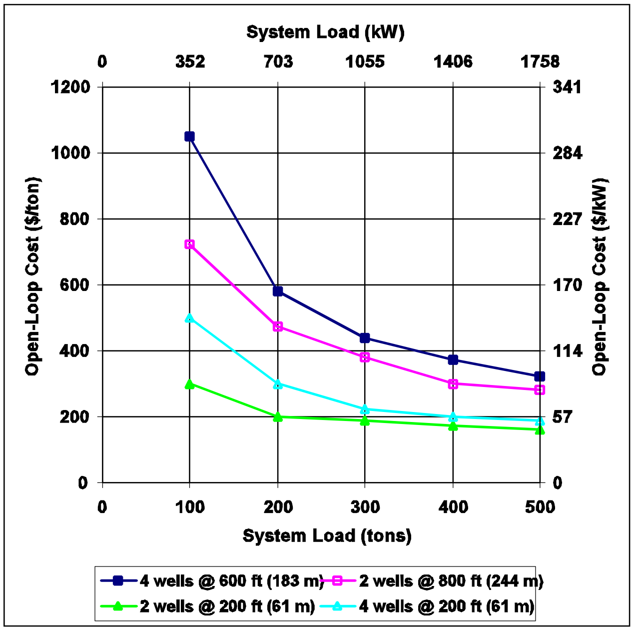


*Figure 7.* *Open-loop system costs for 60°F groundwater (Source: Outside the Loop Newsletter, Vol. 1, No. 1, 1998).*

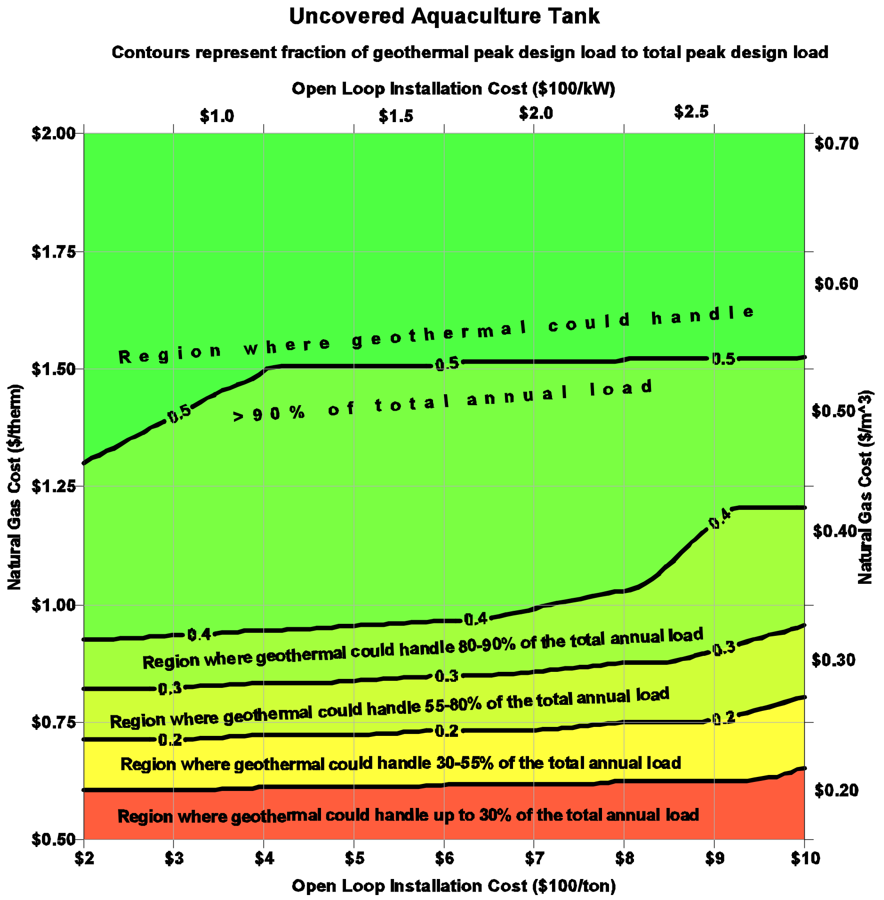


*Figure 8.* ***Open-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat uncovered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).***

$700/ton ($200/kW) for uncovered tanks and up to about $875/ton ($250/kW) for covered tanks. Above these costs per ton (kW), an open-loop system could still be installed to handle 80-90% of the annual load for either covered or uncovered tanks. Note also the relative "flatness" of the 0.1 to 0.4 curves in Figures 8 and 9. This reflects the economies of scale with open loop systems; only two to four wells are needed if enough ground water is present. Thus, a greenhouse would need to be sited at a location where there is sufficient groundwater supply.

## CONCLUDING SUMMARY

This study has examined the feasibility of aquaculture tank heating with closed- and open-loop GHP systems. Heating loads were computed for three climates across the U.S. The net present value of a 20-year life-cycle was determined for various GHP base-load fractions.

The results of this study show that the practice of covering aquaculture tanks with greenhouse-type structures can reduce heating demands by 55%. The economic analysis has shown that the feasibility of heating aquaculture tanks with closed-loop GHP systems is strongly dependent on the natural gas cost and the ground-loop installation cost. The lowest life-cycle cost was observed when the closed-loop GHP system handles only a portion of the total annual heating requirement. At natural gas rates of $1.00/therm ($0.35/m$^3$), depending on loop installation costs and whether or not the aquaculture tanks are covered, a closed-loop GHP system sized at 7-25% of the peak load could be installed to handle from about 25-70% of the annual load.

The economics of open-loop systems for the cases examined, as may be expected, are more attractive than closed-loop systems. In all situations examined, at natural gas prices of $1.00/therm ($0.35/m$^3$), the lowest life-cycle cost was observed at the GHP system sized at about 40% of the peak load. At that size, an open-loop system could handle over 80% of the annual heating load. At low-to-moderate installation costs of $200-$700/ton ($57/kW-$200/kW), over 90% of the annual heating load could be handled.

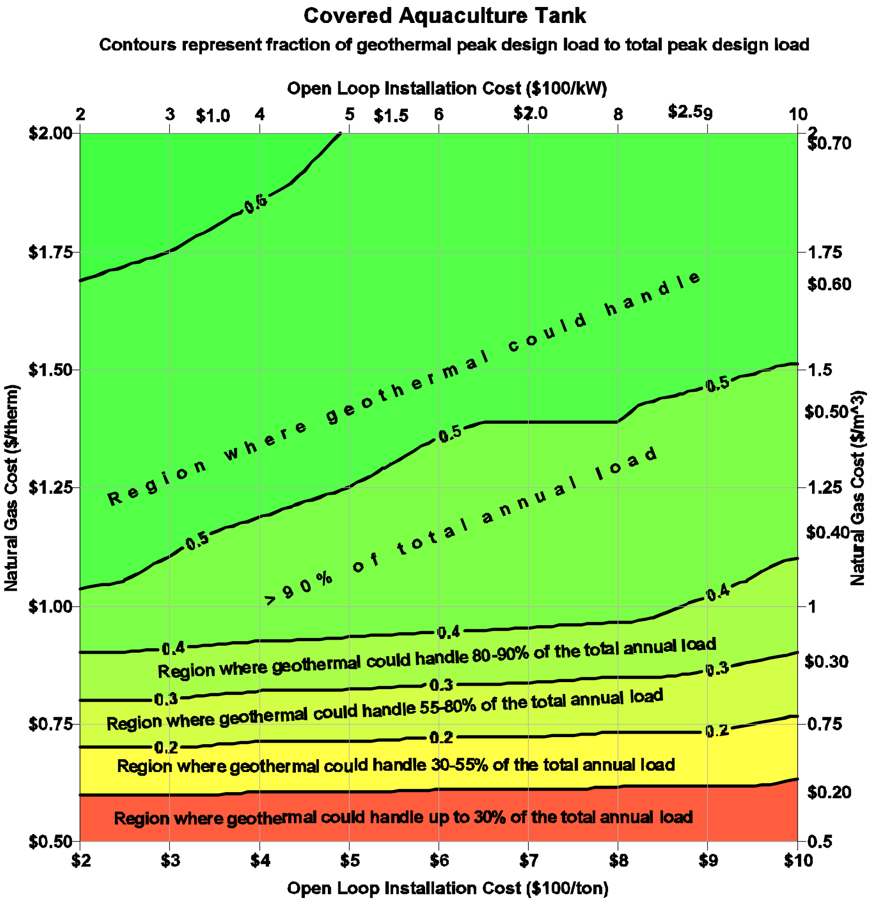


*Figure 9. Open-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat covered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).*

# RESIDENTIAL SWIMMING POOL HEATING WITH GEOTHERMAL HEAT PUMP SYSTEMS

**Andrew Chiasson, P.E.**
**Geo-Heat Center**

## ABSTRACT

The objective of this study is to examine the feasibility of swimming pool heating with geothermal heat pump (GHP) systems in residential applications. Six locations with varying climates are examined across the U.S. A contour plot is presented for use in estimating the potential reduction in ground loop size as a function of the total annual building loads and the total annual swimming pool heating load. Results show that ground loop lengths may be reduced by up to about 20% in southern U.S. climates with the addition of a swimming pool, but may be as much as double in northern U.S. climates. A simple economic analysis demonstrates that it would not be economically justifiable to heat a swimming pool with a GHP system in northern U.S. climates due to the extra ground loop required to meet additional heating demands. In contrast, immediate savings could be realized in southern U.S. climates since the pool can accept heat from the heat pump system that would be otherwise rejected to the ground.

## INTRODUCTION

A frequently asked question by prospective and current residential geothermal heat pump (GHP) owners is, "Can I use it to heat my pool?" The short answer in the past has been "Yes, but it depends on the climate." The design challenge arises from the fact that GHP systems are exactly that: they are systems. The addition of a swimming pool to a GHP system changes the heat balance of the original system (i.e., without a pool), and the new design depends on the climate.

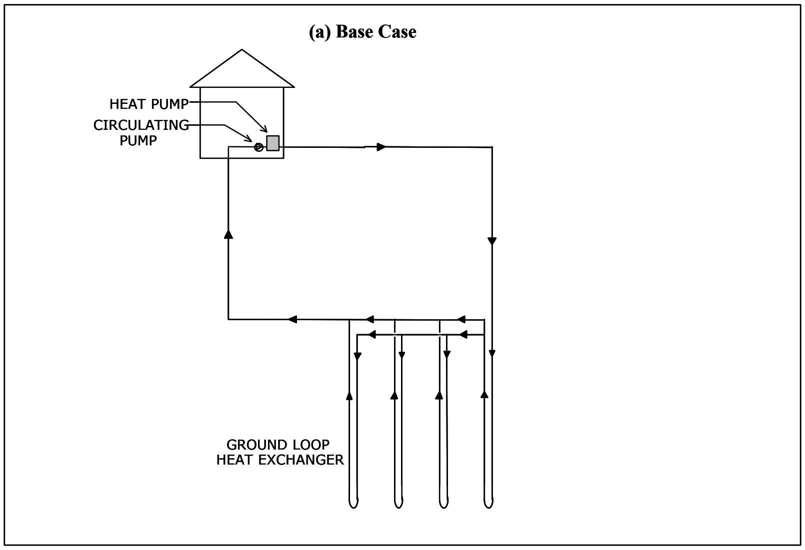
In northern climates, more heat is generally extracted from the ground than is rejected during the year. Therefore, a water-to-water heat pump and more ground loop would be required to heat a pool in summer months, but the amount of extra ground loop needed would depend on the length of the swimming season and on the heating/cooling loads profile for the home during the remainder of the year. In southern climates, the opposite occurs and more heat is generally rejected to the ground than is extracted during the year. In these cases, heat from the ground loop that would otherwise be rejected to the ground can be used to heat a swimming pool either directly or with a water-water heat pump. The decision to heat a pool with a GHP is an economic one, similar to the decision to heat/cool a home with a GHP. There are tradeoffs between first cost and operating cost savings.

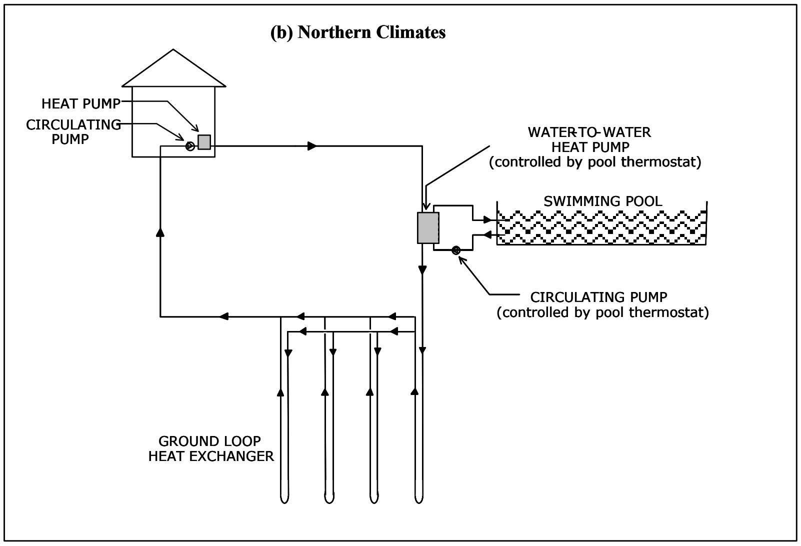
The objective of this paper is to determine if it is economically feasible to heat an outdoor swimming pool with a GHP system. Six climatic locations across the United States are examined: Boston, MA; Charlotte, NC; Dallas, TX; Denver, CO; Los Angeles, CA and Seattle, WA. A graph is presented to estimate the relative change in overall ground loop length when swimming pool heating is incorporated into a GHP system. Finally, an economic analysis is conducted.

## APPROACH

Figure 1 illustrates the system scenarios that were considered. The approach used in the analysis is summarized as follows:

- Annual heating and cooling loads were computed for a 2,000-sq ft(186-m$^2$) home of new, tight construction.
- A vertical-bore ground loop was sized for the house with a heat pump entering fluid temperature of 90°F (32.2°C) maximum and 35°F minimum (1.7°C) (Figure 1a). An earth thermal conductivity of 1.2 Btu/hr-ft-°F (2.0 W/m-K) was assumed.
- Monthly swimming pool heating loads were computed based on the following assumptions:
  - A pool size of 30 ft long x 20 ft wide x 5 ft average depth (9.1m x 6.1m x 1.5m)
  - Only **outdoor, underground pools** are considered
  - An outdoor swimming season of June through August for northern climates, and mid May through mid-September for southern climates.
  - A pool setpoint temperature of 80°F (26.7°C), representing the average monthly pool temperature
  - Heat transfer processes considered were: *incident solar radiation gain (with 10% shading assumed), convection to the atmosphere, evaporation, thermal radiation to the sky, and conduction to the ground.* These are illustrated in Figure 2.
  - Loads were computed for cases where the pool remains uncovered at all times and where the pool is covered at night.
- The vertical-bore ground loop was re-sized for the combined loads of the house and pool (Figure 1b and 1c) and compared to the ground loop size required for the house only (Figure 1a). For southern climates, some heat rejection from the ground loop to the pool was accomplished with the configuration shown in *Figure 1c*.
- A simple economic analysis of pool heating was conducted.


(a) Base Case


(b) Northern Climates

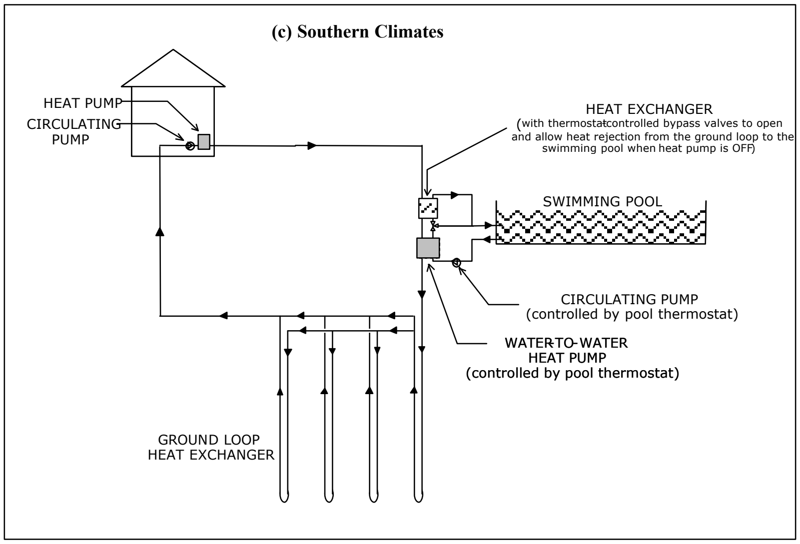

(c) Southern Climates

*Figure 1. Schematic diagrams of the pool heating scenarios examined.*

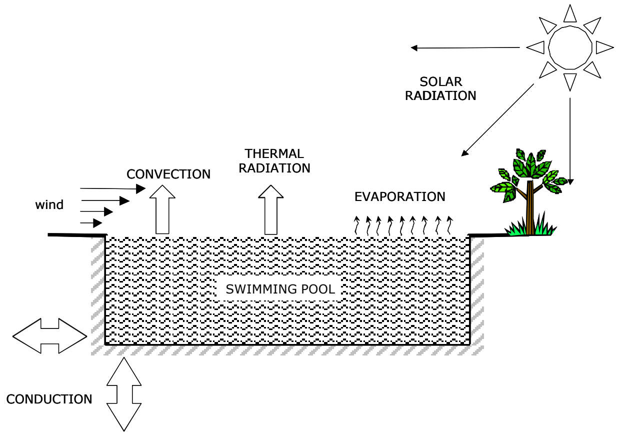


*Figure 2.* ***Environmental heat transfer processes in swimming pools.***

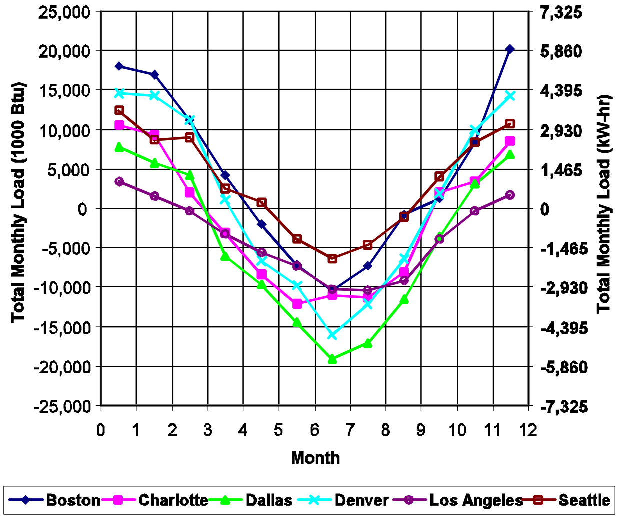


*Figure 3.* ***Total monthly heating and cooling loads for the cities examined (note, heating loads are positive and cooling loads are negative).***

## RESIDENTIAL HEATING & COOLING LOADS

The residential heating and cooling loads for the six locations are shown graphically in Figure 3 and summarized in Table 1. The EFLH for heating (for example) is defined as the total annual heating requirement divided by the peak heating load. An important value shown in Table 1 (to be used later in this study) is the ratio of total annual cooling to total annual heating. It provides a measure of the heating or cooling dominance of a building. When this value is near unity the building is approximately balanced with regard to annual loads.

## SWIMMING POOL HEATING LOADS

The monthly heating loads are summarized in Figure 4. A review of Figure 4 shows that covering the pool at night can save significantly on pool heating energy consumption. Covering the pool eliminates evaporation losses and nearly eliminates convection losses. However, it may be advantageous to leave the pool uncovered in southern climates for a portion of the summer season. In these cases, more heat may be rejected from the ground loop to the pool, and the pool would act like a *supplemental heat rejecter.* This concept of supplemental heat rejection is receiving considerable attention in commercial building applications to prevent heat build-up in the ground.

## GROUND LOOP SIZING

The results of the ground loop sizing are presented as a useful contour plot in Figure 5. The contours represent the relative change of the ground loop as a function of x and y. The x-variable is the ratio of total annual cooling load to total annual heating load (see Table 1) for the house. The y-variable is similar to the x-variable, except the denominator is the total annual house heating load plus the total annual pool heating load. The "1" contour line means no change in relative ground loop length. Above and to the right of this line, ground loop savings can be realized with the addition of a swimming pool. Below and to the left of this line, additional ground loop is needed to heat a swimming pool. The gray

**Table 1. Summary of Heating and Cooling Load Data**

| | **Heating** | | **Cooling** | | **Total Annual Cooling to Total Annual Heating Ratio** |
|---|---|---|---|---|---|
| **City** | **Peak Load 1000 Btu/hr (kW)** | **EFLH*** | **Peak Load 1000 Btu/hr (kW)** | **EFLH*** | |
| Boston, MA | 38.0 (11.1) | 2,453 | 31.2 (9.1) | 1,305 | 0.44 |
| Charlotte, NC | 29.7 (8.7) | 1,697 | 37.8 (11.1) | 1,818 | 1.37 |
| Dallas, TX | 25.6 (7.5) | 1,522 | 47.4 (13.9) | 1,955 | 2.38 |
| Denver, CO | 38.9 (11.4) | 2,261 | 52.4 (15.4) | 1,360 | 0.81 |
| Los Angeles, CA | 16.7 (4.9) | 1,637 | 41.1 (12.0) | 1,734 | 2.61 |
| Seattle, WA | 26.3 (7.7) | 2,734 | 30.5 (8.9) | 1,040 | 0.44 |

* EFLH = Annual equivalent full load hours

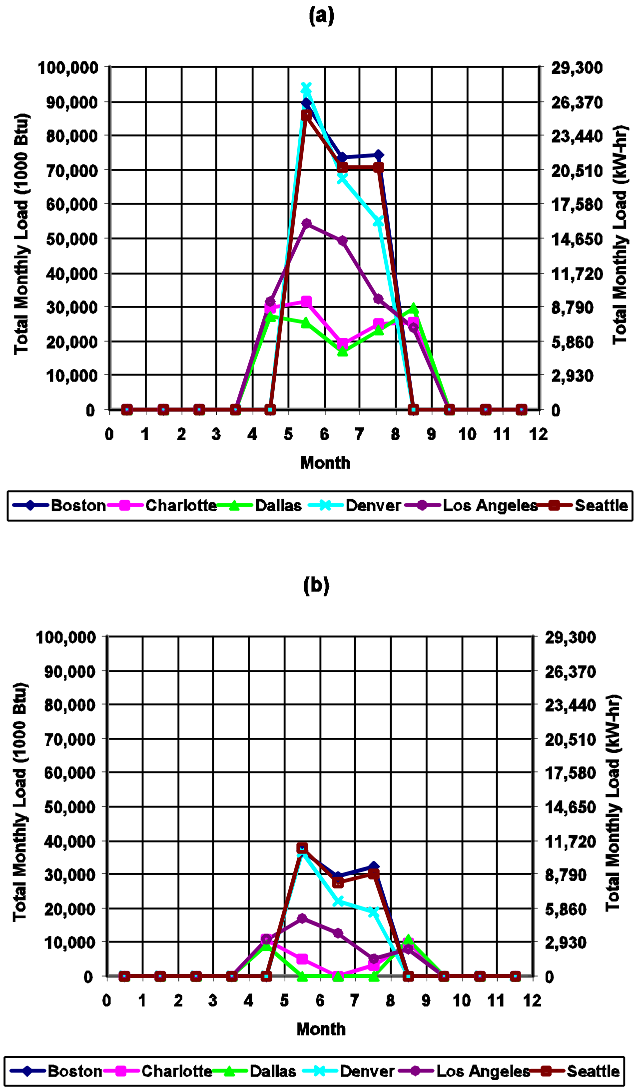


***Figure 4.*** ***Swimming pool heating loads for an outdoor pool kept at 80ºF (26.7ºC);, where, the pool is (a) uncovered and (b) covered at night. Note, the pool seasons described in the text.***

region is not applicable since it would represent pool cooling, not heating.

Some interesting conclusions can be made from observation of Figure 5. For the cases examined, ground loop length reduction is not possible until the ratio of total annual house cooling to total annual house heating exceeds about 1.25 to 1.30. For the Boston and Seattle cases, about double the amount of ground loop would be required to handle the swimming pool heating loads. For the cooling-dominated cases (Charlotte, Dallas, and Los Angeles), up to about 15% ground loop reduction was possible for covered pools. However, there appears to be an optimum balance point of pool heating load and ground loop length reduction as seen by the uncovered pool cases. For the Dallas case, an uncovered pool resulted in an additional 5% ground loop length reduction but no significant change was observed for the Los Angeles and Charlotte cases. For the Los Angeles and Charlotte cases, the additional heat to the pool began driving these cases to become heating-dominated. Therefore, the optimal situation for pool heating in warm climates would involve some schedule of covering and uncovering the pool.

Figure 5 could be used during the planning stages of choosing a swimming pool heating system. **It should not be used to replace a detailed design and analysis**. As an example use of Figure 5, consider a home where the ratio of total annual cooling to total annual heating is 2. Enter Figure 5 at $(x,y) = (2,2)$ (i.e., no pool heating). The pool heating loads would be computed separately, but values in Figure 4 could provide estimates scaled for various pool sizes. The annual pool heating loads are then added to the total house heating loads to compute a new ratio on the *y-axis*. A reduction in ground loop length could then be estimated.

## ECONOMIC ANALYSIS

A simple economic analysis was conducted to evaluate the feasibility of incorporating swimming pool heating into a GHP system. The following cost assumptions were used in the analysis:

C Ground loop installation costs are widely variable across the U.S. An average cost of \$8/ft (\$26/m) of vertical bore was assumed.

C Water-to-water heat pump costs were estimated at \$1000/ton (\$3516/kW) of nominal capacity

C Electricity cost rate was \$0.10 per kWh.

C The alternative pool heating mechanism was assumed to be a natural gas-fired pool heater. Costs were taken from R.S. Means Mechanical Cost Data. Natural gas prices were taken as \$0.85/therm (\$0.30/m$^3$).

Results of the economic analysis are presented in Figure 6 in the form of simple cumulative annual cash flows. For the "Geothermal Heat Pump" cases, first costs include the differential cost of the ground loop (either positive or negative) with respect to the base case and the heat pump and heat exchanger equipment. For the "Natural Gas" cases, first costs include the cost of the gas-fired heater. Annual costs include the fuel costs only.

A review of Figure 6a (for the Denver case) clearly shows that it is not economically justifiable to use a GHP system for pool heating in heating-dominated climates. With the additional cost of the ground loop and heat pump, the simple payback period is unacceptably long, on the order of 30+ years. For a more balanced climate such as the Charlotte case, the payback period is more acceptable, on the order of 5 years. For the cooling-dominated cases (Dallas and Los Angeles) the ground loop cost savings more than pays for the water-to-water heat pump and the payback period is immediate.

## CONCLUDING SUMMARY

This study has examined the feasibility of swimming pool heating with geothermal heat pump systems in residential applications. Space heating, cooling, and outdoor swimming

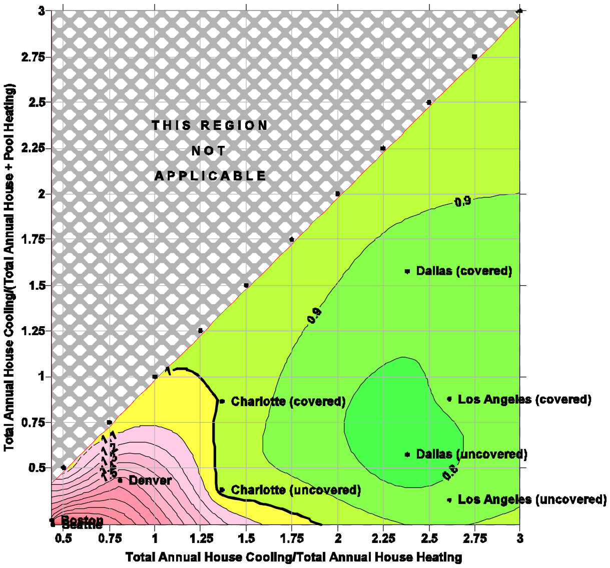


*Figure 5.* ***Contour plot showing relative changes in ground loop size as a function of total annual building loads and total annual pool heating loads. "Uncovered" refers to an uncovered pool. Boston, Denver and Seattle pools are covered.***

pool heating loads were computed for a residential building in six varying climates across the U.S. A vertical-bore ground-loop field was sized for each case with and without the pool.

The results of this study show that ground loop lengths may be reduced by up to about 20% in southern U.S. climates with the addition of a pool. However, required ground loop length may need to be doubled in northern U.S. climates. A contour plot was presented showing the potential reduction in ground loop size as a function of the total annual heating load for the building, total annual cooling load for the building, and total annual heating load for the swimming pool. A simple economic analysis showed that it would not be feasible to incorporate a swimming pool into a GHP system in northern U.S. climates due to the extra ground loop required. On the contrary, immediate savings could be realized in southern U.S. climates.

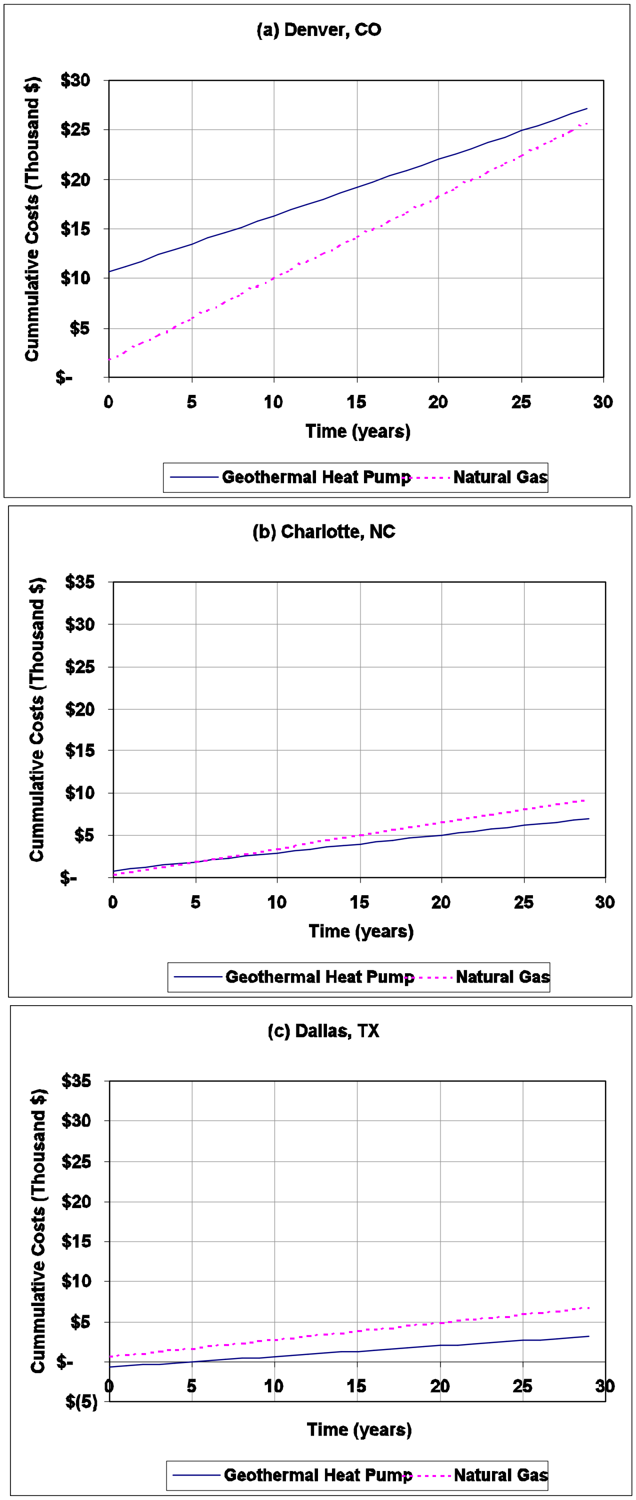


*Figure 6.* ***Cumulative annual cash flow for three example cases.***

# FISH REARING PONDS CASCADED FROM BINARY POWER GENERATION

**Gene Culver**
**Geo-Heat Center**

This article presents result of an investigation into heating fish ponds using geothermal effluent from a binary power generation plant. The investigation was the result of an inquiry to the Geo-Heat Center and is based on a particular location–but should be applicable to any location with similar climate–with appropriate modifications.

## GIVEN INFORMATION

4,000 gpm of 205°F geothermal effluent available (not suitable for fish habitat).

| | |
|---|---|
| Minimum temperature | -30°F |
| Coldest month average temp. | 20.6°F |
| Coldest month average wind | 10 mph |

4 ponds, 30 ft x 90 ft x 4 ft average depth
Desired temp. 70-75°F
Ponds plastic lined to prevent seepage with sand on plastic
Approximately 2 acres of fire suppression ponds available as bio-filter and source of oxygenated water adjacent to fish pond site
25% of fish pond volume exchange with fire pond water per week

Heating design assumptions, 0°F, 10 mph wind

Calculated heat loads:

| | |
|---|---|
| Evaporation | 440,850 Btu/hr/pond |
| Convection | 384,910 |
| Radiation | 15,470 |
| Total | 841,230 x 4 = 3,365,920 Btu/hr |

Makeup water @ 25%/wk is a bit more than evaporation at design heating conditions–and a bit less than evaporation during summer months.

The proposer presented the idea of heating the ponds by flowing the 205°F geothermal effluent through steel pipes on the pond bottoms or resting the pipes on cement blocks. After some thought, it was proposed that:

1. Pipes on the bottom would not transfer heat effectively; since, they would likely be partially buried and there would be no water circulation around them. Also, they may rapidly deteriorate the plastic liners; unless, there was considerable depth of sand.
2. Pipes on blocks would promote heat transfer but present problems in harvest using sein nets.
3. In both 1 and 2, water near the pipes would be much too hot for the fish, and with only natural convection, there may be cold spots–promoting crowding in the desired temperature zones. Also, the hot pipes would present a danger to workers during the occasional need to wade in the pond for husbandry purposes.
4. A recirculating system utilizing a heat exchanger to supply relatively hot water to one end of the pond with return at the other would also result in a temperature gradient promoting crowding. Supplying warm water closer to fishes desired temperature would require larger more expensive heat exchanger and/or increased flow rates requiring larger more expensive pumps and higher operating costs.

The final proposed system was patterned after ponds successfully used to grow prawns, mosquito fish and rainbow trout some 20 years ago at Oregon Institute of Technology. That system used 135°F geothermal effluent cascaded from one of the campus buildings in the ponds; since, the chemistry was suitable for the animals.

A proposed schematic for the system is shown in Figure 1. The pumps, controls and heat exchanger could all be located in a small shelter near the ponds.

Geothermal effluent from the power plant is teed off from an existing pipeline between the power plant and injection well. Peak flow would be 55 gpm. Geothermal enters the heat exchanger at 205°F and exits at 76°F at peak load conditions. Pressure drop is 0.98 psi. Fluid chemistry dictates titanium plates in the exchanger. Steel or FRP piping will be required on the geothermal side of the exchanger.

PVC piping was proposed for the fish pond side of the system; where, the supply side is at 135°F. Although PVC pressure rating is reduced at elevated temperature, at 135°F it has 0.26 of its pressure rating at 73°F or 55 psi in sizes up to 4 inches. Proposed maximum pressure is 15-20 psi.

From pump #1, 108 gpm of about 70°F water flows through the heat exchanger and is heated to 135°F, then through an adjustable pressure limiting valve, and to the distribution and diffusion piping. Distribution and diffuser piping are 2-in. PVC. (More about diffuser hole size and spacing later.) Pond level is controlled by 4-in. screened

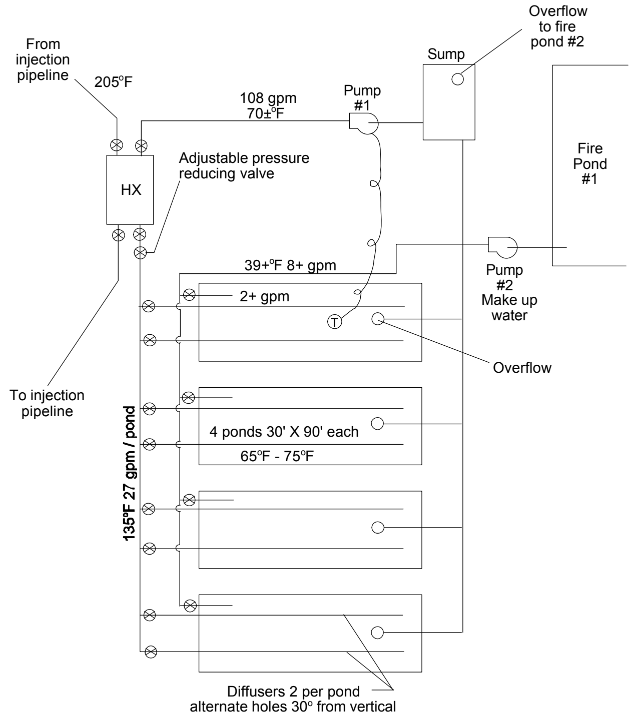


***Figure 1.   Pond layout.***

overflow pipes set at the appropriate level and connected to a sump via underground PVC. Over flow from the sump goes to a fire pond. Pressure drop across this side of the exchanger is 3.7 psi.

Makeup water is supplied by pump #2 at a minimum of 8 gpm (2 gpm per pond) as required for bio-filtering. Manual balancing valves permit adjusting each pond's flow. During summer, this must be increased to allow for higher evaporation rates.

Geothermal fluid flow through the heat exchanger is continuous; although, it can be controlled manually by one of the isolation valves. Pond temperature is sensed in one or more of the ponds, and controlled by turning pump #1 on or off. Some experimentation may be required to find the best location for the sensor. Alternatively, each pond could be controlled by a temperature sensor and a solenoid valve at each pond (not shown). When ponds are at temperature and all solenoid valves closed, a pressure switch at the pump would turn it off and on again, when one or more solenoid valves opened.

Flow through the holes in a diffuser pipe is somewhere between the flow through a short pipe connecting two tanks with unequal fluid levels and a square edged thick plate orifice. The general equation is of the form:

$$Q = C_D A\sqrt{2g P_1 - P_2}$$

where, $C_D$ is an experimental-derived coefficient of discharge ranging from 0.61 for the tanks to about 0.80 for the orifice. Not finding a good reference for the value of $C_D$ in this configuration and remembering that the people who made OIT's diffusers 20 years ago made several trial runs before they arrived at the proper size, it was decided to experimentally determine some flows versus pressure and hole diameter. The experimental setup is shown in Figure 2. The results are shown graphically in Figure 3.

For instance, results indicate that at 12 psi at the pressure valve and allowing for 2 psi loss in piping, 0.607 gpm will flow through a 3/32-dia. Hole, requiring 23 holes per diffuser pipe to supply 27 gpm per pond at peak load. At 3-ft hole spacing, 69 ft of diffuser is required. Other combinations of pressure and hole size result in other numbers of holes and spacing.

A caveat: when drilling small holes by hand in soft materials, the holes are almost invariably larger than the drill size. Our $C_D$ values based on the equation above were 0.72-0.73.

## MAJOR COMPONENT COSTS

| | |
|---|---:|
| Heat exchanger | $5,640 |
| Pump #1 4-hp | 780 |
| Pump #2 ½-hp | 150 |
| Pressure control valve | 450 |
| PVC 2-in, 1,000 ft | 310 |
| PVC 4-in., 250 ft | 280 |
| 8 2-in. PVC valves | 200 |

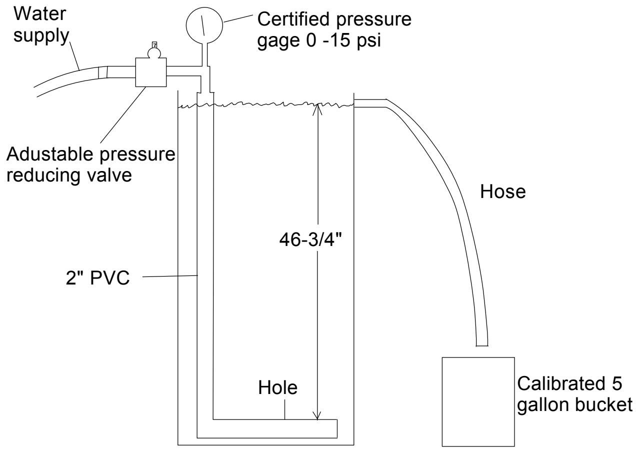


***Figure 2.   Experiment setup.***

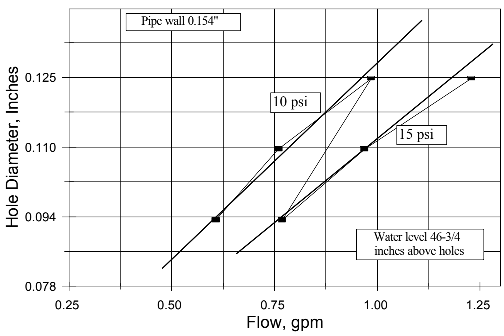


***Figure 3.   Experiment results.***

# DESIGN AND INSTALLATION OF A NEW DOWNHOLE HEAT EXCHANGER FOR DIRECT-USE SPACE HEATING

**Andrew Chiasson, P.E.**
**Geo-Heat Center**

## INTRODUCTION

The downhole heat exchanger (DHE) is used extensively in Klamath Falls, OR, in over 500 installations to provide space heating and domestic hot water from a single well. The most common construction of DHEs is black iron pipe due to its low cost and relative ease of installation. Several DHE materials of construction have been tried throughout their history, (see article by G. Culver, this issue) but a low-cost, maintenance-free DHE has been elusive.

Steel DHEs exhibit failure due to corrosion, usually at the air-water interface in the well. A 1974 study of DHEs in Klamath Falls (Culver, et al., 1974) revealed that the lifetime of a DHE in Klamath Falls at that time ranged from between 5 and 22 years, with an average lifetime of 14.1 years. DHEs in artesian wells were found to last longer, about 30 years. Based on some recent experiences in Klamath Falls, some DHEs experience failure due to corrosion in less than two years. With the cost of black iron pipe approximately doubling in the past few years and the continued uncertainty in predicting DHE lifetime, it still remains desirable to find alternatives to steel DHEs. This article describes the installation of a DHE made of cross-linked polyethylene (PEX) plastic.

## BACKGROUND OF THE PROJECT

A black iron DHE at a 1,500-ft$^2$ (140-m$^2$) residence in Klamath Falls failed in October 2004 due to corrosion (Figure 1). The homeowner reported that the DHE had just been replaced 1.5 years prior. Corrosion of the steel had resulted in the formation of pinholes in the pipe and subsequent excessive leakage of municipal water into the well (municipal water is typically tied into DHE's with a pressure-regulating valve to provide operating pressure to the system). The length of the steel DHE was 160 ft (48.7 m) with a nominal diameter of 1½ in. (38 mm).

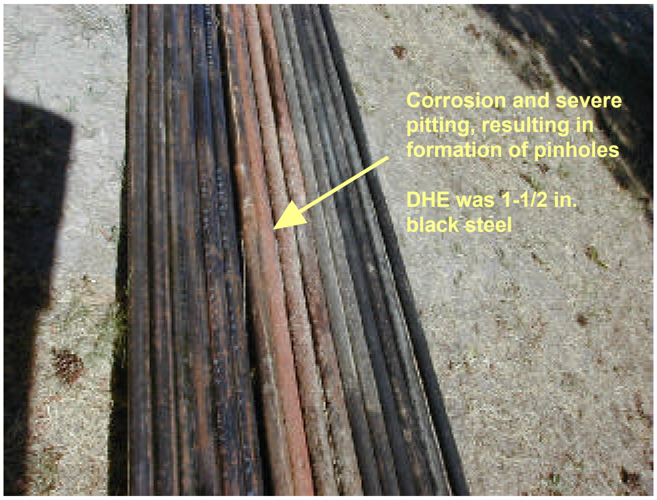


*Figure 1. Corrosion o the DHE resulting in the formation of severe pitting and pin holes.*

A review of existing information on the well revealed that there was no well log or driller's report. The Geo-Heat Center had been involved with various studies on this particular well since the 1970s and there was anecdotal information that the well was probably installed in the 1940s or 1950s. The well has an 8-in. (203-mm) nominal diameter steel surface casing, which is believed to extend to only about 15 ft (4.6 m) below grade. Figure 2 shows one of the several temperature measurement profiles taken on this well. The average well water temperature at the time of measurement, as shown in Figure 2, was 205°F (96°C). Historical static water levels have consistently been about 90 ft (27.4 m) below grade and the well depth is 322 ft (98 m) below grade. Therefore, the usable (submerged) length of the old steel DHE was approximately 70 ft (21 m).

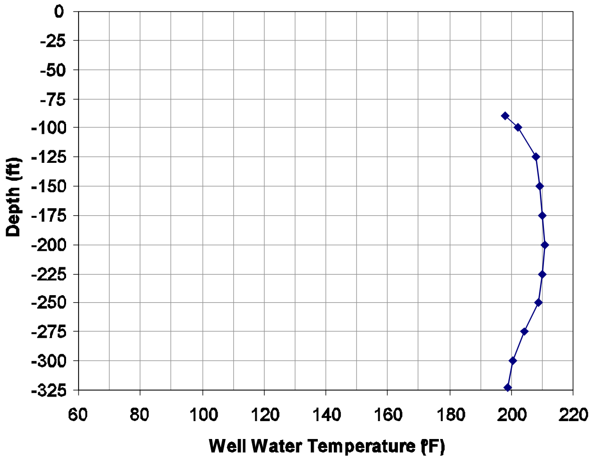


*Figure 2. Well temperature profile taken in August 1976.*

The heating system in the residence is a forced-air unit with a hot water hydronic coil (Figure 3). The air-handling unit and air supply and return ducts are installed in a crawl space. Water flows to and from the DHE in the well by natural convection (thermosyphon), so no pump is nstalled. Domestic hot water is supplied by an electric hot water tank in the house, not the geothermal well.

***Figure 3. Air-handling unit with hot water coil installed in the crawl space.***

## NEW DHE INSTALLATION

### PEX Pipe

The new DHE installed in the well is constructed of cross-linked polyethylene plastic (PEX) pipe. Polyethylene is available in different forms, depending on the molecular structure. High-density polyethylene (HDPE) is the standard pipe used in geothermal heat pump systems and is color-coded black. Yellow HDPE pipe is being used to replace steel piping in natural gas pipelines. PEX pipe is readily available and is commonly used in radiant floor heating applications and in potable water plumbing. The "cross-linking" procedure is a chemical process that produces a long molecular chain that results in a more durable material that can withstand a wide range of pressures and temperatures.

The main reasons for choosing PEX pipe is it's temperature rating, durability and chemical resistance. A manufacturer of PEX pipe reports that an independent laboratory in Sweden has subjected a test sample of PEX to a temperature of 203°F (95°C) and pressure of 152 pounds per square inch (psi) (1048 kPa) since 1973. PEX pipe is rated at 100 psi (689 kPa) at 180°F (82°C) and 80 psi (552 kPa) at 200°F (93°C). HDPE pipe, for the sake of comparison, is only rated up to 140°F (60°C).

PEX tubing is available with an oxygen diffusion barrier to prevent corrosion of metal parts of the system. As this installation was a retrofit with metal components remaining in the system, we used PEX with an oxygen barrier as conservative measure.

### Design and Assembly of the DHE

The two main design parameters controlling the PEX DHE sizing included length and diameter of the pipe. The length is the most important parameter affecting the overall heat extraction rate from the well. The pipe diameter was sized to make sure that the pressure drop was similar to that of the previous system, which was known to thermosyphon without difficulty and provide adequate heat to the home.

Another consideration in the design of the DHE was the wellbore diameter. Prior to DHE installation, the well was reamed out and the driller reported that the hole was 8-in (203 mm) diameter to a depth of 270 ft (82 m), but then narrowed to 6-in. (152 mm). Since a 1-in. (25.4-mm) PEX u-tube assembly is about 5.75 in. (146 mm) in overall diameter, it was deemed too risky to attempt to push it into a 6-in. (152-mm) diameter hole. Based on heat loss calculations for the home and thermal properties of the PEX pipe, it was determined that two loops of 180 ft (*270 ft of 8-in. hole - 90 ft static water level = 180 ft submerged*), 1-in. nominal diameter, would be more than adequate to provide heat to the home.

Details of the design procedure will be forthcoming in a future paper, but a brief discussion is presented here. For a DHE, the heat extraction rate (*q*) per unit length of pipe is simplified as:

$$q = \frac{1}{R}\left(T_{in} - T_{out}\right) \tag{1}$$

where *q* is in units of But/hr/ft (W/m), *R* is the overall pipe thermal resistance per unit length in units of °F/(Btu/(hr-ft)) or °C/(W/m), and $T_{in}$ and $T_{out}$ are the temperatures of fluid inside and outside the pipe. Considering the heat transfer processes involved in DHEs (Figure 4), the key parameter in Equation 1 is the overall pipe resistance. This term combines the effect of internal convection, pipe wall conduction, and external convection and is given by:

$$R = \frac{1}{h_{in} 2\pi r_{in}} + \frac{\ln\left( r_{out} / r_{in} \right)}{2\pi k} + \frac{1}{h_{out} 2\pi r_{out}} \tag{2}$$

where *h* is the convection coefficient, *r* is the pipe radius, *k* is the pipe thermal conductivity, and the subscripts *in* and *out* refer to the inside and outside of the pipe. Using known values of the pipe thermal conductivity for steel and PEX and typical flow rates in DHEs as reported by Culver (1999), the overall thermal resistance is computed to be about four times greater for PEX than for steel. This means that four times the amount of 1-inch PEX DHE is required to transfer heat at the same rate as 1½-inch steel DHE.

It is interesting to note that the thermal conductivity of steel is around 30 Btu/hr-ft-°F (52 W/m-°C); while, the thermal conductivity of PEX is about 0.25 Btu/hr-ft-°F (0.43 W/m-°C). However, since the pipe thermal conductivity affects only one term in the overall thermal resistance, pipe thermal conductivity values greater than 6 Btu/hr-ft-°F (10.4 W/m-°C) have a negligible effect on the overall thermal resistance value.

Figure 5 shows photographs of the PEX DHE. The entire DHE was constructed of PEX materials, including the compression-type fittings and elbows. The compression-type fittings are unique to PEX material; the compression fitting is placed over the end of the pipe to be joined to an elbow (or other fitting) and an expansion tool is used to expand the pipe and compression fitting. The elbow (or other fitting) is quickly inserted into the pipe end, and then the pipe and compression fitting returns to its original shape via the "memory" of the plastic, resulting in an extremely tight fitting.

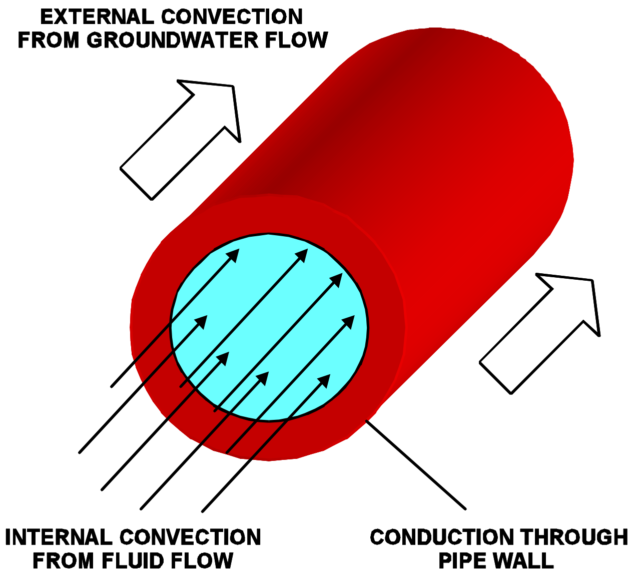


*Figure 4. Heat transfer processes in a single pipe of a DHE.*

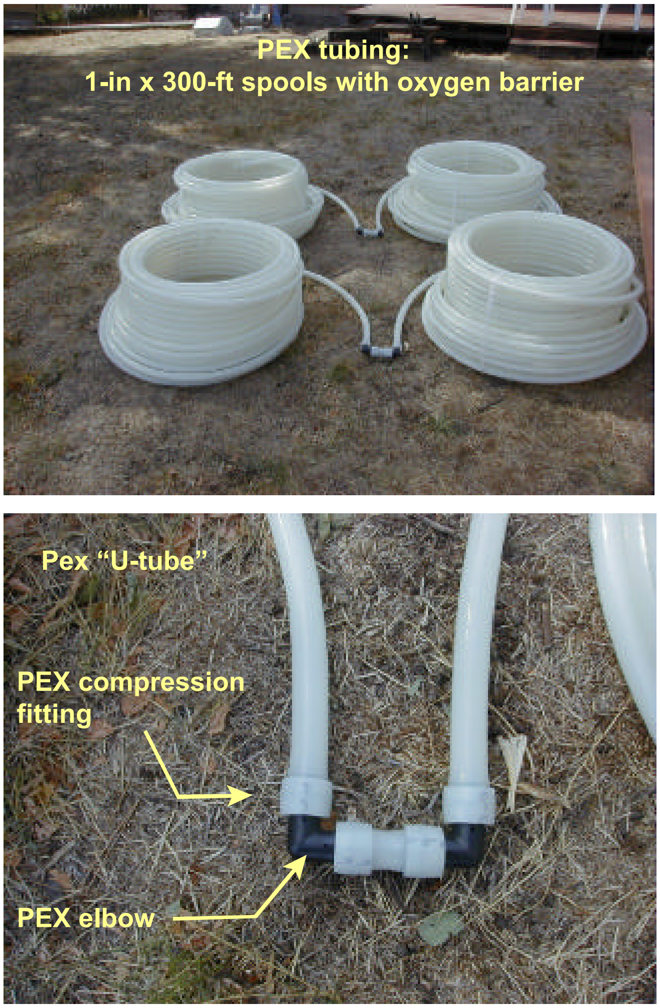


*Figure 5. PEX downhole heat exchangers prior to installation.*

A considerable portion of the design phase consisted of devising a method to easily and reliably install the DHE into the well. As it was judged doubtful that PEX U-tubes could simply be pushed into the well (especially through the water column) another scheme was necessary. It was, therefore, decided to fasten the PEX U-tubes to the leftover steel pipe from the original DHE to facilitate pushing the PEX tubing into the well. The steel pipe could then be used as an anchor for the PEX tubing, providing a means to suspend the PEX in the well without stressing the PEX under its own weight.

Another advantage of using the steel pipe as a guide and anchoring device was that it could be used as a "convection promoter" in the well. The advantages of convection promoters have been examined by Freeston and Pan (1983). Their function is essentially to provide a conduit for water to circulate within the well by natural convection, preventing the formation of stagnant cold water zones. This was done by leaving the bottom of the steel pipe open and using a tee-piece as one of the pipe couplings below the water level. A schematic of the downhole assembly is shown in Figure 6.

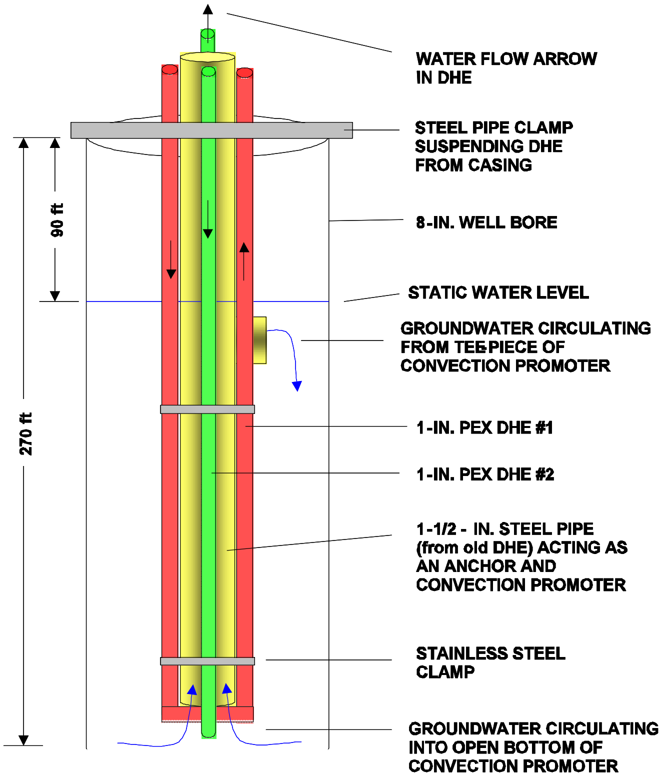


*Figure 6. Schematic of PEX assembly.*

**Installation of the DHE**

Photos of the installation procedure are shown in Figures 7 and 8, showing the process of lowering the DHE assembly into the well. The DHE was successfully installed to a depth of 252 ft (76.8 m). The entire installation process took about three hours to complete.

*Figure 7.* ***PEX DHE prio to installation, showing the two PEX U-tubes fastened to the steel pipe from the old DHE, which was used as an installation guide, anchor and convection promoter.***

*Figure 8.* ***Process of lowering the DHE assembly into the well, showing fastening of the PEX tubing to the steel pipe guide with stainless steel clamps.***

Figure 9 shows the final installation prior to enclosing the piping and instrumentation. The instrumentation consists of pressure gauges, temperature gauges, and temperature probes at four locations: inlet and outlet water in the DHE, and supply and return air in the house. The temperatures measured by the probes are recorded by a data logger at 5-min. intervals.

**Preliminary Performance Monitoring**

Performance monitoring of the PEX DHE began on October 18, 2004 and is on-going. Results of the full heating season will be the subject of a future article. So far, the lowest recorded water temperature exiting the DHE was 174.8°F (79.3°C); when, the outdoor air temperature was 7°F (-13.9°C). The supply air temperature at that time was still in excess of 125°F (51.7°C), keeping the house at 74.5°F (23.6°C). The water temperature exiting the DHE is routinely measured at 178 -180°F (81-82°C), keeping the house at 78-80°F (25.5-26.7°C). No problems have been encountered, thus far.

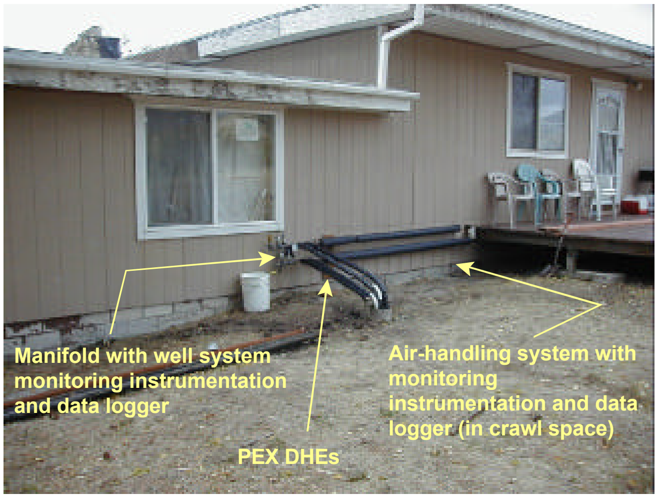


*Figure 9.* ***Final installation showing insulated piping and manifold prior to installing pipe enclosure.***

**Economics of a PEX DHE**

The ultimate success of any new DHE will be in the economics. At this preliminary stage of the project, it is beneficial to perform a simple economic analysis.

Material costs of 1½-in. black iron pipe are on the order of $3/ft, or $6/ft of DHE (since, a DHE consists of two legs). Material cost of 1-in. PEX tubing with the oxygen barrier is on the order of $2.20/ft, and the same tubing without the oxygen barrier is about $1.55/ft. Therefore, if corrodible materials are eliminated from the plumbing system, and one chooses the 1-in. PEX tubing without the oxygen barrier and uses the design described in this article (i.e., two U-tubes fastened to a 1½-in. steel guide), the DHE cost would be $9.20/ft (4 x $1.55/ft for the PEX tubing + $3/ft for a 1½-in. steel guide). Assuming quadruple the length of PEX pipe is required relative to steel, double the length of the double U-tube PEX DHE would be required.

To put these costs in perspective, consider a new DHE in a well with a 50-ft (15-m) static water level and 100 ft (30 m) of submerged steel DHE required. Using the above material costs, a 1½ -in. steel DHE would cost about $900. An equivalent double U-tube PEX DHE would cost $2300. Assumed labor costs are an additional $300 for the steel DHE and $400 for the PEX DHE. Assuming a future cost of $500 each time the steel DHE corrodes at the air-water interface in the well (i.e,. labor and material costs to replace only two 21-ft sections of corroded pipe), three episodes of this type of corrosion failure would be necessary for the PEX DHE to pay for itself. However, this does not include eventual total replacement of the steel DHE.

**Lessons Learned**

Thus far, the PEX DHE has performed better than expected. Admittedly, more tubing was installed than necessary as a conservative measure, and more refinement is needed in the design calculations.

The use of a pipe reel would have greatly expedited the installation process. Pipe reels are routinely used for installing ground loops in the geothermal heat pump industry. As these installers know, managing polyethylene tubing once it is uncoiled can be very difficult, particularly in cold weather.

The use of pipe conduit bends on the PEX tubing at the well casing top is necessary. Without these, the PEX will easily kink over the well casing, restricting flow and possibly causing a leak.

## THE FUTURE OF PEX DHEs

The future of PEX DHEs may not just lie in corrosion protection, but in a total maintenance-free DHE. It is conceivable that a PEX DHE could be installed directly in a borehole, similar to that for heat pump applications, and gravel-packed in place. This would eliminate the need for the extra "steel guide" described above and would eliminate the need for a traditional water well as in current applications. Certainly, more heat exchange length would be required for the DHE, but the extra cost may offset future maintenance items. An expensive maintenance item for geothermal well owners in Klamath Falls is the bailing of sediment and rock fragments from the well that accumulate over time. The presence of sediment around a steel DHE also accelerates corrosion. The direct-burial of PEX DHEs in vertical boreholes will be addressed in a future article.

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# A BRIEF HISTORY OF DHE MATERIALS

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**Author's Note**: Not much information is recorded about DHE materials and life times. When good references existed, they were cited. Other than those, the information herein is based on conversations with drillers, installers, homeowners and observations over some 43 years.

## KLAMATH FALLS, OREGON

The first downhole heat exchanger (DHE) in Klamath Falls, Oregon, perhaps the first in the world, was installed in 1931 by a local plumber, Charles B. "Charlie" Leib, as an experiment and as a favor to a friend. Charlie had worked as a plumber/pipe fitter in Pennsylvania, moved to Klamath Falls in 1928, and worked for a local plumbing shop. Much of his work was repairing pumps and piping, and cleaning out cast iron radiators in the geothermal systems then in use. They used the geothermal water directly in the systems at that time (Fornes, 1981).

Charlie knew from experience that hot water boilers would thermo syphon to circulate hot water in a system. He figured the geothermal resource could act as the fire in a water tube boiler or the steam in a steam-to-water tube and shell exchanger. Money was tight during the depression, so he used the cheapest materials available–black iron pipe and cast iron fittings to put a U-tube DHE in his friends artesian well. It worked. It lasted 25 years, when the well, cased only about 20 feet, caved in.

Before long DHEs were being installed in other wells and their success in reducing problems in the aboveground parts of the system led to increased drilling of the resource (Figure 1). In non-artesian wells, corrosion near the water level was the major problem; although, failures do occur at other locations (Figures 2 and 3). Non-artesian DHE life was generally on the order 10 - 15 years–in artesian wells, about twice as long.

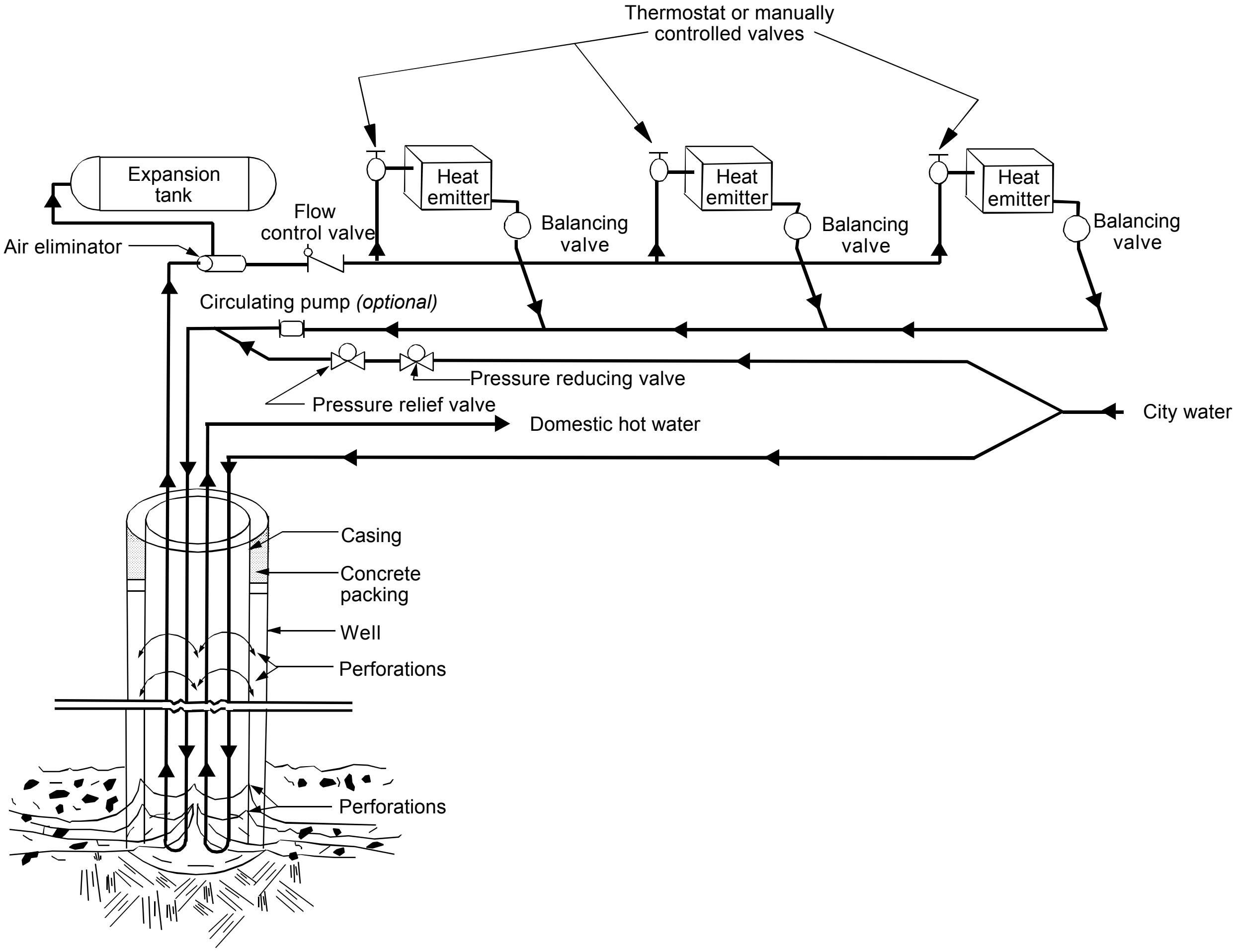

*Figure 1. Typical downhole heat exchanger system (Klamath Falls, OR).*

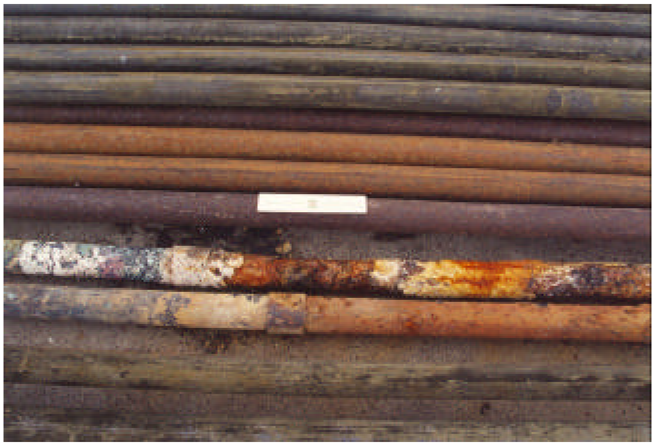

*Figure 2.* ***Corrosion and failure of a residential DHE at the air/water interface.***

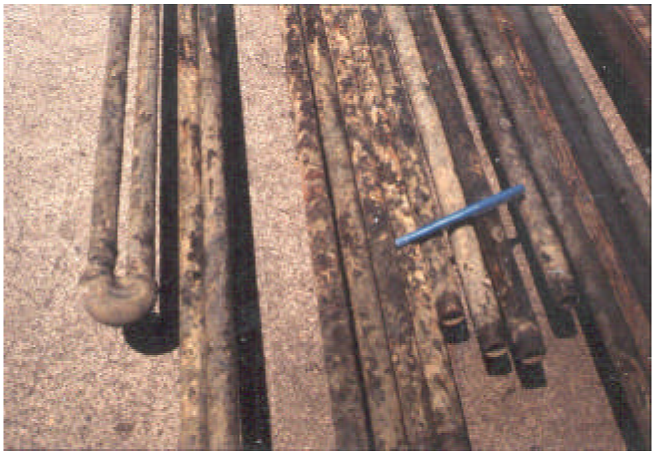

*Figure 3.* ***Corrosion and pitting of DHE replaced in 1974. Note the Reverse loop at the bottom of the heat exchanger.***

Early efforts to solve the problem included use of galvanized pipe, brass pipe at the waterline, and dumping used motor oil down the well.

Use of zinc galvanized pipe was doomed to failure. We now know that geothermal water leaches zinc and at above 135°F, the anode cathode relationship of zinc and iron reverses. Any scratches in the galvanized coating caused by handling or pipe wrench jaws during tightening, caused rapid localized pitting rather than the slower general corrosion of bare pipe. Some of the installers were aware of this and only a very few galvanized DHEs were installed.

Use of brass pipe at the water level was a bit more successful. Although, no written records are known, installers estimate in some cases, life was extended 5-10 years. The main problem was that since the resource was being more fully utilized, including wells being pumped, water levels were fluctuating–up in summer and down in winter. Since brass pipe is about 10 times as expensive as black iron, only short 10-20 ft sections were installed. Unless the installer accurately predicted water level over the future 20 years, the brass section could be above or below the water level much of the time.

In one well, what appeared to be the tubes and header of a U-tube and shell exchanger had been used as a DHE. A well driller had been called in to replace a DHE. The black iron DHE had been pulled and the well was being bailed to clean out, when the object was encountered. It was fished out in good condition except for fishing damage. It appeared to be yellow brass or naval bronze tubes and header, 7-in. diameter and 8 ft long with four U-tubes. It appeared to have been hung on black iron pipes which had corroded where it was attached due to dissimilar metals. None of the local drillers or DHE installers knew about it; so, how long it was in service or laid on the well bottom, remains a mystery.

Because DHEs in capped artesian wells had about double the life of those with water levels below ground surface, it was summarize that water vapor was the culprit. Used motor oil, which would float on the surface and reduce vaporization, was dumped down wells. It was also believed that the oil would creep up the pipes some distance preventing water vapor contact. The practice was prohibited by state water resource rule; since, it contaminated the resource and some people were drinking, washing dishes and clothes, bathing and using it in swimming pools. There was also the potential for mixing with public water supply aquifers. Paraffin was substituted in many cases, but the practice probably continued in others.

In 1990, Swisher and Wright published results of experiments that showed that paraffin did in fact reduce corrosion above the water surface by a factor of a bit less than three - **but** - corrosion rate just above and below the surface was still unacceptable. The also showed that fairly rigorous exclusion of air reduced corrosion rate from 500 micro-meters per year, down to about 10 micro-meters per year, a factor of 50. Their recommendation, after the DHE is installed, was to seal the wellhead. Any oxygen in the well will be used fairly quickly and corrosion will cease (Swisher and Wright, 1990). This has been done on several wells by welding a cap or use of closed cell foam-in-place insulation material. We'll have the real results in 15 - 20 years–or when the well owners agree to inspecting their DHE.

All of the above failed to address the problem of corrosion well below the water level. This typically occurs at the very bottom of the DHE or where the DHE either contacts or is very near the well wall. It appears to be more pronounced in wells only partially cased. Wells are rarely drilled perfectly straight. DHEs never hang perfectly straight because of slight differences in pipe length, coupling tightening and the fact that the hot leg thermally expands more than the cold leg. One leg usually spirals around the other.

This type of corrosion is believed to be at least partially caused by stray induced electrical currents. Just how these are induced is unknown. Currents of several milliamps were measured between the DHE and a grounding rod at several residences with shorter than normal DHE life. In one case, over 30 milliamps were measured. This was traced to a faulty refrigerator with the electrical system grounded to water pipes–a common practice in older homes.

In an attempt to solve the problem of stray electrical currents supposedly accelerating the corrosion of DHE, an experiment with isolation junctions and a sacrifical electrode was tried (Newcombe, 1976). The thought was that commercially available unions using steel-on-neoprene could be used to electrically isolate the pipes suspended in the well from the residence. These unions can be installed at the top of the well in place of standard unions to couple the suspended hairpin loop to the pipes leading to the residence. In addition, any stray current originating in the well plumbing itself can be negated or rendered harmless when a sacrifical anode is attached to the suspended well pipes needing a cathodic protection. The anode is a preparation of sacrifical metals and chemical which, when wet and buried in the ground, forms a cell ("battery') causing a small current to flow from the pipes through the attached wire to the anode and, hence to ground. Normal current flow is thereby reversed. Commercial anodes which are sacrificed need to be periodically replaced– perhaps every five years. Cathodic protection generally can be installed on any existing well pipe without removing the pipe from the well. A rule of thumb is: "2 milliamperes of negative current is required to protect each square foot of surface pipe exposed to water." Very deep wells would require special consideration in that the bottom section receives less protective current.

The one well that we are aware of, that used the sacrificial electrode, had poor results in that the DHE failed again in a short period. Unfortunately, there is no documentation of the installation or results, thus the procedure is questioned and needs to be investigated further. Insulating unions in piping between the building and DHE at the wellhead and good connection (i.e., tack weld at DHE to casing) seems to reduce the problem.

One solution tried by a Klamath Falls homeowner was X-Tru-Coat. He installed it himself. X-Tru-Coat is a thin wall, black iron pipe coated with mastic, then with an extruded polyethylene cover. It was used as underground natural gas pipe. Polyethylene becomes very soft and the plasticizer migrates out at about 150°F causing brittleness and cracking. The DHE life was only a few years.

The formation of scale on DHEs forms a protective coating. The Langlier Saturation Index, a measure of water's tendency for scale deposition, ranged from +0.02 to 0.75 in Klamath Falls geothermal fluids. Non-artesian, with an index of +0.02, had a repair frequency of five years, wells with index between +0.45 and +0.75 repair frequency of 10 to 20 years. Artesian wells with index of +0.75 had lives between 29 and 34 years (Culver, 1974).

Inspection of DHEs after removal sometimes reveals long deeply corroded lines with little or no scale along one side of the DHE. Presumably, this is where a DHE lies against the well wall or casing and movement due to thermal expansion and contraction scrapes off the scale exposing fresh material for corrosion.

Today, there are over 500 geothermal wells in Klamath Falls, most have DHEs. Many of the old artesian wells that used geothermal water directly in the system have been converted to DHEs because of a city ordinance requiring injection of used water and the cost of a second well.

The latest innovation is an experiment by the Geo-Heat Center using PEX (cross-linked polyethylene) installed in October 2004. (See article by Andrew Chiasson in this issue of the *Bulletin*.)

## RENO, NEVADA

The first DHE in the Moana area of Reno, Nevada, was installed in 1950 in a 167°F, 850-ft deep well. The material was a 2-in. copper pipe U-tube (locally called a trombone). Moana area geothermal water generally has less than 1,000 ppm total dissolved solids, pH 8.2, with 0.2 ppm $H_2S$ (Bateman and Scheibach, 1975 ). This is quite similar to Klamath Falls geothermal water.

Only anecdotal estimates of the life of the copper DHEs is available. These range from 3 to 6 years average life with none lasting as long as 10 years. Based on the life of copper components in contact with similar geothermal water in other applications, this seems reasonable. Considering the homes were large, over 3000 sq ft, many had swimming pools heated and snow melt systems, and the cost of DHE repair compared to conventional fuel cost was not a great concern. Copper continued to be the material of choice until the mid-to-late 1970s.

The increasing cost of conventional fuel and especially the federal residential energy tax credit program combined with growth of the Reno area, prompted a greater than 4-fold increase in the number of homes using geothermal between 1975 and 1996 (Flynn, 2001). This, of course, increased the desire for longer life DHEs.

The first change was to substitute black iron pipe for the copper in the upper portion of the well with a copper tube helix in the lower hotter portion.

This reduced the initial cost, but not the repair frequency of the copper portion. Next, the entire U-tube was replaced with black iron pipe, which reportedly increased DHE life to about 10 years.

In about 1980, non-metallic U-tubes were installed, including polyethylene in a few lower temperature wells, as well as, polybutylene and CPVC (chlorinated polyvinyl chloride). All of these materials have reduced pressure ratings at elevated temperatures. Polyethylene's maximum temperature is 140°F; where, it has a pressure rating of 0.2 of the rating at 73°F. Polybutylene is similarly rated at 160°F. Even CPVC which has a maximum temperature rating of 210°F is derated to 46 psi at 200°F. This means that if the static water level exceeds 106 ft, its rating would be exceeded at 200°F. Some of the well bottom hole temperature exceeds 215°F. These materials are also subject to long-term creep, especially at elevated temperature, which could cause bursting.

In 1981, 1982 and perhaps 1983, fiberglass epoxy pipes were tried. This product was similar to its metal counterpart in that it had machine cut threads on the pipe and in the fiberglass epoxy couplings. It has seen extensive satisfactory use in aboveground and shallow burial in corrosive soils carrying hot brines in oil fields at temperatures above any encountered at Moana.

After a short time, many failures occurred, always at or very close to the couplings. This was attributed to water vapor entering the cut fiberglass fibers; so, the threads were epoxy coated similar to doping metal pipe threads and with an epoxy coating after make up. Failures still occurred. The final determination was that, in wells with low water levels, the threads were subjected to tensile stresses not present in aboveground use; where, stress was compressive due to pressure and thermal expansion. Happily, the manufacturers warranted the pipe, including labor.

In some wells, those with higher water levels, the pipe is still in service after 25 years. So far as is known, no one has attempted to determine the maximum depth to water for satisfactory service life.

The well drilling company doing most of the DHE business in Moana is now recommending threaded and coupled 304 stainless steel. Currently, SST is about $10 per ft for 1-½ in.–about three times the cost of black iron, but less than brass and some non-metallics.

Today, there are an estimated 250 geothermal wells in the Moana area of Reno, NV. Most of these have DHEs–many of which are pumped with small submersible pumps to increase temperatures. Nevada regulations prohibit pumping except when an injection well is utilized. No new wells have been drilled in the area in the last 10 years (Flynn, 2001).

## NEW ZEALAND

The only other concentrated DHE use is in New Zealand at Taupo and Rotorura. There were about 500 geothermal wells in use in Taupo in 1987, about half utilizing DHEs (Curtis, 1988). Most wells in Rotorura historically were discharged to the surface. In 1985, the Geothermal Task Force recommended discharge be stopped an DHEs installed. Most wells were shut in and only less than a dozen DHEs were in use in Rotorura in 1990.

Well boreholes will not stand open in the softer formations; so, the convection flow outside the casing is not possible. Wells are equipped with a convection promoter (Figure 4) with the DHE either inside or outside the promoter–but the corrosion problems are the same–at the water level. As far as is known, black iron pipe is the only material used for the DHEs–the rigorous exclusion of air by sealing the top.

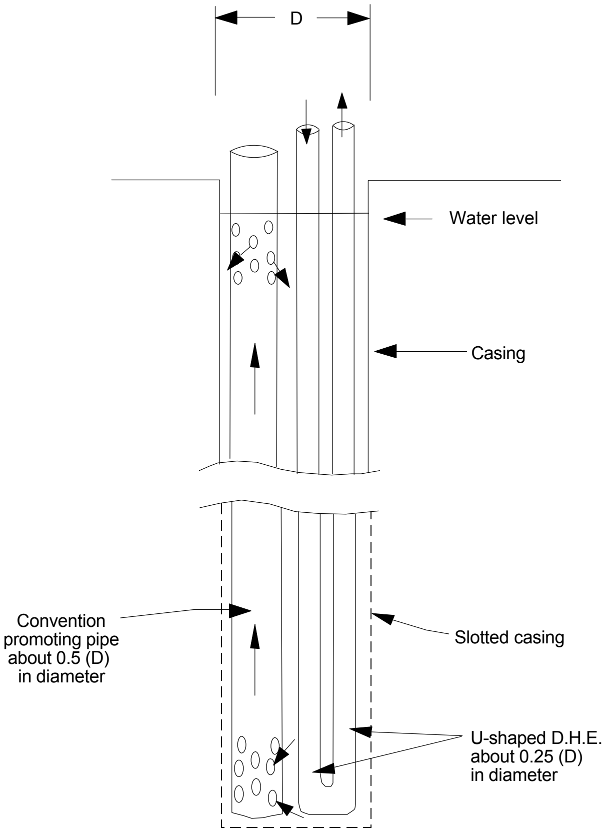

***Figure 4. Convection promoter and DHE (New Zealand type).***

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# GEOTHERMAL WEBSITES

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The Internet has become such an important part of our every day life. It can be used to correspond with people across the world, a lot faster than to send a letter in the mail. The Internet has a wealth of information that is available to anybody just by searching for it. Sometimes you get more information than you ever wanted to know and sometimes you can't find any information.

This shows only a small portion of the websites and their links that have a variety of geothermal information. Some of the websites below are located in the U.S.; others, international, including, geothermal associations, and websites where you can access publications. Most of the websites listed below also have links to other websites for even more information. A more complete paper with more information on the websites can be found in the *Stanford 30th Workshop Proceedings (2005).*

## GENERAL

Stanford Geothermal Program
http://ekofisk.stanford.edu/geotherm.html

Geo-Heat Center
http://geoheat.oit.edu

Geothermal Resources Council
http://www.geothermal.org/index.html

International Geothermal Association
http://iga.igg.cnr.it/index.php

World Geothermal Congress 2005
http://www.wgc2005.org

Energy & Geoscience Institute - University of Utah
http://egi-geothermal.org/

Southern Methodist University Geothermal Laboratory
http://www.smu.edu/geothermal/

The Global Heat Flow Database of the International Heat Flow Commission
http://www.heatflow.und.edu/index2.html

Department of Energy - Geothermal Energy Program
http://www.eere.energy.gov/geothermal

National Renewable Energy Laboratory (NREL) Geothermal Technologies Program
http://www.nrel.gov/geothermal/

Department of Energy - Geothermal Energy Technical Site
http://geothermal.id.doe.gov/

Sandia National Lab
http://www.sandia.gov/geothermal/

Geothermal Energy Association
http://www.geo-energy.org

Geothermal-biz.com
http://www.geothermal-biz.com/home.htm

The United Nations University - Geothermal Training Programme
http://www.os.is/page/unugtp

European Geothermal Energy council EGEC
http://www.geothermie.de/egec_geothernet/menu/frameset.htm

Great Basin Center for Geothermal Energy
http://www.unr.edu/geothermal

California Energy Commission
http://www.energy.ca.gov

California Department of Conservation Division of Oil, Gas and Geothermal Resources
http://www.consrv.ca.gov/DOG/index.htm

New Energy and Industrial Technology Development Organization (NEDO) - Geothermal Energy Development Department
http://www.nedo.go.jp/chinetsu/indexe.htm

CADDET
http://www.caddet.co.uk/html/geo.htm

International District Energy Association
http://www.districtenergy.org/

Washington State University Energy Program
http://www.energy.wsu.edu/projects/renewables/geothermal.cfm

## HOT DRY ROCK

Swiss Deep Heat Mining Project
http://www.dhm.ch/dhm.html

European HDR project, Soultz-sous-Forets, France
http://www.soultz.net/

Stadtwerke Bad Urach (German)
http://www.geothermie.de/bad_urach.htm

**PUBLICATIONS ONLINE**

Geopubs USGS Western Region Geologic Publications
http://geopubs.wr.usgs.gov/

USGS Open-File Report 99-425 Geothermal Industry Temperature Profiles from the Great Basin
http://wrgis.wr.usgs.gov/open-file/of99-425/webmaps/home.html

Geothermics
http://www.elsevier.com/locate/geothermics

DOE's Scientific and Technical Information - Information Bridge
http://www.osti.gov/bridge/

Office of Scientific and Technical Information - Geothermal Energy Technology
http://www.osti.gov/get/gethome.html

Proceedings for Multiple Integrated Uses of Geothermal Resources - International Geothermal Conference - 2003
http://www.jardhitafelag.is/igc/nytt/

**WEBSITES WITH PICTURES OR SLIDES**

Geothermal Education Office
http://geothermal.marin.org/

National Renewable Energy Laboratory - Photographic Information Exchange
http://www.nrel.gov/data/pix/

**HEAT PUMP WEBSITES**

Geothermal Heat Pump Consortium
http://www.geoexchange.org/

International Ground Source Heat Pump Association
http://www.igshpa.okstate.edu/

European Heat Pump Association
http://www.ehpa.org

GeoCool Lab - Department of Mechanical Engineering - University of Alabama
http://bama.ua.edu/~geocool/

Earth Energy Society of Canada, Ground Source Heat Pumps
http://www.earthenergy.ca/

The IEA Heat Pump Centre (HPC)
http://www.heatpumpcentre.org/