

EXAMPLES OF INDIVIDUAL DOWNHOLE HEAT EXCHANGERS SYSTEMS IN KLAMATH FALLS

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INTRODUCTION

The downhole heat exchanger (DHE), used extensively in Klamath Falls in over 500 installations, provides heating for one or more homes from a single geothermal well. The DHE eliminates the problem of disposal for geothermal fluids, since only heat is taken from the well. The heat exchanger consists of a loop of pipe or tubes (locally called a coil) suspended in the geothermal well through which "clean" secondary city water is pumped or allowed to circulate by natural convection. These systems offer substantial economic savings over surface heat exchangers where a single-well system is adequate. The maximum output of large installations is typically less than 2.73×10^6 Btu/hr (2.88×10^6 kJ/hr) or 0.8 MWt, with well depths up to about 500 feet (150 m), and may be economical under certain conditions at well depths of 1500 feet (450 m). However, typical DHE output for individual homes tends to be less than 250,000 Btu/hr (260,000 kJ/hr) or 0.07 MWt.

In order to obtain maximum output, the well must be designed to have an open annulus between the well bore and the casing, and perforations above and below the heat exchanger surface - just below the water surface and at the hot aquifer. The cross-sectional area of the annulus and the casing should be about equal, with the area of the perforations twice this area. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing, through the upper perforations, with new geothermal water mixing with the old (Fig. 1).

If the design parameters of the bore diameter, casing diameter, heat exchanger length, tube diameter, number of loops, flow rates and inlet temperature are carefully selected, the velocity and mass flow of the natural convection cell in the well may approach those of a conventional shell-and-tube heat exchanger. Based on experience, local heating system contractors estimate approximately 1 foot of DHE pipe per

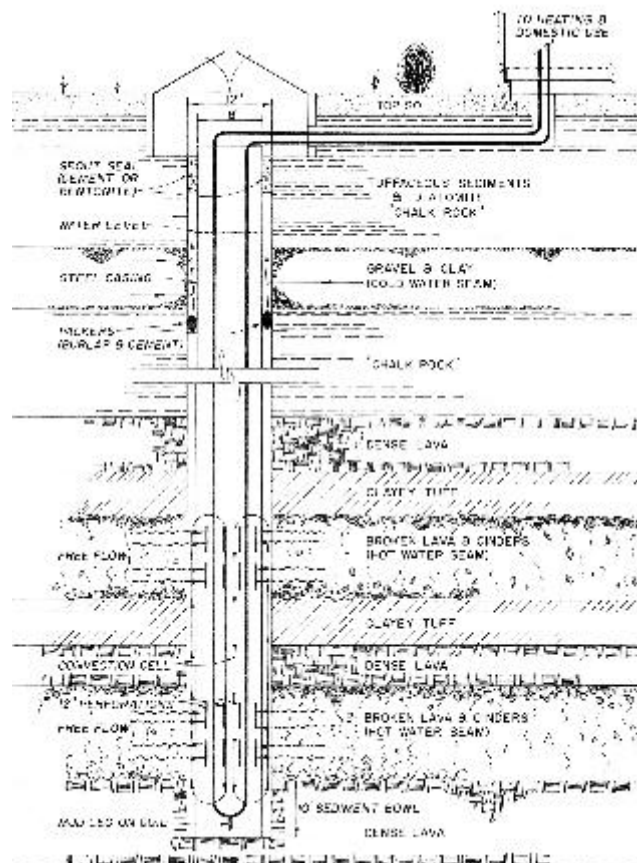


Figure 1. Typical downhole heat exchanger (DHE) installation.

1,500 Btu/hr (1.4 kW/m) as an average output. Thermo-syphon circulation will provide 3 to 5 psi (0.2 to 0.35 bar) pressure difference in the supply and return lines to circulate 15 to 25 gpm (0.9 to 1.6 L/s), with a 10 to 20°F (6 to 11°C) temperature change. Circulation pumps are required in cooler wells or in larger systems to increase the flow rate and system heat output.

The following description are of two systems in Klamath Falls, illustrating a basic installation and a more complex one. Both installations, located in the “Hot Springs” area of the city, have a well that supplies heat to two homes, but the design would be similar for just one home using the well.

BASIC INSTALLATION

This basic installation uses a well to provide heating for two adjacent homes using three DHEs. The well is 200 feet (60 m) deep, a temperature of 196° F (91°C) at the top, 204°F (96°C) at the bottom, and a static water level of 75 feet (23 m) below the casing top. It was drilled in 1954 and cased to the bottom with a 10-inch (25-cm) diameter casing. The casing is torch perforated just below the water surface and at the bottom of the well in the live water area. The perforations are about 0.5 inches (1.2 cm) wide and 6 inches (15 cm) long for a total distance of about 15 feet (4.6 m). The casing is sealed with cement from the surface down to 21 feet (6.4 m), and then the annulus is open below this point providing about a 1-inch (2.5-cm) clearance.

Originally there were four heat exchangers in the well, two 2-inch (5-cm) diameter closed-loop pipes for space heating and two 3/4-inch (2-cm) diameter open loop pipes for domestic hot water heating - one set for each home. After 19 years of service, the black iron pipe DHEs were replaced due to corrosion at the water line. The two 2-inch (5-cm) diameter heating pipes were replaced with a single 2.5-inch (6.4-cm) diameter heating loop which is now shared by both homes. The present configuration is shown in Figure 2. Several pounds of paraffin, place in the well annually, were used to



Figure 2. Well with three DHEs, a single 2-inch (5-cm) pipe used for space heating and two 3/4-inch (2-cm) pipes used for domestic hot water.

prevent corrosion at the air-water interface. In addition, a steel cap on top of the casing also helps prevent the introduction of air into the well, which is the recommended solution to prevent corrosion since paraffin can pollute the aquifer. The DHEs, which were replaced in 1974 (Fig. 3), are still in service.



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

The space heating system consists of baseboard hot water radiators on a two-pipe system with flow control valves on each heating unit. A motorized valve on the return leg of the heating loop controls the flow via a thermostat (Figure 4). Recently, a solid state controller hooked to a storage battery



Figure 4. Two loops from the DHE entering the home—one for space heating and the other for domestic hot water.

was installed, in case of a Y2K power failure, as seen in Figure 5. A 10-gallon (38 liter) expansion tank is connected to the high point in the heating system and a pressure reducing and relief valves are part of the cold water supply line used to fill the domestic hot water loop and to initially fill the heating loop. Note that there is no hot water storage for the domestic hot water, and that there is no circulation pump on the space heating loop, as just the flow through the respective DHE is adequate. The entire system is diagramed in Figure 6.



Figure 5. Motorized control valve, solid state controller and expansion tank - the pressure reducing and pressure relief valves in the foreground.

The original cost for the well and DHEs in 1954 was about \$2,400, and the estimated cost at today's prices is \$10,000 for the well and casing and \$3,000 for the three DHEs. The annual O & M costs are only for the electricity to run the motorized valve and the equivalent annual cost of replacing part of the DHE on about a 20- to 25-year interval, amounting to probably less than \$100 per year.

The estimated annual heating and domestic hot water costs for the two homes at about 4,500 square feet total (420 square meters) of heated space using natural gas would be about \$1,600 per year or \$2,400 per year for electricity (the common alternatives in Klamath Falls), plus \$5,000 for the capital cost of two furnaces and hot water heaters. This would give simple payback of about 5.5 and 3.5 years respectively and at 7% interest on investment of about 7 and 4 years respectively at today's cost. Deeper wells will obviously make the payback period longer -- the simple payback period for a 500-foot (150-m) deep well would be approximately 13 and 8 years respectively. Thus, deeper wells need more customers or a high heating demand to justify the investment.

COMPLEX INSTALLATION

A second home, approximately one mile (1.6 km) away, has a much more complex heating system, which also has a well shared by a neighbor.

A 375-foot (114-m) deep well was drilled in 1981. The bottomhole temperature was 204°F (96°C) and the static water level at 220 feet (67 m) below the surface. The well was completed with an 8- inch (20-cm) diameter casing to 130

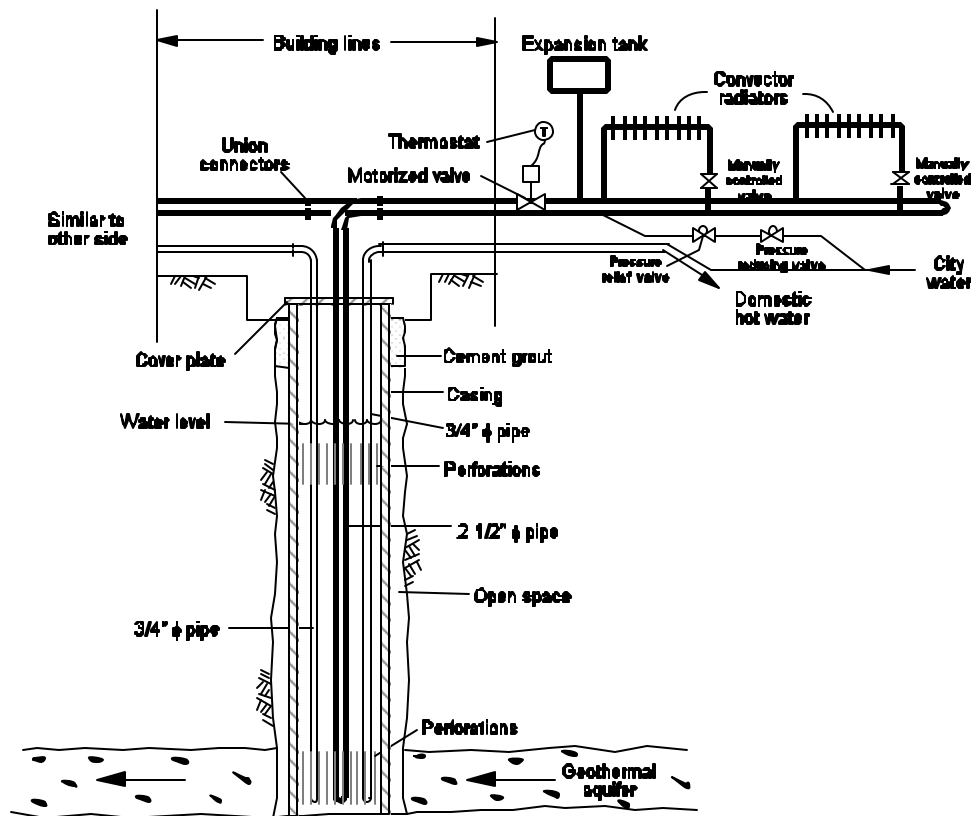


Figure 6. Diagram of the entire system for the basic installation.

feet (40 m) and a 6-inch (15-cm) diameter liner from top to the bottom. This allowed about a 1-inch (2.5-cm) clearance between the casing and annulus below the water surface. The 8 inch (20 cm) casing was sealed with a cement-bentonite mixture from the land surface to 130 feet (40 m). The 6 inch (15 cm) casing was perforated from 235 to 255 feet (72 to 78 m) and from 355 to 375 feet (108 to 114 m) below the surface. Geothermal water was first encountered at 250 feet (76 m), thus, as in most instances in Klamath Falls, the aquifer is subartesian.

A single 2.5-inch (6-cm) DHE 357 feet (109 m) long was placed in the well and then teed off at the top of the well to provide a supply to each home (Fig. 7). A 2-inch supply line was run into the house where a 1/4 hp (0.2 kW) circulation pump controlled by a thermostat was inserted on the return leg of the DHE to provide adequate heat supply. The other house is supplied from the tee at the well by a 2-inch (5-cm) diameter pipe. The closed loop supply from the DHE is circulated to three different uses: (1) for space heating by a forced air unit (a previous gas fired furnace), (2) for heating domestic hot water, and (3) an for heating an outdoor spa of about 500-gallon (1,900-liter) capacity. The domestic hot water uses the original gas water heater as a storage tank, which is in turn supplies heated water through a shell-and-tube heat exchanger. The flow in the circuit between the shell-and-tube heat exchanger and the water storage unit is assisted by a second 1/4 hp (0.2 kW) circulation pump controlled by a thermostat (Fig. 8). The spa water is heated by another shell-and-tube heat exchanger, with flow controlled by a thermostat.

Heated water can also be supplied to an outside faucet to provide heated water for rapidly filling the spa, when needed.



Figure 7. Well head with a single DHE and two supply lines.

The system has the standard water supply from city water through pressure reducing and pressure relief valves. The expansion tank is located at the high point in the system in the ceiling. The heated water supplied by the DHE to the house can reach about 175°F (80°C) and the pressure is about 8 psi (55 kPa) (Fig. 9).



Figure 8. The interior mechanical system showing the domestic hot water shell-and-tube heat exchanger on the right and the water storage tank on the left. The pipes from the DHE enter at the top-center of the photograph. Circulation pumps can also be seen in the center top.

The cost to drill the well and install the downhole heat exchanger with piping to the houses in 1981 was almost \$12,000 of which \$2,000 was for the DHE and associated piping. Each owner paid half this amount. The mechanical system in the house cost about an additional \$2,000. In 1990 the owner had to repipe the supply line and do some minor repairs for about \$1,000. The original DHE is still in service. At today's prices, the well and DHE would cost \$18,000 and the mechanical system each about \$3,000. The total area for the two houses is about 5,000 square feet (465 square meters) with high beam ceilings, which would cost around \$2,000 and \$3,000 per year to heat with natural gas and electricity respectively (including the spa at each house). The annual O&M cost, mainly to run the circulation pumps would be about \$300. The alternative capital cost of furnaces and water heaters using either natural gas or electricity, would be about \$6,000 total. This would give a simple payback of 10.5 and 6.5 years respectively. At 7% interest on investment, the payback period would increase to 21 and 9 years respectively.

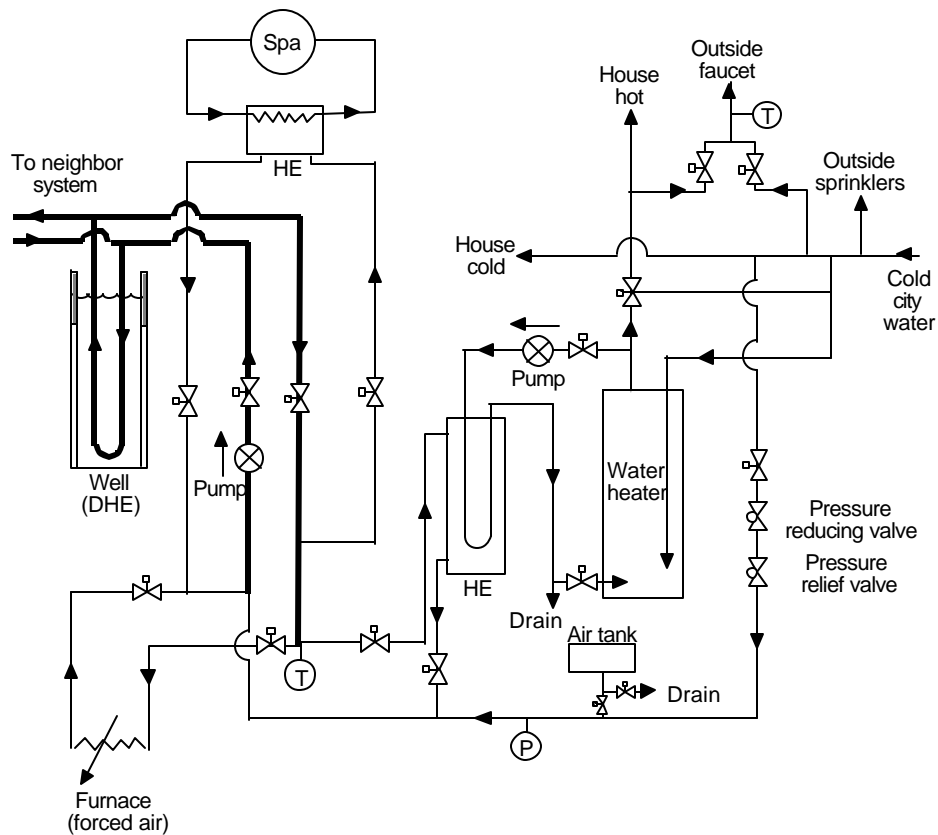


Figure 9. Diagram of the entire system for the more complex installation.

At the time of the installation of the system, there were both state and federal tax credits available for alternate energy home heating and cooling systems. The Oregon tax credit was 25% of the installation cost, up to \$1,000. The federal tax credit was 40% of the cost up to a maximum credit of \$4,000. Thus, each homeowner probably took a \$5,000 credit, reducing the simple payback to approximately 8 years compared to natural gas and 5 years compared to electricity.

The main differences between this system and the basic installation, is that it has circulation pumps and provision for domestic hot water storage along with spa water

heating. It does not require separate DHEs for domestic hot water, but instead has shell-and-tube heat exchangers in the homes. As can be seen, but comparing with the basic example, the payment period increases to the point where it may not be economical due to the deeper well, unless long term investment or rises in natural gas and electricity prices are anticipated. The alternative energy tax credits did make the system economical to install, and was the main reason for drilling the well in 1981.