THE USE OF DOWNHOLE HEAT EXCHANGERS

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The downhole heat exchanger (DHE), used extensively in Klamath Falls, Oregon, in over 500 installations, and in Turkey and New Zealand, provides heating for one or more homes, schools, and apartment buildings from a single geothermal well. The DHE eliminates the problem of disposal of geothermal fluid, since only heat is extracted from the well. The heat exchangers consisting of a loop of pipes or tubes suspended in the geothermal well through which "clean" secondary water is pumped or allowed to circulate by natural convection. The maximum output of large installations is typically less than 3 GJ/hr or 0.8 MWt, with well depths up to about 150 m, and may be economical under certain conditions at well depth of 500 m. However, the typical output for an individual home in Klamath Falls tends to be less than 265 MJ/hr (0.07 MWt). In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and casing, with perforations near the top and bottom of the submerged heat exchanger--just below the water surface and at the hot aquifer at the bottom of the well. Natural convection circulates the well water down inside the casing, through the lower perforations, up in the annulus and back inside the casing through the upper perforations, with the new geothermal water mixing with the old. These vertical convection cell, exposes the DHE to the near maximum temperature of the well water and thus, increases the heat output of the DHE. The heat output from a DHE system is dependent on the bore diameter, casing diameter, DHE length, tube diameter, number of loops in the well, flow rate and temperature of the geothermal fluid. Based on local experience in Klamath Falls, the "rule-of-thumb" is that contractors estimate approximately A1 foot of DHE pipe per 1,500 Btu/hr@ (5,200 kJ/hr/m or1.44 kW/m) as an average output.

Key Words: *downhole heat exchanger, Klamath Falls, convection cell, space heating*

INTRODUCTION

The downhole heat exchanger (DHE) eliminates the problem of disposal of geothermal fluid, since only heat is removed from the well. The exchangers consists of a system of pipes or tubes suspended in the well through which "clean" secondary water is pumped or allowed to circulate by natural convection. These systems typically have an installed capacity of less than one MWt and have been successful in well up to 150 m deep; however, they may be economical under certain conditions of well depth to 500 m. Much of the following material is based on research work at the Geo-Heat Center in Klamath Falls, Oregon as reported by Lund, et al. [6], Culver and Reistad [4] [5], and summarized by Culver and Lund [3].

Several design have proven successful: but, the most popular is a simple hairpin loop or multiple loops of iron pipe, similar to tubes in a U-tube and shell heat exchanger, extending to near the bottom of the well (Figure 1.). Other designs include a set of small multiple tubes with "headers" at each end suspended just below the water surface [4], and using promoter tubes in an existing

well to increase the vertical circulation of water in the well as is done in New Zealand [1]. Their use has also been reported in Reno, Nevada USA; Taupo and Rotorua, New Zealand; Austria; Switzerland and Balcova, Turkey [2] [7].

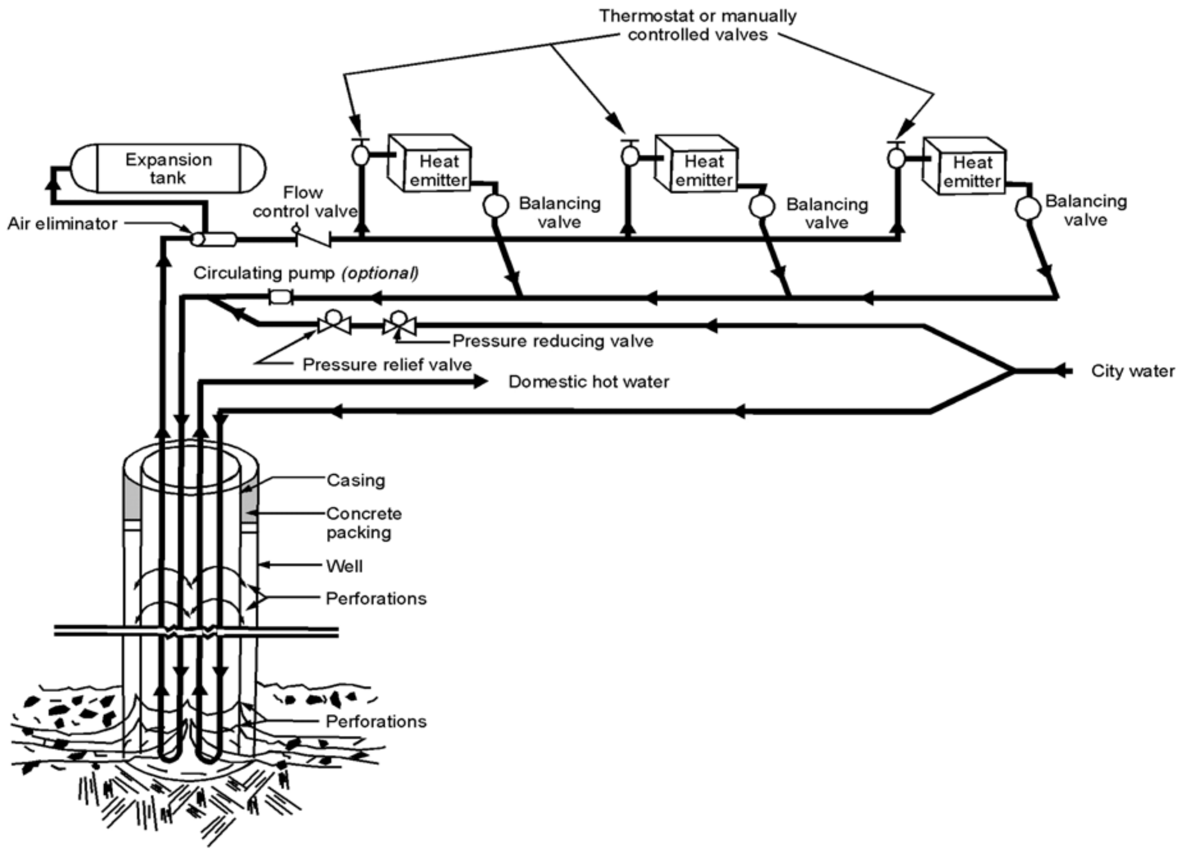

Figure 1. Typical downhole heat exchanger system (Klamath Falls, Oregon).

In order to obtain maximum output with the hairpin loop, the well must be designed to have an open annulus between the wellbore and the casing, and perforations just above the bottom and just below the waterline. 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. If the design parameters of bore diameter, casing diameter, heat exchanger pipe length, tube diameter, number of loops, flow rate and inlet temperature are carefully selected, the velocity and mass flow of the natural convection in the well may approach those of a conventional shell-and-tube heat exchangers.

The interaction between the fluid in the aquifer and that in the well is not fully understood; but, it appears that outputs are higher where there is a high degree of mixing between the aquifer and water in the well, indicating that somewhat permeable formations are preferred.

DESIGN AND CONSTRUCTION DETAILS

The wells in Klamath Falls are 25 to 30 cm in diameter, drilling six m or more into Alive water@ and a 20-cm diameter casing installed. A packer is placed around the casing below any cold water or unconsolidated rock, usually at depths of 6 to 15 m, and the well cemented from the packer to the surface. The casing is torch perforated (1 x 15 cm) in the live water area and just below the lowest static water level. Perforated sections are usually 4 to 9 m long, and the total cross-sectional area of the perforations should be at least one-and-a-half to two times the casing cross section. Wells that are not perforated or have low live water flows, may require a pump to increase the vertical flow and mixing. The casing cross sectional area and that of the annulus (between the casing and the well sides) should be about equal for optimum production.

"Live water" is locally described as a hot water aquifer, above 60°C, with sufficient flow and permeability to wash away the fines produced in a cable-tool (percussion) drilling operation or major lost circulation in rotary drilling.

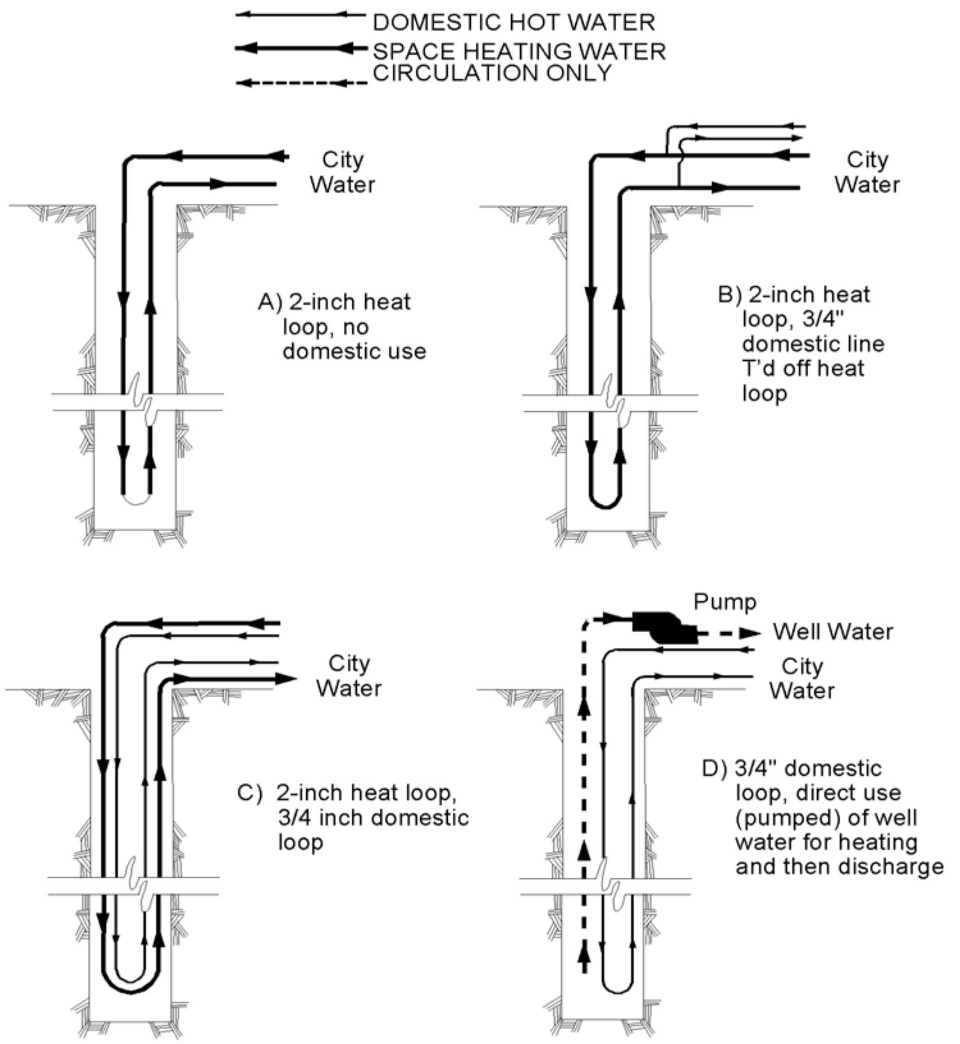

Figure 2. Downhole heat exchanger system configurations (Klamath Falls, Oregon).

The space heating DHE is usually 4- to 5-cm diameter black iron pipe with a return U at the bottom. The domestic water DHE is 2- or 2.5-cm diameter pipe. The return U usually has a 1- to 2-m section of pipe welded on the bottom to act as a trap for corrosion products that may fill the U preventing free circulations. Domestic (city) or clean water is then circulated in the pipes, the heating coil loop being a closed system and the domestic hot water coil being an open system as illustrated in Figure 1. Couplings should be malleable rather than cast to facility removal. Figure 2 illustrates the various configurations of DHE use in geothermal wells.

The first DHE, known as a coil in Klamath Falls, was installed in a geothermal well in the city in about 1930. The temperature of the well water and the predicted heat load determined the length of pipe required. Based on experience, local heating system contractors estimate approximately "one foot of coil per 1500 Btu per hour" output (5,200 kJ/hr/m or 1.44 kW/m) which would require only about 8 m for a typical residence; however, longer sections of 30 to100 m are usually installed between the perforations. The "thermo-siphon" process (or gravity feed in standard hot-water systems) circulates the domestic water, picking up heat in the well and releasing the heat in the building radiators. Circulation pumps are required in cooler wells, shared well or in larger systems to increase the flow rate and temperature. Thermo-siphon circulation will provide 0.21 to 0.35 bar (21 to 35 kPa) pressure difference in the supply and return lines to circulate as much as 1.0 to 1.5 L/s with a 5 to 11^{o}C temperature change producing 80 to 265 MJ/hr (20 to 70 kWt) [4].

CONVECTION CELLS

Although the interaction between the water in the well, water in the aquifer, and the rock surrounding the well is poorly understood, it is known that the heat output can be significantly increased if a convection cell can be set up in the well. Also, there must be some degree of mixing of the water in the well by bringing in new water from the aquifer, mixing with the well water, and then leaving the well to the aquifer.

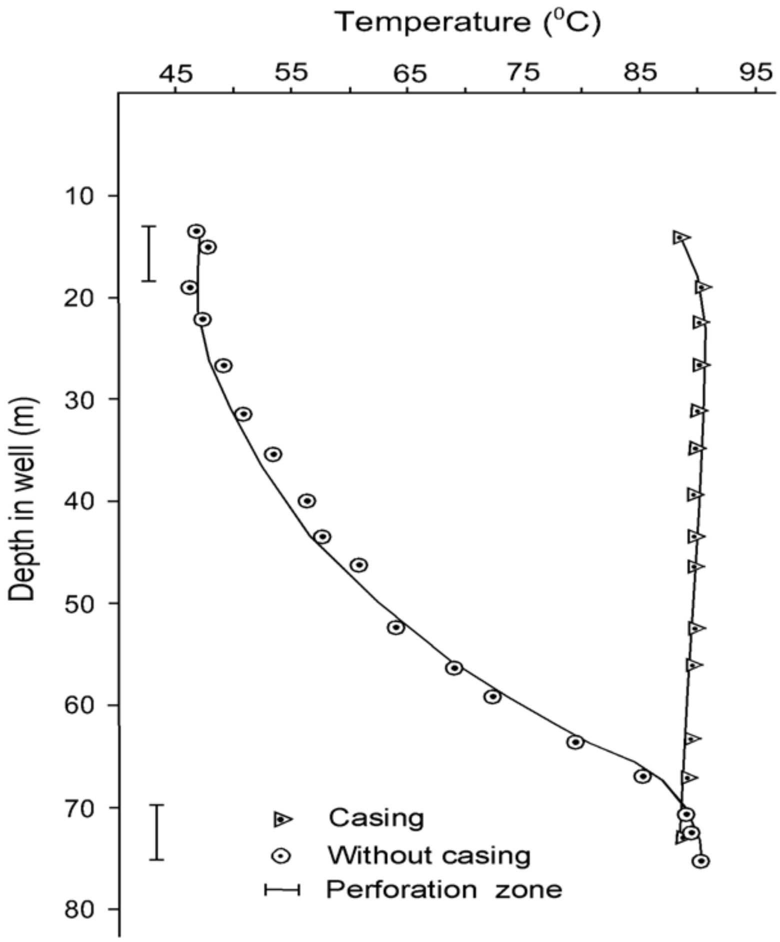

Figure 3. Temperature vs. depth for a geothermal well with and without perforations.

When a well is drilled in a competent formation and will stand open without casing, an undersized casing can be installed. If this casing is perforated just below the lowest static water level and near the bottom or at the hot aquifer level, a convection cell is induced and the well becomes very nearly isothermal between the perforations (Figure 3). Cold surface water and unstable formations near the surface are cemented off above a packer as shown in Figure 1. If a DHE is then installed and heat extracted, a convection cell, flowing down inside the casing and up in the annulus between the well wall and casing is induced. The driving force is the density difference between the water surrounding the DHE and water in the annulus. The more heat extracted, the higher the velocity. Velocities of 0.6 m/s have been measured with very high heat extraction rates; but, the usual velocities are between 0.01 and 0.1 m/s [3].

In Klamath Falls, it has been experimentally verified that when a well is drilled there is no flow in the wellbore (Figure 3). When the undersized perforated casing is installed, a convection cell is set up flowing up the inside of the casing and down the annulus between the casing and well wall. When the DHE is installed and heat is extracted the convection cell reverses, flowing down in the casing (around the DHE) and up the annulus.

EXAMPLES OF DOWNHOLE HEATING EXCHANGER SYSTEMS

Two Klamath Falls, Oregon systems will be briefly described here, the details can be found in Lund [8]. These are described as a "basic installation" and a "complex installation." The latter is the system installed in the author's home.

Basic Installation

The basic installation uses a well to provide heating for two adjacent homes using three DHEs (total heated area is about 420 square meters). The well is 60 m deep, having a temperature of 91°C at the top, 96°C at the bottom, and a static water level of 23 m below the casing top. The 30.5-cm diameter well is cased with a 25-cm diameter casing with perforations just below the water surface and at the bottom of the well in the live water area. The perforations are about 1.2 cm wide and 15 cm long for a total distance of about 4.6 m in each location.

The DHEs consist of one 6.4-cm diameter space heating pipe and two 2-cm diameter domestic hot water pipes (Figure 4). The two domestic hot water loops were necessary since they are open loop and use water that is billed to the customer by the city of Klamath Falls. The space heating loop is a closed system and thus does not consume water. The space heating systems in the homes consists of baseboard hot water radiators on a 2-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. A 38-liter expansion tank is connected to the high point in the heating systems and 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 space heating loop. There are no circulation pumps in the system as the natural thermo-siphoning provides adequate flows.

The cost for the system at today's prices would be $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 (due to corrosion at the air-water interface in the well), amounts to less than $100 per year. With an estimated equivalent annual space heating cost of about $2,000 using natural gas, and $5,000 for the capital cost of two furnaces and hot water heaters, the simple payback for the system would be about 4.2 years.

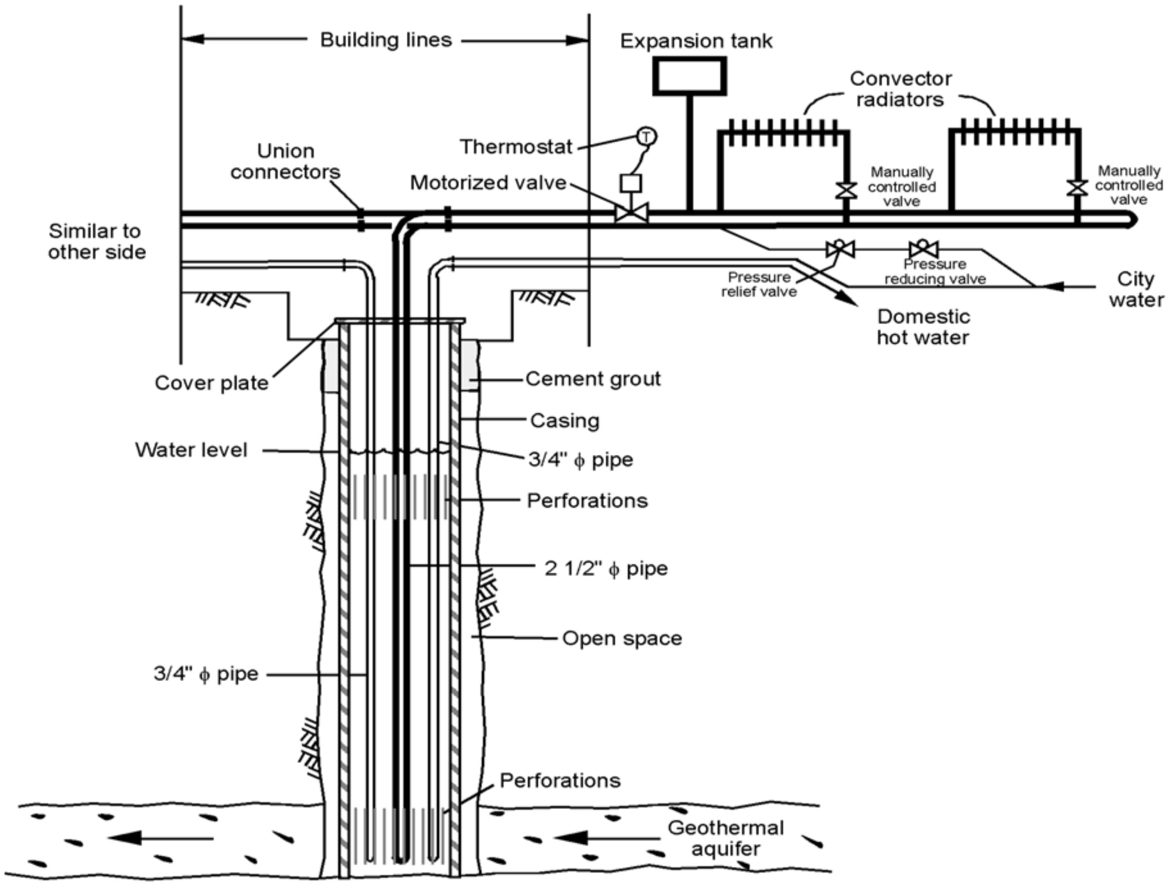

Figure 4. Diagram of the basic installation DHE system.

Complex Installation

The author's home has a more complex system (not designed by the author!), that is also shared with a neighbor (total area 465 square meters with high beam ceilings). A 114-m deep well has a bottom hole temperature of 96°C and a static water level at 67 m below the surface. The well was completed with a 20-cm diameter casing to 40 m, and a 15-cm diameter liner from top to the bottom. This allows about 2.5-cm clearance between the liner and well annulus below the water surface. The liner was perforated from 72 to 78 m and from 108 to 114 m. During drilling, geothermal water was first encountered at 76 m; thus, as in most instances in Klamath Falls, the aquifer is sub-artesian.

A single 6-cm diameter DHE 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. A 5-cm supply line is run into each house where a 0.2 kW circulation pump controlled by a thermostat was inserted on the return leg of the DHE to provide adequate heat supply. 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 the domestic hot water, and (3) for heating an outdoor spa of about 1,900-liter capacity (Figure 5). 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 tank is assisted by a second 0.2 kW-circulation pump controlled by a thermostat. The spa water is heated by another shell-and-tube heat exchanger, with flow also controlled by a third circulation pump and a thermostat. Heated water can also be supplied to an outside faucet to provide heated water for rapidly filling the spa, when needed.

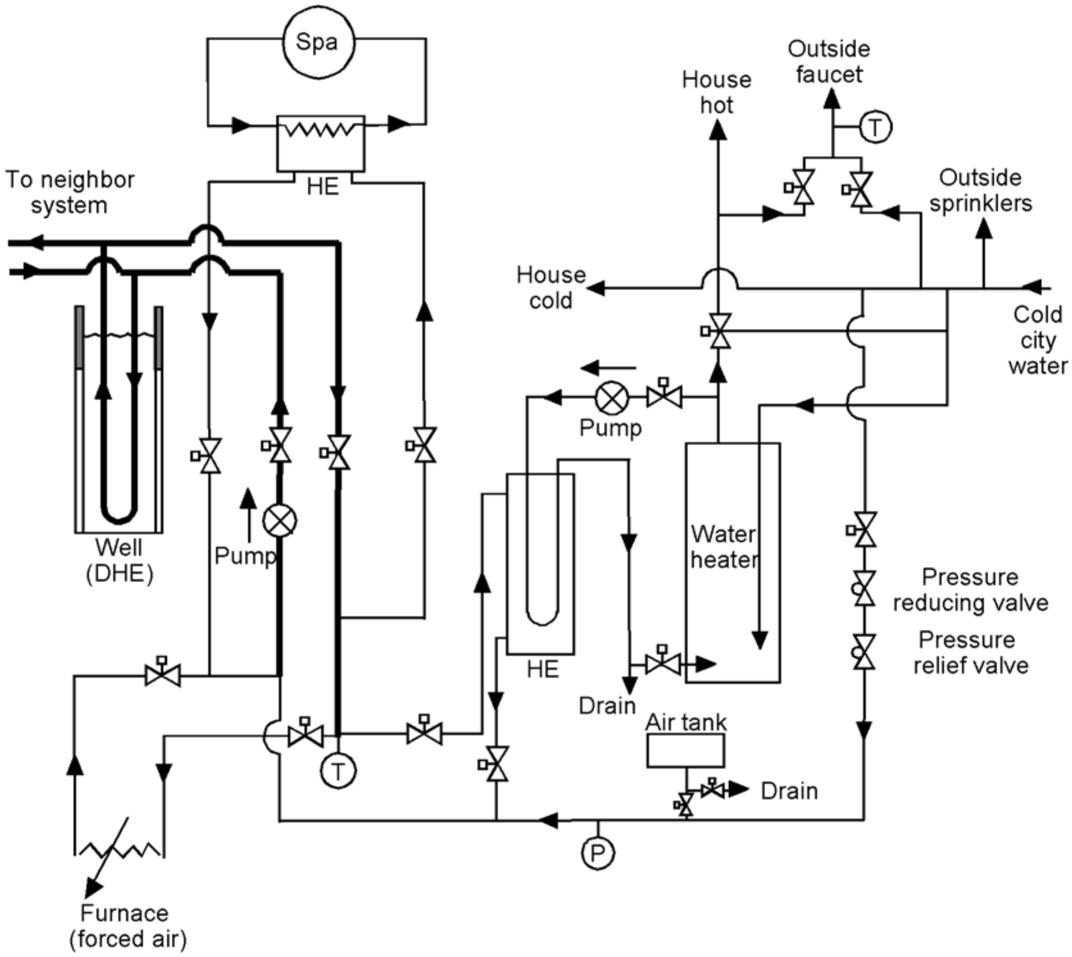

Figure 5. Diagram for the more complex DHE installation.

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 varies between 70 and 80^{o}C, depending upon the heating demand, and the pressure is about 55 kPa.

At today's prices, the well and DHE would cost $18,000 and the mechanical system for each home about $3,000. The cost to operate the system, mainly electricity for the circulation pumps is about $300 per year, as compared to using natural gas at about $3,000 per year. Using natural gas would require a furnace and water heater at about $3,000 for each home. This would give a simple payback of about 6.5 years. At the time of installation in1981, there were both state and federal tax credits available for alternate energy home heating and cooling systems. Thus, the original owners of the homes probably took a $5,000 credit, reducing the payback to about five years.

CONCLUSIONS

Downhole heat exchangers have proven very successful in Klamath Falls, Oregon for heating individual homes, schools and smaller apartment complexes. With approximately 500 of these systems installed on the east-side of the city, the geothermal water is conserved, as only heat is removed from the aquifer. For shallow wells, up to 200 m deep, the systems are economically competitive with natural gas and electricity, the alternate energy sources. This is especially true when two or more home owners share a single well, for schools and for apartment complexes, and these large heating loads can make deeper wells economical In all cases, the well water temperature must be over 60^{o}C and adequate aquifer flow must be present to provide the necessary energy to the system. The well must be cased properly with spacing between the casing and well annulus, and perforated below the static water level and at the bottom near the live water source. As a service to potential home buyers, the Geo-Heat Center has prepared an informational guide to explain the operation of these system [9] which is available on our website at: http://geoheat.oit.edu/pdf/tp103.pdf.

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