INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy
POLISH GEOTHERMAL ASSOCIATION
International Geothermal Days
POLAND 2004
EUROPEAN BRANCH
Under the auspice of
Division of Earth Sciences

1.1.

GEOTHERMAL DIRECT-HEAT UTILIZATION

John W. Lund
Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR, USA

Keywords: Geothermal, direct use, balneology, space heating, district heating, greenhouses, aquaculture, industrial processes, heat pumps

Abstract: Direct utilization of geothermal energy consists of various forms for heating and cooling instead of converting the energy for electric power generation. The major areas of direct utilization are (1) swimming, bathing and balneology, (2) space heating and cooling including district heating, (3) agriculture applications, (4) aquaculture applications, (5) industrial processes, and (6) heat pumps. Major direct utilization projects exploiting geothermal energy exist in about 60 countries, and the estimated installed thermal power is 15,145 MWt utilizing over 52,000 kg/s of fluid. The worldwide thermal energy used is estimated to be at least 190,700 TJ/yr (53,000 GWh/yr)--saving 13.5 million TOE/yr. The majority of this energy use is for space heating (37%), and swimming and bathing (22%). In the USA, the installed thermal power is 5,366 MWt, and the annual energy use is 20,300 TJ (5,640 GWh). The majority of the use (59%) is for the heat pumps (both ground coupled and water source), with bathing and swimming, and fish farming each supplying about 13%.

INTRODUCTION

Direct or non-electric utilization of geothermal energy refers to the immediate use of the heat energy rather than to its conversion to some other form such as electrical energy. The primary forms of direct use include swimming, bathing and balneology (therapeutic use), space heating and cooling including district heating, agriculture (mainly greenhouse heating and some animal husbandry), aquaculture (mainly fish pond and raceway heating), industrial processes, and heat pumps (for both heating and cooling). In general, the geothermal fluid temperatures required for direct heat use are lower than those for economic electric power generation.

Most direct use applications use geothermal fluids in the low-to-moderate temperature range between 50° and 150°C, and in general, the reservoir can be exploited by conventional water well drilling equipment. Low-temperature systems are also more widespread than high-temperature systems (above 150°C); so, they are more likely to be located near potential users. In the U.S., for example, of the 1,350 known or identified geothermal systems, 5% are above 150°C, and 85% are below 90°C (Muffler, 1979). In fact, almost every country in the world has some low-temperature systems; while, only a few have accessible high-temperature systems.

UTILIZATION

Traditionally, direct use of geothermal energy has been on small scale by individuals. More recent developments involve large-scale projects, such as district heating (Iceland and France), greenhouse complexes (Hungary and Russia), or major industrial use (New Zealand and the U.S.). Heat exchangers are also becoming more efficient and better adapted to geothermal projects, allowing use of lower temperature water and highly saline fluids. Heat pumps utilizing very low-temperature fluids have extended geothermal developments into traditionally non-geothermal countries such as France, Switzerland and Sweden, as well as areas of the mid-western and eastern U.S. Most equipment used in these projects are of standard, off-the-shelf design and need only slight modifications to handle geothermal fluids (Gudmundsson and Lund, 1985, and Geo-Heat Center Quarterly Bulletin, 19(1), 1997).

Worldwide (Lund and Freeston, 2001), the installed capacity of direct geothermal utilization is 15,145 MWt and the energy use is about 190,699 TJ/yr (52,976 GWh/yr) utilizing at least 52,746 kg/s of fluid distributed among 58 countries. A summary by region is presented in Table 1. This amounts to saving an equivalent 13.5 million tonnes of fuel oil per year (TOE). The distribution of the energy use among the various types of use is shown in Figure 1 for the entire world, and for comparison, the U.S. (Figure 2). The installed capacity in the U.S. (2000) is 5,366 MWt and the annual energy use is 20,300 TJ (5,640 GWh), saving 3.94 million TOE (Lund and

Boyd, 2000). Internationally, the largest uses are for space heating (37%) (3/4 of which is due to district heating), and for swimming, bathing and balneology (22%); whereas, in the U.S., the largest use is for geothermal heat pumps (59%). In comparison, Iceland's largest geothermal energy use is 77% for space heating 15,600 TJ/yr (4,334 GWh/yr)--primarily with district heating systems (Ragnarsson, 2000).

The Lindal diagram (Gudmundsson *et al.*, 1985), named for Baldur Lindal, the Icelandic engineer who fist proposed it, indicates the temperature range suitable for various direct use activities (Fig. 3). Typically, the agricultural and aquacultural uses require the lowest temperatures, with values from 25º to 90ºC. The amounts and types of chemicals such as arsenic and dissolved gases such as boron, are a major problem with plants and animals; thus, heat exchangers are often necessary. Space heating requires temperatures in the range of 50º to 100ºC, with 40ºC useful in some marginal cases and ground-source heat pumps extending the range down to 4ºC. Cooling and industrial processing normally require temperatures over 100ºC. The leading user of geothermal energy, in terms of market penetration, is Iceland, where more than 86% of the population enjoys geothermal heat in their homes from 26 municipal district heating services, and 50% of the country's total energy use is supplied by direct heat and electrical energy derived from geothermal resources (Ragnarsson, 2000).

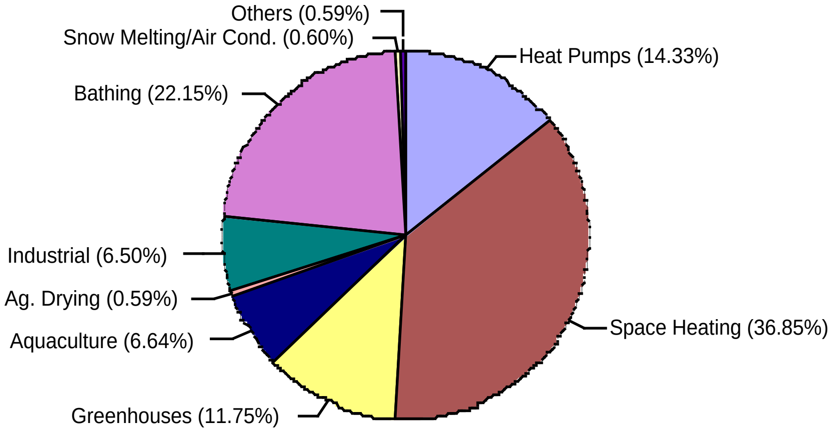

Figure 1. Distribution of geothermal energy use in the world.

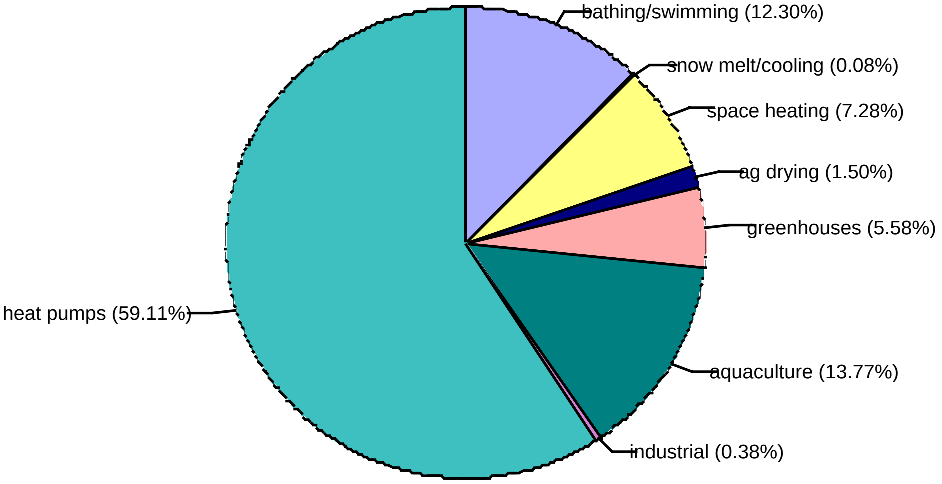

Figure 2. Distribution of geothermal energy use in the U.S.

Table 1. Summary of Regional Geothermal Use in 2000

	Direct-Use			
Region	**MWt**	**%**	**GWh/yr**	**%**
Africa	125	0.8	504	1.0
Americas	4,355	28.8	7,270	13.7
Central	5		38	
North*	4,308		7,013	
South	42		219	
Asia	4,608	30.4	24,232	45.7
Pacific Rim	3,489		18,242	
Central/Mid-East**	1,119		599	
Europe	5,715	37.7	18,905	35.7
Central/East	1,284		4,405	
West/North***	3,872		11,037	
CIS****	559		3,463	
Oceania	342	2.3	2,065	3.9
Total	15,145		52,976	

* Includes Mexico
** Includes Turkey
*** Includes Azores and Guadeloupe
**** Includes Russia, Georgia, and Armenia

Historical Development

Even though the direct-use of geothermal energy has a much longer history of use than electric power generation, the numbers are less reliable. In fact, it is difficult to compare installed capacity and annual use, due to the inclusion or exclusion of bathing, swimming and balneology figures. This has not been consistent, as in the early years this use was not included, but in current reports, it is included but not in a consistent manner. Also, values prior to 1970 were not summarized and up to 1980 could only be estimated from country descriptions in rapporteur reports. The early reports did not include China, a large user of geothermal energy for direct use, due to the political situation at the time, and also did not include the United States; even though, a geothermal district heating system had been installed in Boise, Idaho in 1890 and individual wells had been utilized in Klamath Falls, Oregon, since the 1930s for home heating. Finally, since many direct-uses are small and not concentrated in one place, they are often overlooked by authors reporting on their country.

As a result, the 1961 UN conference in Rome reported only developments in Iceland, New Zealand, Italy, Japan and Kenya (Bodvarsson, 1964). This report described district heating of 45,000 houses in Reykjavik, use of 1,000 wells in Rotorua for space heating, heating of 95,000 m2 of greenhouses in Iceland, production of 21,000 tons/yr of salt in Japan, the pulp and paper plant at Kawerau, the chemical industry at Larderello, pig raising in New Zealand, and chicken hatching in Kenya. The 1970 report of the UN meeting in Pisa included descriptions from Hungary, Iceland, Italy, Japan, New Zealand, and the USSR (Einarsson, 1970). As mentioned above, China and the United States were not included.

The data in Table 2 is based on information in the 1970 UN Conference in Pisa, a report by Lawrence Livermore Laboratory in 1975 (Howard, 1975), the second UN Conference in San Francisco (Armstead, 1975b), papers by Lund in 1979 and 1982, reports from the GRC annual meetings in 1985 and 1990 (Gudmundsson, 1985: Freeston,1990), the World Geothermal Congresses in 1995 in Italy (Freeston, 1996), and the current paper by Lund and Freeston (2001). Starting in 1995, geothermal heat pumps (ground-source heat pumps) were included in the reports and are now a significant part of the totals.

The large increase in installed capacity between 1980 and 1985 is due to the inclusion of pool heating at spas in Japan along with the first available data from China.

The annual growth rate (based on MWt) from 1970 to 1980 was 9.3%, from 1980 to 1990 was 15.2% (which was strongly influenced by data from Japan and China), and from 1990 to 2000 was 6.5%. The overall growth rate over the past 30 years has averaged 10.3% compounded annually. The large increases from 1970 to 1990 (average annual of 12.2%) and the reduction from 1990 to present, was influenced by the availability of cheap fossil fuels and the economic slowdown in southeast Asia.

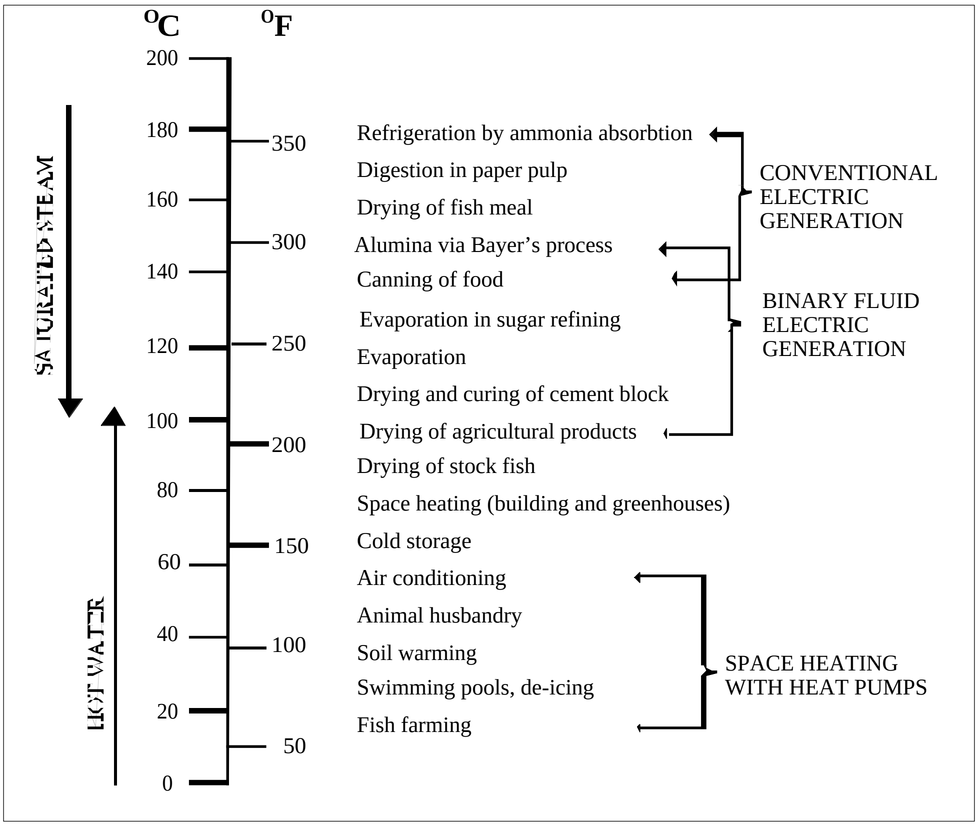

Figure 3. Lindal diagram.

Table 2. Worldwide Development of Geothermal Direct Heat Utilization

	Installed Energy		Number	
Year	MWt	GWh/yr	of Countries	Participants Reporting
1960			5	Iceland, Italy, New Zealand, Japan and Kenya
1970	800 est.	2,200 est.	6	+ Hungary& USSR - Kenya
1975	1,300 est		10	+ France, Philippines, Turkey & USA
1980	1,950		14	+ Austria, Czechoslovakia, Germany & Taiwan
1985	7,072	23,960	24	+ Australia, Canada, China, Colombia, Denmark, Mexico, Poland, Romania, Switzerland & Yugoslavia
1990	8,064		30	+ Algeria, Belgium, Bulgaria, Ethiopia, Greece, Guatemala, Thailand, & Tunisia - some countries not reporting
1995	8,664	31,236	30	Argentina, Georgia, Israel, Macedonia, Serbia, Slovakia, & Sweden - some countries not reporting
2000	15,145	52,976	58	see Lund and Freeston (2001)

Swimming, Bathing and Balneology

Romans, Chinese, Ottomans, Japanese and central Europeans have bathed in geothermal waters for centuries. Today, more than 2,200 hot springs resorts in Japan draw 100 million guests every year, and the "return-to-nature" movement in the U.S. has revitalized many hot spring resorts.

The geothermal water at Xiaotangshan Sanitarium, northwest of Beijing, China, has been used for medical purposes for over 500 years. Today, the 50°C water is used to treat high blood pressure, rheumatism, skin disease, diseases of the nervous system, ulcers and generally for recuperation after surgery. In Rotorua, New Zealand at the center of the Taupo Volcanic Zone of North Island, the Queen Elizabeth Hospital was built during World War II for U.S. servicemen and later became the national hospital for the treatment of rheumatic disease. The hospital has 200 beds, and outpatient service, and a cerebral palsy unit. Both acidic and basic heated mud baths treat rheumatic diseases.

In Beppu on the southern island of Kyushu, Japan, the hot water and steam meet many needs: heating, bathing, cooking, industrial operations, agriculture re-search, physical therapy, recreational bathing, and even a small zoo (Taguchi *et al.*, 1996). The waters are promoted for "digestive system troubles, nervous troubles, and skin troubles." Many sick and crippled people come to Beppu for rehabilitation and physical therapy. There are also eight Jigokus ("burning hells") in town showing various geothermal phenomena, used as tourist attractions.

In the former Czechoslovakia, the use of thermal waters has been traced back before the occupation of the Romans and has had a recorded use of almost 1,000 years. Today, there are 60 spa resorts located mainly in Slovakia, visited by 460,000 patients usually for an average of three weeks each. These spas have old and well-established therapeutic traditions. Depending on the chemical composition of the mineral waters and spring gas, availability of peat and sulfurous mud, and climatic conditions, each sanitarium is designated for the treatment of specific diseases. The therapeutic successes of these spas are based on centuries of healing tradition (balneology), systematically supplemented by the latest discoveries of modern medical science (Lund, 1990).

Bathing and therapeutic sites in the U.S. included: Saratoga Springs, New York; Warm Springs, Georgia; Hot Springs, Virginia; White Sulfur Springs, West Virginia; Hot Spring, Arkansas; Thermopolis, Wyoming and Calistoga, California. The original use of these sites were by Indians, where they bathed and recuperated from battle. There are over 115 major geothermal spas in the U.S. with an annual energy use of 1,500 TJ (Lund, 1996b).

Space Conditioning

Space conditioning includes both heating and cooling. Space heating with geothermal energy has widespread application, especially on an individual basis. Buildings heated from individual wells are popular in Klamath Falls, Oregon; Reno, Nevada, and Taupo and Rotorua, New Zealand. Absorption space cooling with geothermal energy has not been popular because of the high temperature requirements and low efficiency. Geothermal heat pumps (groundwater and ground-coupled) have become popular in the U.S. and Switzerland, used for both heating and cooling.

An example of space heating and cooling with low-to-moderate temperature geothermal energy is the Oregon Institute of Technology in Klamath Falls, Oregon (Figure 4). Here, eleven buildings (approximately 62,000 sq. m of floor space) are heated with water from three wells at 89ºC. Up to 62 L/s of fluid can be provided to the campus, with the average heat utilization rate over 0.53 MWt and the peak at 5.6 MWt. In addition, a 541 kW (154 tons) chiller requiring up to 38 L/s of geothermal fluid produces 23 L/s of chilled fluid at 7°C to meet the campus cooling base load (recently decommissioned)(Boyd, 1999).

District Heating

District heating originates from a central location, and supplies hot water or steam through a network of pipes to individual dwellings or blocks of buildings. The heat is used for space heating and cooling, domestic water heating and industrial process heat. A geothermal well field is the primary source of heat; however, depending on the temperature, the district may be a hybrid system, which would include fossil fuel and/or heat pump peaking.

Geothermal district heating systems are in popperation in at least 12 countries, including Iceland, France, Poland, Hungary, Turkey, Japan and the U.S. The Warm Springs Avenue project in Boise, Idaho, dating back to 1892 and originally heating more than 400 homes, is the earliest formal project in the U.S. The Reykjavik, Iceland, district heating system (Figure 5) is probably the most famous (Frimannsson 1991 and Lund, 1996a). This system supplies heat for a population of around 160,000 people. The installed capacity of 830 MWt is designed to meet the heating load to about -10oC; however, during colder periods, the increased load is met by large storage tanks and an oil-fired booster station (Ragnarsson, 2000).

In France, production wells in sedimentary basins provide direct heat to more than 500,000 people from 61 projects (200,000 housing units) (LaPlaige, et al., 2000). These wells provide from 40 to 100oC water from depths of 1,500 to 2,000 m. In the Paris basin, a doublet system (one production and one injection well) provides 70oC water, with the peak load met by heat pumps and conventional fossil fuel burners (Figure 6).

Agribusiness Applications

Agribusiness applications (agriculture and aquaculture) are particularly attractive because they require heating at the lower end of the temperature range where there is an abundance of geothermal resources. Use of waste heat or the cascading of geothermal energy also has excellent possibilities. A number of agribusiness applications can be considered: greenhouse heating, aquaculture and animal husbandry, soil warming and irrigation, mushroom culture, and bio-gas generation.

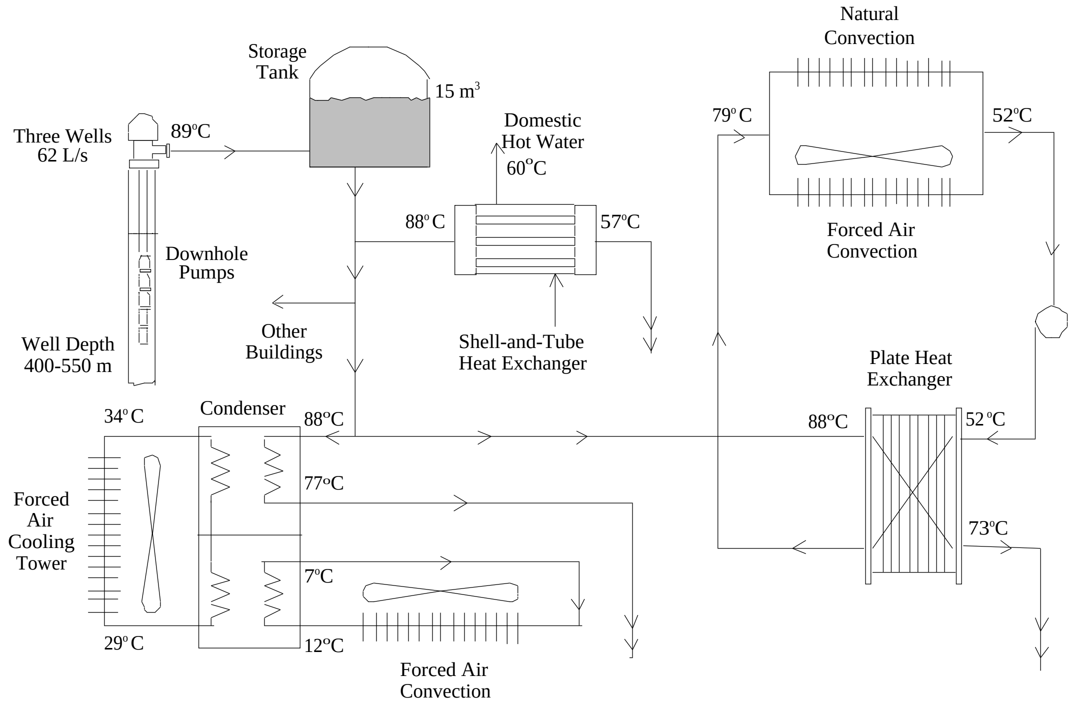

Figure 4. Oregon Institute of Technology heating and cooling system.

Numerous commercially marketable crops have been raised in geothermally heated greenhouses in Tunisia, Hungary, Russia, New Zealand, Japan, Iceland, China and the U.S. These include vegetables, such as cucumbers and tomatoes, flowers (both potted and bedded), house plants, tree seedlings, and cacti. Using geothermal energy for heating reduces operating costs (which can account for 35% of the product cost) and allows operation in colder climates where commercial greenhouses would not normally be economical.

The use of geothermal energy for raising catfish, shrimp, tilapia, eels, and tropical fish has produced crops faster than by conventional solar heating. Using geothermal heat allows better control of pond temperatures, thus optimizing growth (Figure 7). Fish breeding has been successful in Japan, China and the U.S. A very successful prawn raising operation, producing 400 tons of Giant Malaysian Freshwater Prawns per year at US$ 17 to 27/kg has been developed near the Wairakei geothermal field in New Zealand (Lund and Klein 1995). The most important factors to consider are the quality of the water and disease. If geothermal water is used directly, concentrations of dissolved heavy metals, flurorides, chlorides, arsenic, and boron must be considered.

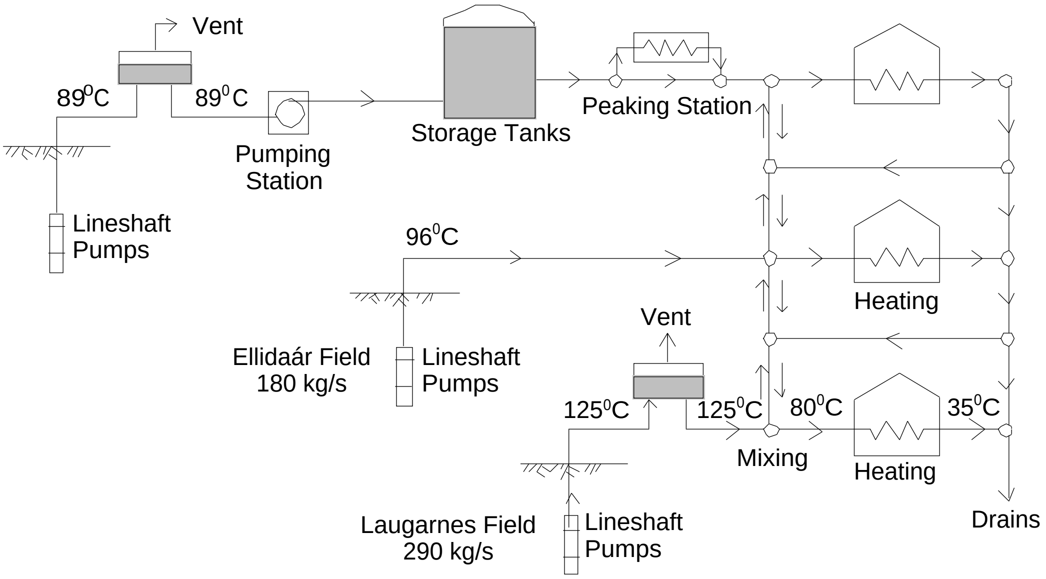

Figure 5. Reykjavik district heating.

Livestock raising facilities can encourage the growth of domestic animals by a controlled heating and cooling environment. An indoor facility can lower mortality rate of newborn, enhance growth rates, control diseases, increase litter size, make waste management and collection easier, and in most cases improved the quality of the product. Geothermal fluids can also be used for cleaning, sanitizing and drying of animal shelters and waste, as well as assisting in the production of bio-gas from the waste.

Industrial Applications

Although the Lindal diagram shows many potential industrial and process applications of geothermal energy, the world's uses are relatively few. The oldest industrial use is at Larderello, Italy, where boric acid and other borate compounds have been extracted from geothermal brines since 1790. Today, the two largest industrial uses are the diatomaceous earth drying plant in northern Iceland and a pulp, paper and wood processing plant at Kawerau, New Zealand. Notable U.S. examples are two onion dehydration plants in northern Nevada (Lund 1995), and a sewage digestion facility in San Bernardino, California. Alcohol fuel production has been attempted in the U.S.; however, the economics were marginal and thus this industry has not been successful.

Drying and dehydration are important moderate-temperature uses of geothermal energy. Various vegetable and fruit products are feasible with continuous belt conveyors (Figure 8) or batch (truck) dryers with air temperatures from 40o to 100oC (Lund and Rangel 1995). Geothermally drying alfalfa, oni-ons, pears, apples and seaweed are examples of this type of direct use. A new development in the use of geothermal fluids is the enhanced heap leaching of precious metals in Nevada by applying heat to the cyanide process (Trexler, *et al.* 1990). Using geo-thermal energy increases the efficiency of the process and extends the production into the winter months.

EQUIPMENT

Standard equipment is used in most direct-use projects, provided allowances are made for the nature of geothermal water and steam. Temperature is an important consideration, so is water quality. Corrosion and scaling caused by the sometimes unique chemistry of geothermal fluids, may lead to operating problems with equipment components exposed to flowing water and steam. In many instances, fluid problems can be designed out of the system. One such example concerns dissolved oxygen, which is absent in most geothermal waters, except perhaps the lowest temperature waters. Care should be taken to prevent atmospheric oxygen from entering district heating waters; for example, by proper design of storage tanks. The isolation of geothermal water by installing a heat exchanger may also solve this and similar water quality derived problems. In this case, a clean secondary fluid is then circulated through the used side of the system as shown in Figure 9.

The primary components of most low-temperature direct-use systems are downhole and circulation pumps, transmission and distribution pipelines, peaking or back-up plants, and various forms of heat extraction equipment (Figure 9). Fluid disposal is either surface or subsurface (injection). A peaking system may be necessary to meet maximum load. This can be done by increasing the water temperature or by providing tank storage (such as done in most of the Icelandic district heating systems). Both options mean that fewer wells need to be drilled. When the geothermal water temperature is warm (below 40ºC), heat pumps are often used.

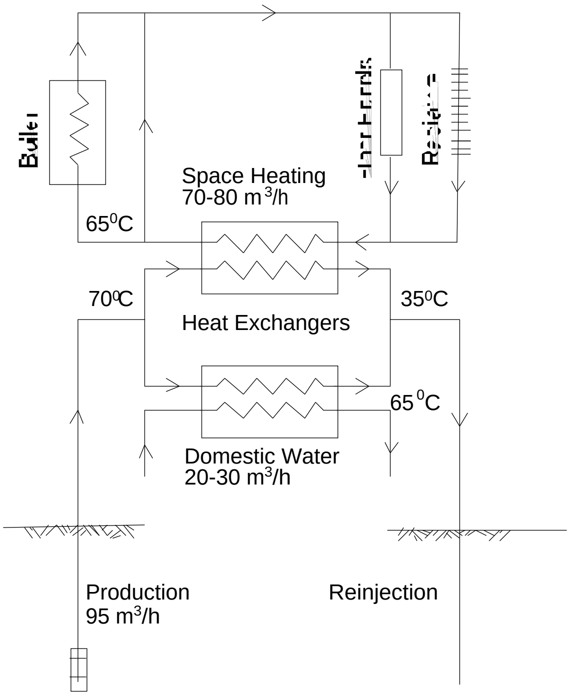

Figure 6. Melun l'Almont (Paris) doublet heating system.

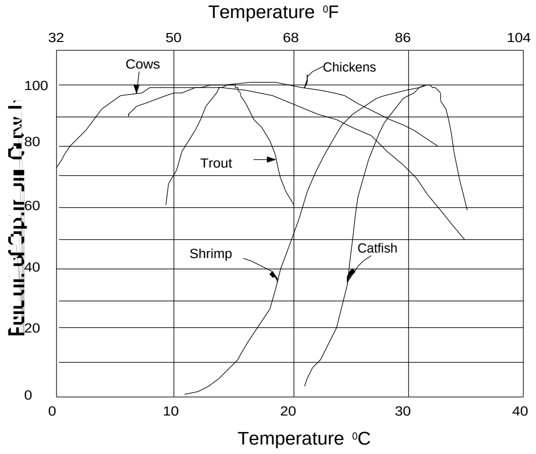

Figure 7. Effect of temperature on animal and fish growth.

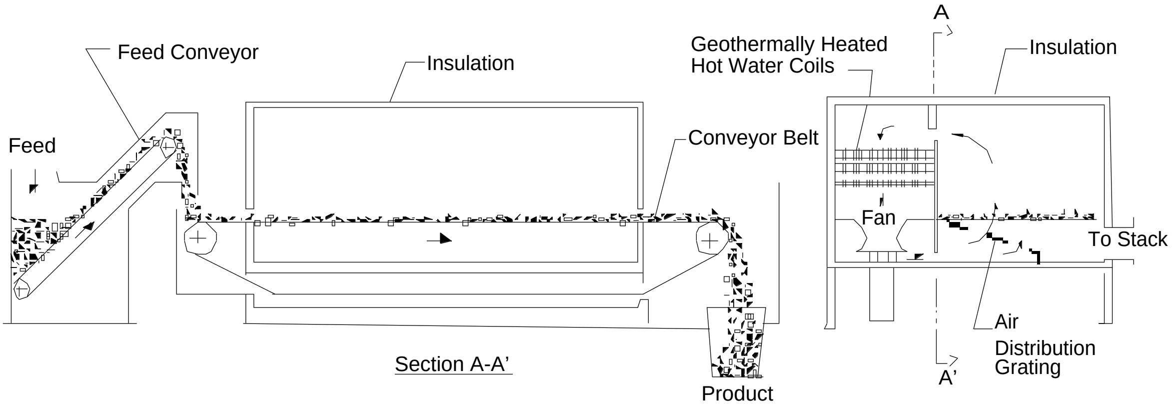

Figure 8. Continuous belt dehydration plant, schematic.

The major units will now be described in the same order as seen by geothermal waters produced for district heating. Detailed discussion of equipment design and use can be found in Lund *et al.* (1998).

Downhole Pumps

Unless the well is artesian, downhole pumps are needed, especially in large-scale direct utilization system. Downhole pumps may be installed not only to lift fluid to the surface, but also to prevent the release of gas and the resultant scale formation. The two most common types are: lineshaft pump systems and submersible pump systems.

The lineshaft pump system (Figure 10) consists of a multi-stage downhole centrifugal pump, a surface mounted motor and a long driveshaft assembly extending from the motor to the pump. Most are enclosed, with the shaft rotating within a lubrication column which is centered in the production tubing. This assembly allow the bearings to be lubricated by oil, as hot water may not provide adequate lubrication. A variable-speed drive set just below the motor on the surface, can be used to regulate flow instead of just turning the pump on and off.

The electric submersible pump system (Figure 11) consists of a multi-stage downhole centrifugal pump, a downhole motor, a seal section (also called a protector) between the pump and motor, and electric cable extending from the motor to the surface electricity supply.

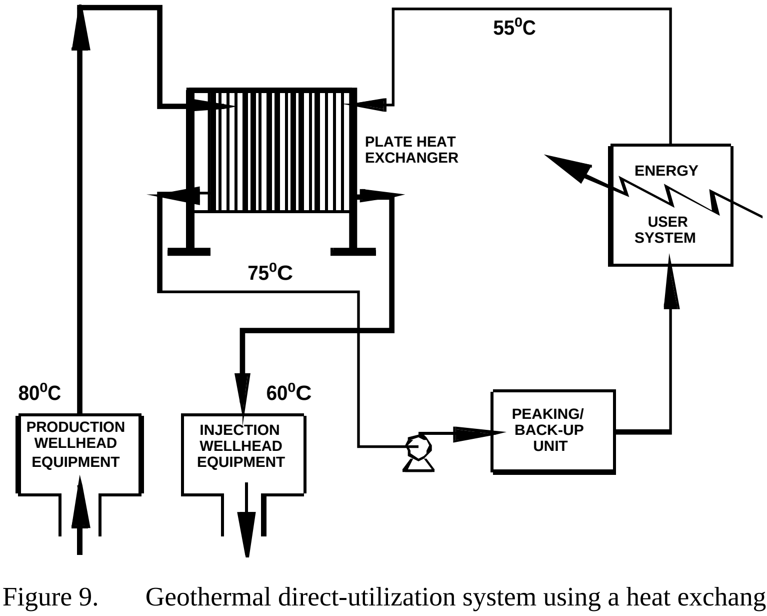

Figure 9. Geothermal direct-utilization system using a heat exchange

Both types of downhole pumps have been used for many years for cold water pumping and more recently in geothermal wells (lineshafts have been used on the Oregon Institute of Technology campus in 89oC water for 45 years). If a lineshaft pump is used, special allowances must be made for the thermal expansion of various components and for oil lubrication of the bearings. The lineshaft pumps are preferred over the submersible pump in conventional geothermal applications for two main reasons: the lineshaft pump cost less, and it has a proven track record. However, for setting depths exceeding about 250 m, a submersible pump is required.

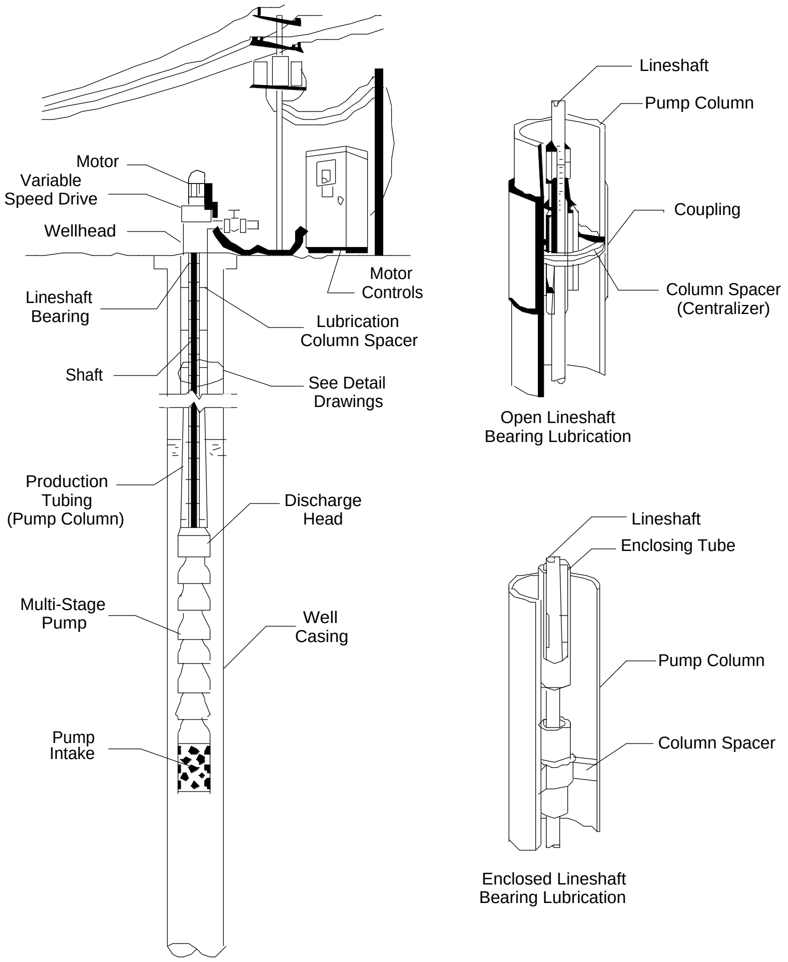

Figure 10. Lineshaft pump.

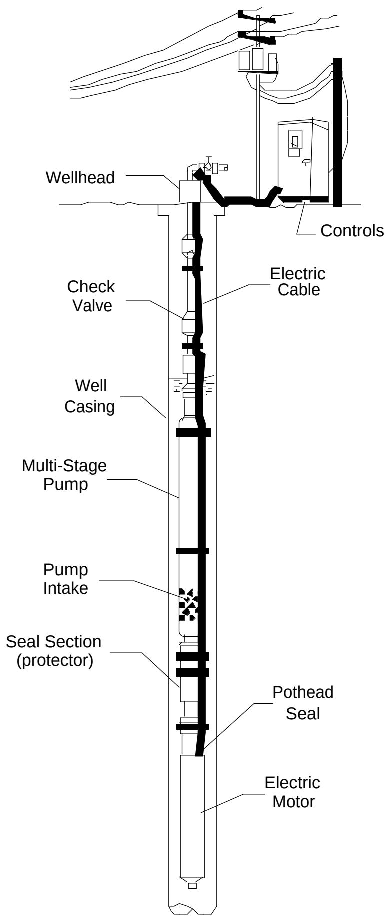

Figure 11. Submersible pump.

Piping

The fluid state in transmission lines of direct-use projects can be liquid water, steam vapor or a two-phase mixture. These pipelines carry fluids from the wellhead to either a site of application, or a steam-water separator. Thermal expansion of pipelines heated rapidly from ambient to geothermal fluid temperatures (which could vary from 50 to 200ºC) causes stress that must be accommodated by careful engineering design.

The cost of transmission lines and the distribution networks in direct-use projects is significant. This is especially true when the geothermal resource is located at great distance from the main load center; however, transmission distances of up to 60 km have proven economical for hot water (i.e., the Akranes project in Iceland–Ragnarsson & Hrolfsson, 1998), where asbestos cement covered with earth has been successful (see Figure 13 later).

Carbon steel is now the most widely used material for geothermal transmission lines and distribution networks; especially if the fluid temperature is over 100ºC. Other common types of piping material are fiberglass reinforced plastic (FRP) and asbestos cement (AC). The latter material, used widely in the past, cannot be used in many systems to-day due to environmental concerns; thus, it is no longer available in many locations. Polyvinyl chloride (PVC) piping is often used for the distribution net-work, and for uninsulated waste disposal lines where temperatures are well below 100ºC. Conventional steel piping requires expansion provisions, either bellows arrangements or by loops.

A typical piping installation would have fixed points and expansion points about every 100 m. In addition, the piping would have to be placed on rollers or slip plates between points. When hot water pipelines are buried, they can be subjected to external corrosion from groundwater and electrolysis. They must be protected by coatings and wrappings. Concrete tunnels or trenches have been used to protect steel pipes in many geothermal district heating systems. Although expensive (generally over U.S.$300 per meter of length), tunnels and trenches have the advantage of easing future expansion, providing access for maintenance and a corridor for other utilities such as domestic water, waste water, electrical cables, phone lines, etc.

Supply and distribution systems can consist of either a single-pipe or a two-pipe system. The single-pipe is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system, the fluid is recirculated so the fluid and residual heat are conserved. A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems cost typically 20 to 30 percent more than single-piped systems.

The quantity of thermal insulation of transmission lines and distribution networks will depend on many factors. In addition to minimize the heat loss of the fluid, the insulation must be waterproof and water tight. Moisture can destroy the value of any thermal insulation, and cause rapid external corrosion. Above- ground and overhead pipeline installlations can be considered in special cases. Considerable insulation is achieved by burying hot water pipelines. For example, burying bare steel pipe results in a reduction in heat loss of about one-third as compared to aboveground in still air. If the soil around the buried pipe can be kept dry, then the insulation value can be retained. Carbon steel piping can be insulated with polyurethane foam, rock wool or fiberglass. Below ground, such pipes should be protected with polyvinyl chloride (PVC) jacket; aboveground, aluminum can be used. Generally, 2.5 to 10 cm of insulation is adequate. In two-pipe systems, the supply and return lines are usually insulated; whereas, in single-pipe systems, only the supply line is insulated.

At flowing conditions, the temperature loss in insulated pipelines is in the range of 0.1 to 1.0°C/km, and in uninsulated lines, the loss is 2 to 5°C/km (in the approximate range of 5 to 15 L/s flow for 15-cm diameter pipe)(Ryan 1981). It is less for larger diameter pipes (i.e., less than 2°C loss is experienced in the new aboveground 29 km long and 80 and 90 cm diameter line (with 10 cm of rock wool insulation) from Nesjavellir to Reykjavik in Iceland. The flow rate is around 560 L/s and takes seven hours to cover the distance. Uninsulated pipe costs about half of insulated pipe, and thus, is used where temperature loss is not critical. Pipe material does not have a significant effect on heat loss; however, the flow rate does. At low flow rates (off peak), the heat loss is higher than as greater flows. Figure 12 shows fluid temperatures, as a function of distance, in a 45-cm diameter pipeline, insulated with 50 cm of urethane.

Steel piping is shown in most case, but FRP or PVC can be used in low-temperature applications. Aboveground pipelines have been used extensively in Iceland, where excavation in lava rock is expensive and difficult; however, in the USA, below ground installations are more common to protect the line from vandalism and to eliminate traffic barriers. A detailed discussion of these various installations can be found in Gudmundsson and Lund (1985).

Several examples of aboveground and buried pipeline installations are shown in Figure 13.

Heat Exchangers

The principal heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods (Figure 14). The counter-current flow and high turbulence achieved in plate heat exchangers, provide for efficient thermal exchange in a small volume. In addition, they have the advantage when compared to shell-and-tube exchangers, of occupying less space, can easily be expanded when addition load is added, and cost 40% less. The plates are usually made of stainless steel; although, titanium is used when the fluids are especially corrosive. Plate heat exchangers are commonly used in geothermal heating situations worldwide.

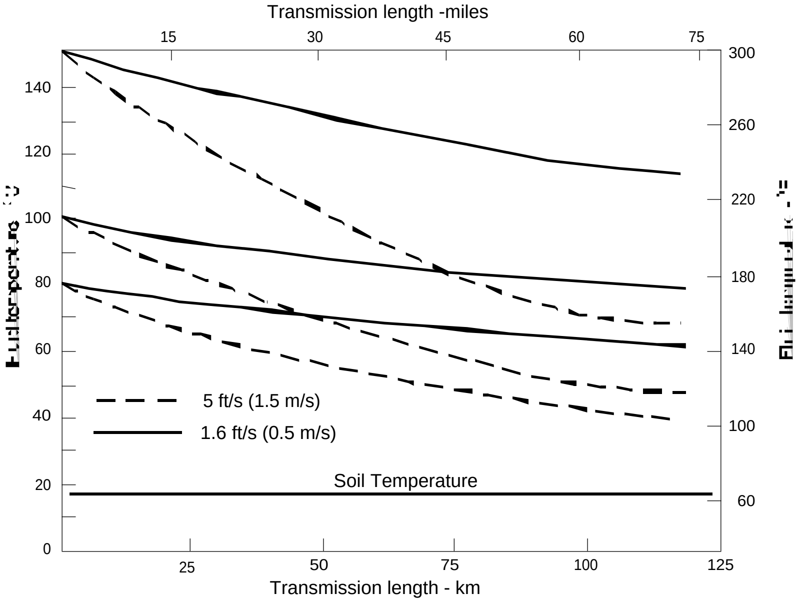

Figure 12. Temperature drop in hot water transmission line.

Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (difference between incoming and outgoing fluid temperature), and the larger size.

Downhole heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads such as the heating of individual homes, a small apartment house or business. The exchanger consists of a system of pipes or tubes suspended in the well through which secondary water is pumped or allowed to circulate by natural convection (Figure 15). In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and casing, and perforations above and below the heat exchanger surface. 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 (Culver and Reistad 1978; GHC Quarterly Bulletin, Vol. 20, No. 3, 1999). The use of a separate pipe or promoter, has proven successful in older wells in New Zealand to increase the vertical circulation (Dunstall and Freeston 1990).

Heat Pumps

At the present time, ground-coupled and groundwater (often called ground-source or geothermal) heat pump systems are being installed in great numbers in the United States, Switzerland and Germany (Kavanaugh and Rafferty 1997; Rybach and Sanner, 2000). Groundwater aquifers and soil temperatures in the range of 5 to 30oC are being used in these systems. Ground-source heat pumps (GSHP) utilize groundwater in wells or by direct ground coupling with vertical heat exchangers (Figure 16). Just about every state in the USA, especially in the mid-western and eastern states are utilizing these systems in part subsidized by public and private utilities. It is estimated that almost 70,000 ground-water systems, and more than 210,000 closed-loop vertical and 170,000 horizontal systems are already in use.

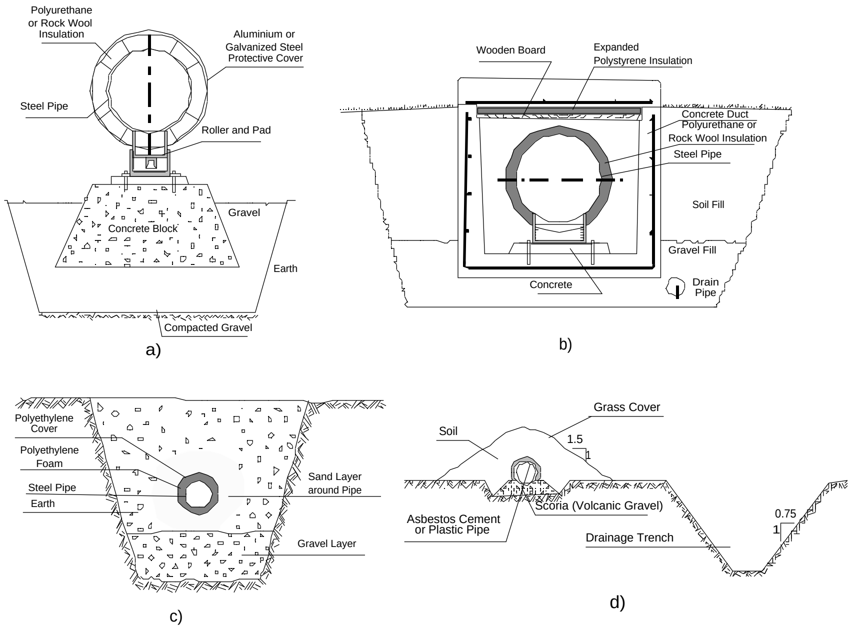

Figure 13. Examples of above- and below-ground pipelines: a) aboveground pipeline with sheet metal cover, b) steel pipe in concrete tunnels, c) steel pipe with polyurethane insulation and polyethylene cover, and d) asbestos cement pipe with earth and grass cover

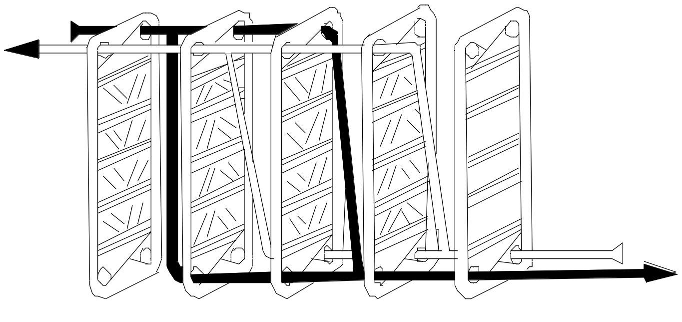

Figure 14. Plate heat exchanger.

Like refrigerators, heat pumps operate on the basic principle that fluid absorbs heat when it evaporates into a gas, and likewise gives off heat when it condenses back into a liquid. A geothermal heat pump system can be used for both heating and cooling. The types of heat pumps that are adaptable to geothermal energy are the water-to-air and the water-to-water. Heat pumps are available with heating capacities of less than 3 kW to over 1,500 kW.

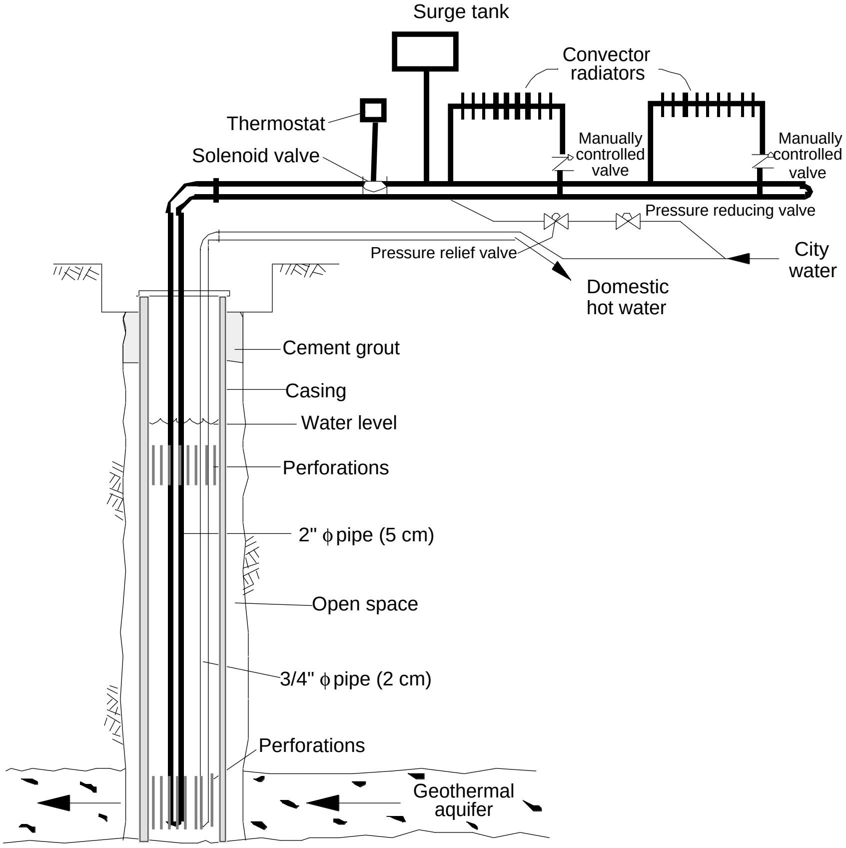

Figure 15. Downhole heat exchanger (typical of Klamath Falls, Oregon).

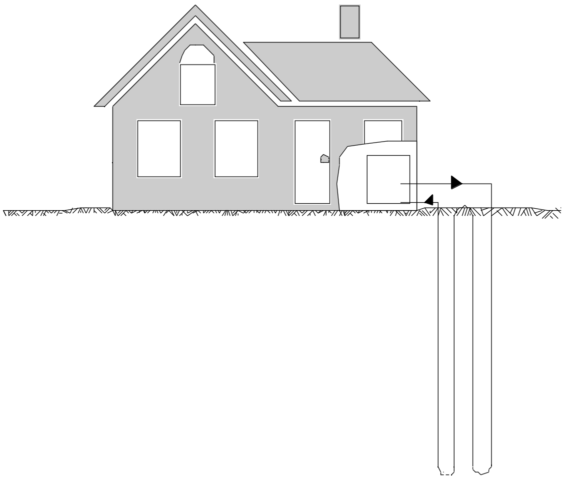

Figure 16. Typical ground-source heat pump installation.

Convectors

Heating of individual rooms and buildings is achieved by passing geothermal water (or a heated secondary fluid) through heat convectors (or emitters) located in each room. The method is similar to that used in conventional space heating systems.

Three major types of heat convectors are used for space heating: 1) forced air, 2) natural air flow using hot water or finned tube radiators, and 3) radiant panels (Figure 17). All these can be a dapted directly to geothermal energy or converted by retrofitting existing systems.

Refrigeration

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems (Rafferty, 1983 and 1998). The lithium bromide system is the most common because if uses water as the refrigerant. However, it is limited to cooling above the freezing point of water. The major application of lithium bromide units is for the supply of chilled water for space and process cooling. They may be either one- or two-stage units. The two-stage units require higher temperatures (about 160oC); but, they also have high efficiency. The single-stage units can be driven with hot water at temperatures as low as 77oC (such as at Oregon Institute of Technology - see Figure 4). The lower the temperature of the geothermal water, the higher the flow rate required and the lower the efficiency. Generally, a condensing (cooling) tower is required, which will add to the cost and space requirements.

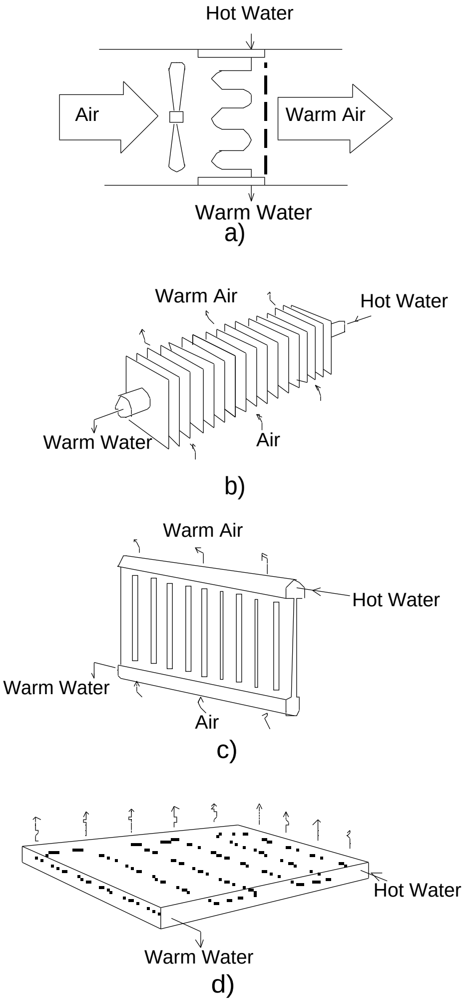

Figure 17. Convectors: a) forced air, b) material convection (finned tube), c) natural convection (radiator), and d) floor panel.

For geothermally-driven refrigeration below the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above about 120°C for a reasonable performance. Figure 18 illustrates how the geothermal absorption process works.

ECONOMIC CONSIDERATIONS

Geothermal projects require a relatively large initial capital investment, with small annual operating costs thereafter. Thus, a district heating project, including production wells, pipelines, heat exchangers, and injection wells, may cost several million dollars.

By contrast, the initial investment in a fossil fuel system includes only the cost of a central boiler and distribution lines. The annual operation and maintenance costs for the two systems are similar, except that the fossil fuel system may continue to pay for fuel at an every-increasing rate; while, the cost of the geothermal fuel is stable. The two systems, one with a high initial capital cost and the other with high annual costs, must be compared.

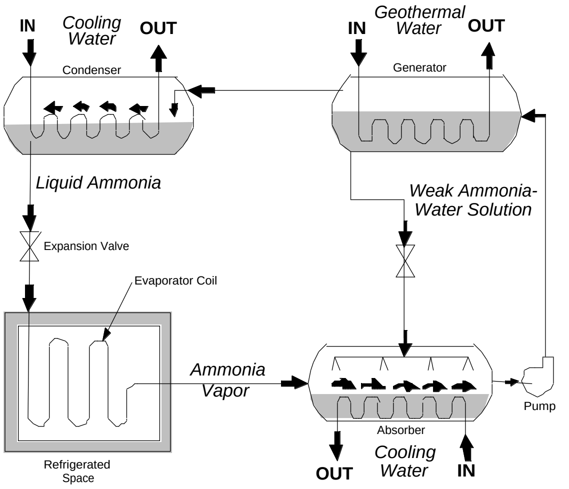

Figure 18. Geothermal absorption refrigeration cycle.

Geothermal resources fill many needs: power generation, space heating, greenhouse heating, Industrial processing, and bathing to name a few. Considered individually, however, some of the uses may not promise an attractive return on investment because of the high initial capital cost. Thus, we may have to consider using a geothermal fluid several times to maximize benefits. This multistage utilization, where lower and lower water temperatures are used in successive steps, is called cascading or waste heat utilization. A simple form of cascading employs waste heat from a power plant for direct use projects (Figure 19).

Geothermal cascading has been proposed and successfully attempted on a limited scale throughout the world. In Rotorua, New Zealand, for example, after geothermal water and steam heat a home, the owner will often use the waste heat for a backyard swimming pool and steam cooker. At the Otake geothermal power plant in Japan, about 165 tonnes per hour of hot water flows to downstream communities for space heating, greenhouses, baths and cooking. In Sapporo, Hokkaido, Japan, the waste water from the pavement snow melting system is retained at 65oC and reused for bathing.

Examples of current district heating costs are 0.23 to 0.42 cents/1,000 kcal (0.27 to 0.49 cents/kWh) in Turkey, compared to 3.4 cents/kWh for natural gas and 11.2 cents/kWh for electricity based heating (Mertoglu, et al., 1999). The Klamath Falls, Oregon district heating system charges 1.6 to 2.0 cents/kWh (Lund, 1999). This is 50 - 80% of the natural gas cost, depending upon the efficiency of the gas conversion, and the comparable cost for electricity in the city is 5.5 cents/kWh. Construction costs for heating in Turkey are 850 to 1,250 US$/kW and the cost per residence is around 2,000 US$, an investment that is amortized in 5 to 10 years. Stefansson (1999) reports an average consumer heating cost in 1995 for four European countries as 2.4 cents/kWh.

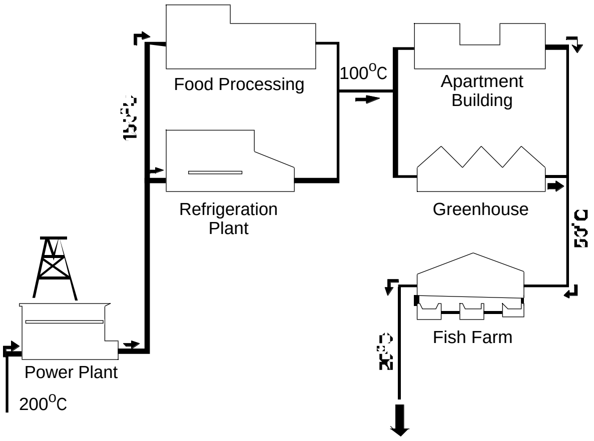

Figure 19. An example of cascading.

Other estimates (1990 data) of the capital cost for various direct use projects in the U.S. are as follows:

Space heating (individual):	US$ 463/kW of installed capacity
District heating:	US$ 386/kW of installed capacity
Greenhouses:	US$ 120/kW of installed capacity
Aquaculture:	US$ 26/kW of installed capacity

International data (Freeston, 1996) gives US$ 270/kW of installed capacity for all projects reported, with a range from US$ 40 to US$ 1880/kW. In the U.S., the annual operation and maintenance cost is estimated at 5% of the installed cost.

FUTURE DEVELOPMENTS

There appears to be a large potential for the development of low-to-moderate enthalpy geothermal direct use across the world which is not currently being exploited due to financial constraints and the low price of competing energy sources. Given the right environment, and as gas and oil supplies dwindles, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy.

Future development will most likely occur under the following conditions:

1. Collocated resource and uses (within 10 km apart),
2. Sites with high heat and cooling load density (>36 MWt/sq. km).
3. Food and grain dehydration (especially in tropical countries where spoilage is common),
4. Greenhouses in colder climates,
5. Aquaculture to optimize growth--even in warm climates, and
6. Ground-coupled and groundwater heat pump installation (both for heating and cooling).

REFERENCES

Boyd, T. L., 1999. The Oregon Institute of Technology Geothermal Heating System - Then and Now, *Geo-Heat Center Quarterly Bulletin*, Vol. 20, No. 1, Klamath Falls, OR, pp. 10-13.

Culver, G. G. and G. M. Reistad, 1978. Evaluation and Design of Downhole Heat Exchangers for Direct Applications, Geo-Heat Center, Klamath Falls, OR.

Dunstall, M. G. and D. M. Freeston, 1990. U-Tube Downhole Heat Exchanger Performance in a 4-in. Well, Rotorua, New Zealand, *Proceedings of the 12th New Zealand Geothermal Workshop*: 229-232.

Freeston, D. H., 1996. Direct Uses of Geothermal Energy 1995, *Geothermics*, 25(2): 189-214.

Frimannsson, H., 1991. Hitaveita Reykjavikur After 60 Years of Operation - Development and Benefits, *Geo-Heat Center Quarterly Bulletin*, Vo. 13(4),: 1-7.

Geo-Heat Center, 1997. *Quarterly Bulletin*, 19(1), Geothermal Direct-Use Equipment: 38 p.

Geo-Heat Center, 1999. Downhole Heat Exchangers, *Geo-Heat Center Quarterly Bulletin*, Vol. 20, No. 3 (September), Klamath Falls, OR, 28 p.

Gudmundsson, J. S.; Freeston, D. H. and P. J. Lienau, 1985. The Lindal Diagram, *Geothermal Resources Council Transaction*, 9(1): 15-19.

Gudmundsson, J. S. and J. W. Lund, 1985. Direct Uses of Earth Heat, *Energy Research*, 9: 345-375.

Kavanaugh, S. and K. Rafferty, 1997. Ground-Source Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, Atlanta, GA: 167 p.

LaPlaige, P.; Jaudin, F.; Desplan, A. and J. Demange, 2000. The French Geothermal Experience: Review and Perspective, *Proc. of the World Geothermal Congress 2000*, pp. 283-296.

Lienau, P. J.; Lund, J. W. and G. Gene Culver, 1995. Geothermal Direct Use in the United States, Update: 1990-1994, *Proc. World Geothermal Congress 1995*: 363-372.

Lund, J. W., 1990. Geothermal Spas in Czechoslovakia, *Geo-Heat Center Quarterly Bulletin*, 12(2): 20-24.

Lund, J. W., 1995. Onion Dehydration, *Geothermal Resources Council Transaction*, 19: 69-74.

Lund, J. W. and R. Klein, 1995. Prawn Park - Taupo, New Zealand, *Geo-Heat Center Quarterly Bulletin*, 16(4): 27-29.

Lund, J. W. and M. A. Rangel, 1995. Pilot Fruit Drier for the Los Azufres Geothermal Field, Mexico, Proc. of the World Geothermal Congress 1995: 2335-2338.

Lund, J. W., 1996a. Hitaveita Reykjavikur and the Nesjavellir Geothermal Co-Generation Power Plant, *Geo-Heat Center Quarterly Bulletin*, Vol. 17(4): 7-13.

Lund, J. W., 1996b. Balneological Use of Thermal and Mineral Waters in the USA, *Geothermics*, 25(1): 103-148.

Lund, J. W.; Lienau, P. J. and B. C. Lunis (editors), 1998. *Geothermal Direct-Use Engineering and Design Guidebook*, Geo-Heat Center, Klamath Falls, OR: 470 p.

Lund, J. W., 1999. "Geothermal Use in Klamath Falls, Oregon," *Technika Poszukiwan Geologicznych*, Geosynoptka i Geotermia, Vol. 4-5, Polish Academy of Sciences, Krakow, Poland, pp. 69-76.

Lund, J. W. and T. L. Boyd, 2000. Geothermal Direct-Use in the United States, Update: 1995 - 1999, *Proceedings of the World Geothermal Congress 200, Japan*

Lund, J. W. and D. H. Freeston, 2001. Worldwide Direct Uses of Geothermal Energy 2000, Geothermics, Vol. 30, No. 1, Elsevier Science Inc., Oxford, UK, pp. 29-68.

Mertoglu, O.; Dokuz, I.; Canlan, A.; Bakir, N., Kaya, T. and T. Ozbeck, 1999. "Geothermal Applications in Turkey: The Technology and Economics." *Proc. of the European Geothermal Conference, Basel, 1999*, Vol. 1, Bulletin d'Hydrogeologre No. 17, Peter Lang. Berne, pp. 57-64.

Muffler, L. P. J., editor, 1979. Assessment of Geothermal Resources of the United States - 1978, *USGS Circular 790*, Arlington, VA.

Rafferty, K., 1983. Absorption Refrigeration: Cooling with Hot Water, *Geo-Heat Center Quarterly Bulletin*, Vol. 8(1): 17-20.

Rafferty, K., 1998. "Chapter 13: Absorption Refrigeration," *Geothermal Direct-Use Engineering and Design Guidebook*, Geo-Heat Center, Klamath Falls, OR, pp. 299-306.

Ragnarsson, A., 2000. Iceland Country Update, *Proc. of the World Geothermal Congress 2000, Japan*, pp. 363-376.

Ragnarsson, A. and I. Hrolfsson, 1998. Akranes and Borgarfjordur District Heating System, *Geo-Heat Center Quarterly Bulletin*, Vol. 19, No. 4 (December), Klamath Falls, OR, pp. 10-13.

Ryan, G. P., 1981. Equipment Used in Direct Heat Projects, *Geothermal Resources Council Transactions*, 5: 483-485.

Rybach. L. and B. Sanner, 2000. Ground-Source Heat Pump Systems - The European Experience, *Geo-Heat Center Quarterly Bulletin*, Vol. 21, No. 1 (March), Klamath Falls, OR, pp. 16-26.

Stefansson, V., 1999. "Economic Aspects of Geothermal Development," *International Workshop on the Direct Use of Geothermal Energy*, Ljubljana, Slovenia, (Nov.), p. 19.

Taguchi, S.; Itoi, R. and Y. Ysa, 1996. Beppu Hot Springs, *Geo-Heat Center Quarterly Bulletin*, (17(2): 1-6.

Trexler, D. T.; Flynn, T. and J. W. Hendrix, 1990. Heap Leaching, *Geo-Heat Center Quarterly Bulletin*, 12(4): 1-4.