Geothermal Space Heating

Dr. R. Gordon Bloomquist, Ph.D.

Washington State University Energy Program

Abstract

The use of geothermal resources for space heating dominates the direct use industry with approximately 37% of all direct use development. Of this, 75% is provided by district heating systems. In fact, the earliest known commercial use of geothermal energy was in Chaudes-Aigues Cantal, France, where a district heating system was built in the 14th century. Today, geothermal district space heating projects are found in 12 countries and provide some 44,772 TJ of energy yearly. Although temperatures in excess of 50°C are generally required, resources as low as 40°C can be used in certain circumstances, and, if geothermal heat pumps are included, space heating can be a viable alternative to other forms of heating at temperatures well below 10°C.

Keywords: Space heating, District heating, peaking, absorption technology

Introduction

Space heating with geothermal energy is one of the most common and widespread direct uses of geothermal resources. Space heating comprises over 37% of the total direct use worldwide (See Figure 1). If geothermal heat pumps are included, space heating accounts for more than 50% of all geothermal non-electric uses.

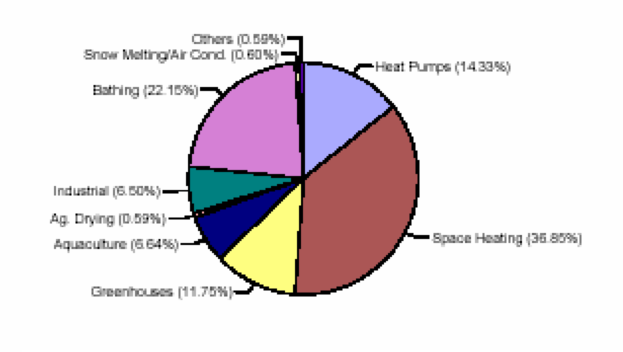

Figure 1, Distribution of Geothermal Energy in the World, Lund 2000.

Space heating is also one of the oldest direct uses of geothermal, and as early as the 14th century the inhabitants of the French village of Chaudes-Aigues Cantal were enjoying the benefits of geothermal space heating delivered to them via a district heating network that is still in operation today. In the U.S., many cities in the west enjoy direct use space heating, many dating from the early 1900's.

Space heating can be provided by means of pumped wells or through the use of downhole heat exchangers. Where temperatures are insufficient to meet the space heating requirements of residential or commercial buildings, heat pumps can be used to boost the temperature to desired levels.

Space heating can be provided on a building by building basis or increasingly via a district heating network that supplies the needs of multiple consumers via an underground piping network connected to one or multiple wells or downhole heat exchangers.

Provision of space cooling is also possible using geothermal resources either through use of a reversing heat pump or if temperatures are high enough, i.e. >100-110° C, through use of absorption technology. Although provision of cooling from direct heat geothermal has to date been very uncommon, increasing worldwide demand for air conditioning will almost surely result in further research and developments in this area.

Direct Space Heating

The heating of individual commercial and residential structures from a pumped well or downhole heat exchanger is by far the simplest form of direct geothermal heating. In the case of a pumped well, the geothermal water is pumped from the well and to the structure where a heat exchanger transfers the energy from the geothermal source to an in-building system. The geothermal water is then returned to the aquifer via an injection well or disposed to the surface. Where high enough temperatures are encountered at a relatively shallow depth, e.g. 20-200 meters, downhole exchangers may be used (See Figure 2), replacing the need for pumping of the geothermal fluid from the reservoir as well as need for a disposal system. Heat is provided through either a forced air system (common in the United States) or through a hydraulic heating system comprised of radiators or through a radiant floor or ceiling system. Most systems are also designed to provide domestic hot water.

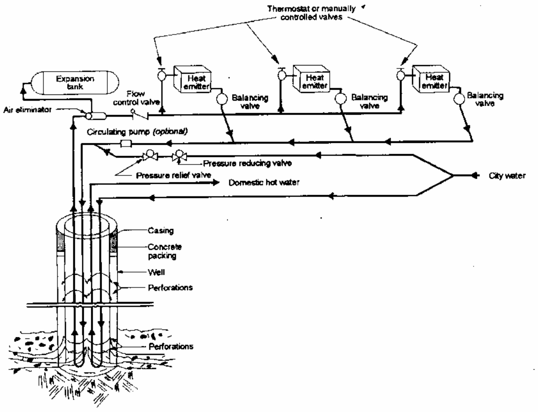

Figure 2, Downhole heat exchanger
Geothermal Direct-Use Energy Guidebook, Lund, Lienau & Lunis 1991.

Critical system components include the well, pump(s) if the well does not flow artesian, a downhole or surface heat exchanger and the heat delivery system. Some systems retain the ability to provide both backup and/or peaking through the use of a conventional fossil fuel or electric boiler or furnace and some may contain a storage facility to help reduce peak pumping requirements.

Small individual geothermal space heating systems are found throughout much of the world. The United States, many countries of Western and Central Europe, Russia, China, New Zealand and Iceland all contain excellent examples of such systems. The use of downhole heat exchangers has been especially popular in the United States (primarily Klamath Falls, Oregon), New Zealand (primarily Rotorua) and in Turkey.

District Heating

District heating, and in some cases district cooling networks are designed to provide space heating and/or cooling to multiple consumers from a single well or from multiple wells or fields. The development of geothermal district heating, led by the Icelanders, has been one of the fastest growing segments of the geothermal space heating industry and now accounts for over 75% of all space heating provided from geothermal resources worldwide. District heating is also one of the oldest uses of geothermal energy, and the first documented geothermal district heating system was built in Chaudes-Aigues Cantal, France in the 14th century. In the United States the Boise, Idaho system known originally as the Artesian Hot and Cold Water Company and later as the Boise Warm Springs Water District went online in 1893 and is now one of the four independent systems that serve the Boise metropolitan area (Bloomquist, 2000). The early to mid 1980's saw the development of several geothermal district heating systems in Idaho, Oregon, New Mexico and California, and although growth of these systems has continued, no new system has come online since the late 1980's due to extremely low natural gas prices. Iceland has, however, been the leader in the development of geothermal district heating systems, and as of today over 97% of the inhabitants of the capitol city of Reykjavik enjoy the benefits of geothermal district heating, and in excess of 90% of the total Icelandic population can now count on geothermal district heating to supply their space heating as well as domestic hot water heating requirements. Iceland may soon lose its leadership role as Turkey is quickly emerging as a leader in the development of new geothermal district heating systems. By 2000, Turkey had over 51,600 residences connected to district heating networks and projects that by 2010 approximately 500,000 residences or 30% of the residences in the country will receive geothermal district energy services (Lund, 2002). In addition, several other countries have developed or are developing geothermal district heating systems, including Hungary, Romania, France, Poland, China and even Sweden and Denmark to name just a few.

Although the demand for district cooling is growing at a tremendous rate worldwide, the author is aware of only one district cooling system that derived its energy from geothermal. That system was established at the Oregon Institute of Technology in Klamath Falls, Oregon in the early 1980's and was based on the use of the 88°C geothermal water that also supplies the Institute's district heating system. The system consisted of a 1,055 kW lithium bromide absorption heat pump and a conventional cooling tower. The system operated until 2000 but was replaced at that time by a conventional electrical driven chiller. The primary reason for the decommission of the geothermally driven absorption heat pump was the low efficiency of the system due to the moderate temperature of the geothermal fluid available. In fact the 1,055 kW unit could only produce approximately 528 kW of cooling at the temperature of the geothermal fluid available. Most lithium bromide absorption units are designed to operate optimally at temperatures in excess of 120°C. Advances in absorption technology and/or the use of binary turbine driven refrigeration equipment could, however, open the door to the much greater use of geothermal in district cooling applications.

A geothermal district energy system consists of one or multiple wells or in some cases even well fields, well and circulating pumps, transmission and distribution piping, central or individual building heat exchangers, peaking/backup boilers and/or thermal storage units and a system for metering. For the individual consumer the equipment is identical or similar to that used in individual systems, i.e. either a forced air or radiant system.

Because of the scale of most geothermal district energy systems, wells will generally be drilled with a larger diameter and often much deeper than would be cost effective for an individual system. Depths in excess of several hundred meters are not uncommon in many systems, and some may be as deep as 2000-3000+ meters. Most wells will require pumping to bring the water to the surface and to maintain the pressure so as to prevent release of gases that could result in scale formation. Both line shaft and downhole pumps have been successfully used with line shaft pumps being preferred in the U.S. and with downhole pumps more common in Europe and much of the rest of the world. New advances in downhole pump technology may pave the way for their use in higher temperature wells, and their ability to be used in deviated wells make them an obvious choice in many applications. Most pumps are equipped with variable speed drives in order to conserve energy as well as better meet system requirements.

Transmission and distribution piping is generally pre-insulated and jacketed welded steel. However, asbestos cement and some other types of non-metallic pipe have been used successfully in some applications. The use of non-metallic pipe is more common in cooling systems than in heating systems and the pipe may or may not be insulated. Both above and below ground transmission lines are common, but distribution piping is almost always underground except in unique applications such as military bases where above ground piping appears to be much more acceptable and common. When placed above ground, expansion loops and anchors are a necessity and supports must be constructed so as to allow for some pipe movement. When installed below ground, direct burial is preferred and most common. Expansion is accounted for through the use of compensators, and pre-stressing the pipe before burial is all the more common. During construction, it is vital that welds be thoroughly checked and that water-tight mufflers are used wherever jointing occurs. Once the muffler is installed, the area between the pipe and the muffler jacket is insulated. The muffler ensures that no water will reach the carrier pipe and result in severe external corrosion. In direct buried systems the use of a leak detection system is often employed and although not necessary, the minimal extra cost is often considered to be very inexpensive insurance. A three wire leak detection system may also double as a signal mechanism for the control of valves. In some below-ground applications, covered trenches or utilidors are used, but their extra cost is very difficult to justify in most applications. They do, however, provide easy access to the piping system for maintenance and repair. If the pipes are installed in covered trenches or utilidors, proper anchors and expansion loops must be used to minimize stress. In larger systems, valves and bypasses are used to reduce the risk of water hammer when flow velocity must be rapidly changed or stopped. Meters installed at critical locations provide data used by operations personnel, and increasingly common real-time computer models provide operators with not only enhanced system control but also reduced operation costs by controlling and optimizing the system to best meet load. Savings may occur in electricity to drive pump motors, fossil fuels used in peaking and in a reduction in required personnel (Figure 3). (Bloomquist, Strunge and Van Blaricum, 2002)

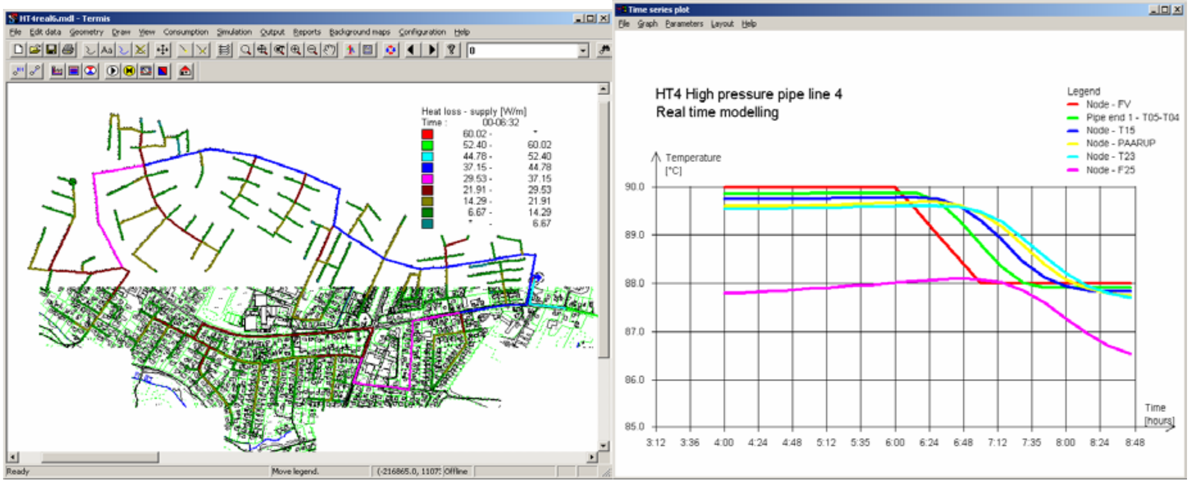

Figure 3. TERMIS Plot of Heat Loss from Pipes and a Dynamic Simulation Showing the Temperature Propagation. Bloomquist, Strunge & Van Blaricum, 2002.

Although geothermal fluids may be circulated through the transmission and distribution system directly to end users and in some cases even through the end users' heating system, the practice is discouraged due to the serious risk of corrosion and/or scaling. The heat in the geothermal fluid is instead most often transferred to a secondary fluid for transmission and/or distribution. Such systems are often referred to as closed loop systems. The geothermal fluid is then returned to the reservoir through the use of an injection well. The distribution fluid used is generally water containing freeze and corrosion protection additives, although in some countries the use of de-ionized water is common. The heat transfer is accomplished through the use of a heat exchanger. Although both tube and shell and plate and frame exchangers have been successfully utilized, plate and frame exchangers command the largest part of the market due to their better heat transfer characteristics (lower approach temperatures), relatively compact size and the ease with which they can be expanded and cleaned. (See Figure 4)

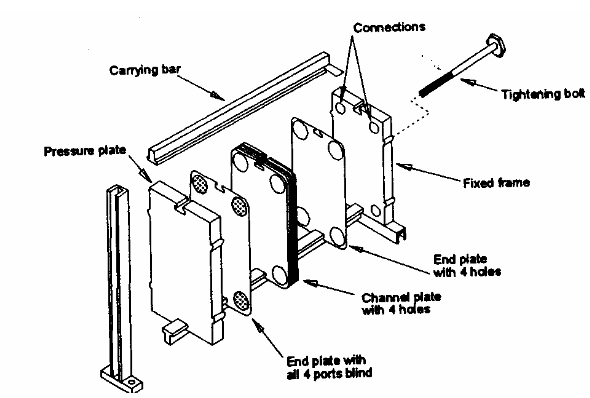

Figure 4, Plate & frame heat exchanger, Lund, Lienau & Lunis 1991.

Both closed and open loop systems may incorporate thermal storage and/or peaking and/or backup equipment into the "production plant". Thermal storage equipment can minimize the flow required of the geothermal wells needed to meet peak demand. However, despite the availability of thermal storage facilities, meeting peak demand solely with geothermal requires substantially increased flows – sometimes as much as a 50% increase in flow with increased demand. This is because the temperature that is available from the geothermal wells cannot be varied, forcing system operators to meet peak only by increasing flow. Peaking can be provided through the use of fossil fuel boilers, electric boilers or heat pumps. Meeting peak solely by increasing geothermal flow also requires a substantial over-sizing of the transmission and/or distribution piping network of from 40 to 60%. Alternatively, peak can be met by varying temperatures while holding flow constant. Since in an idealized load duration curve, peak demand occurs only 3 to 5% of the time (Figure 5), the penalty from using fossil fuels to meet peak demand is easily offset by the savings that can be achieved by limiting the number of production and injection wells and the cost savings that result by optimizing (i.e. minimizing) the diameter of the transmission and distribution piping networks. Research conducted by the author found that incorporation of peaking into the system design can reduce the number of production and injection wells by up to 50% and reduce the diameter of transmission and/or distribution piping by from 40 to 60%. Reducing pipe diameter not only reduces capital cost but also results in savings from reduced thermal losses during a baseload system operation.

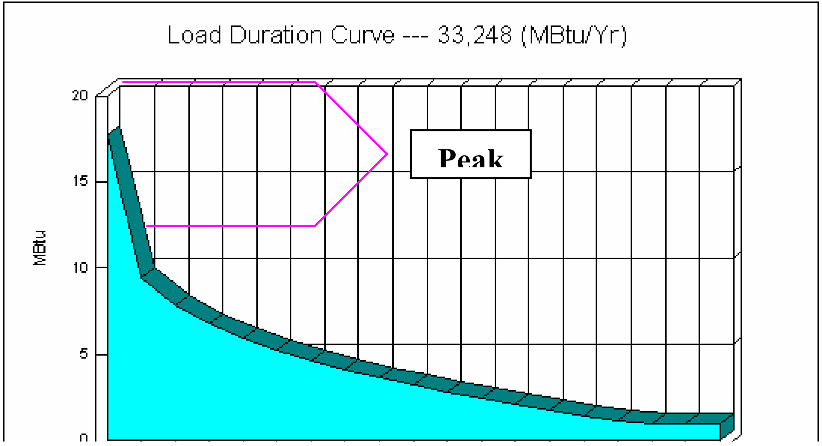

Figure 5. Typical Load Duration Curve.

District cooling is becoming an increasingly important utility service in many parts of the world. In the United States, the development of district cooling systems has far outpaced the development of new district heating systems, and even in such relatively mild climatic areas such as Sweden, district cooling is becoming a major area for new development.

Unfortunately, none of these new systems are based on the use of geothermal energy, and as was noted above, the only such system with which the author is familiar is the one that served the Oregon Institute of Technology campus.

Recent advances in absorption technology (primarily lithium bromide systems) could, however, allow for much greater utilization of low to moderate temperature geothermal resources (110-150°C) in district cooling applications. Absorption technology (Figure 6) may be applied through the production of cooling at a central location with subsequent distribution to multiple consumers or, as is occurring in many European countries that have existing district heating systems, on a building by building basis with the heat input provided through the circulating district heating loop.

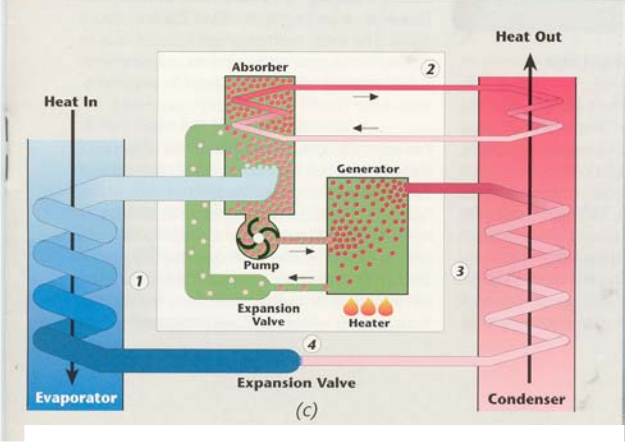

Figure 6. Absorption technology, IEA, 1992.

The one downside of using lithium bromide absorption technology is that minimum temperature achievable is approximately 5°C, allowing for storage only in the liquid phase. Ammonia absorption can achieve sub-freezing temperatures, thus allowing for ice storage, however, the COP is extremely low, e.g. .2-.3. Work underway on the use of an organic Rankine Cycle-driven refrigeration machine could provide the breakthrough that is needed to make low temperature geothermal district cooling a reality.

End users of a district energy system may be connected directly to the distribution network with system distribution fluids circulated directly through the user's HVAC system or each end user may be connected to the central distribution system via a heat exchanger or exchangers – one for heating and a second for the provision of domestic hot water. Generally users are connected via a plate and frame heat exchanger (sometimes of brazed plate configuration, see Figure 7) or a spiral exchanger (Figure 8) (Bloomquist & Wegman, 1998). In some systems where de-ionized water is circulated through the distribution networks, the heat exchanger may be eliminated and the system circulating fluids circulated directly to the in-building equipment. In-building equipment is most common in room radiators, however, in the United States the use of forced air or ceiling or floor radiant heat is common. The use of heat exchangers is often a requirement in multiple story buildings where additional pumping is required and/or where liability issues preclude direct connections.

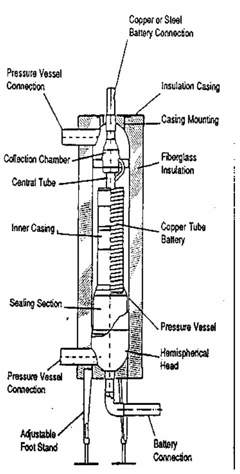

Figure 8, Spiral Heat Exchanger, Bloomquist & Wegman, 1998.

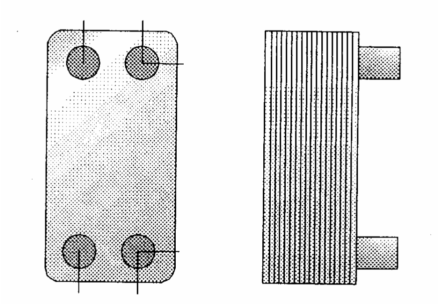

Figure 7, Brazed plate configuration, Lund, Lienau & Lunis 1991.

Most district energy systems utilize some sort of metering of energy consumption for billing purposes, although some systems use a flat rate approach based on billing on a per square meter of conditioned space or flow basis. In the case of flat rate billing on the basis of flow, flow limiters are installed that restrainflow to a certain pre-determined limit. Where energy consumption is used as the basis for billing, energy meters that integrate in-flow and out-flow temperatures and flow are the standard (in the U.S. they are referred to as BTU meters). Energy or flow meters remotely monitorable may also provide real time data for system operation as well as eliminate the need for personnel for meter reading and billing as well as the updating of databases and system maps (Figure 9). (Bloomquist, Strunge & Van Blaricum, 2002)

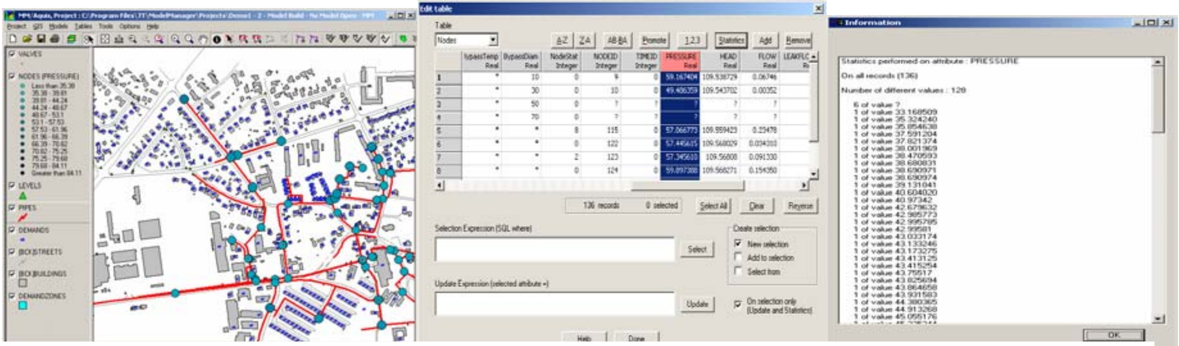

Figure 9. Thin client on GIS GUI including SQL analysis on results.
Bloomquist, Strunge & Van Blaricum 2002.

Geothermal Heat Pumps

Geothermal heat pumps are an ever increasing means of providing space conditioning through the use of low temperature (<10°C – ca 40°C) geothermal resources (Figure 10).

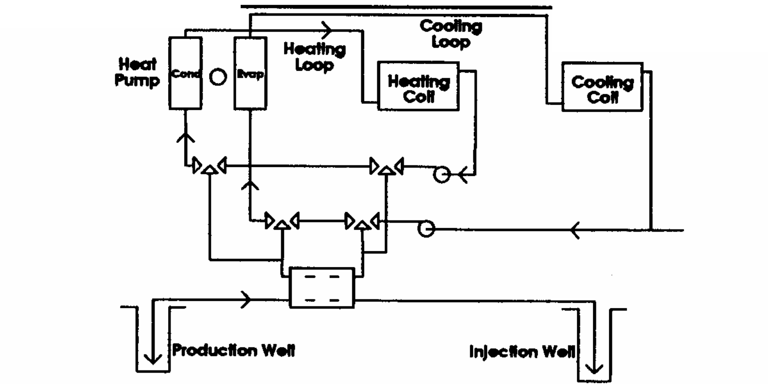

Figure 10, Geothermal Heat Pump
Geothermal Heat Pumps, Electric Ideas Clearinghouse, 1993

Geothermal heat pumps are mechanical devices that can provide heating and/or cooling (See Figure 10). In heating mode, heat extracted from the earth or from ground water is boosted by the heat pumps to meet space heating requirements. In cooling mode, heat is extracted from the interior of the building and the earth or ground water serves as a heat sink.

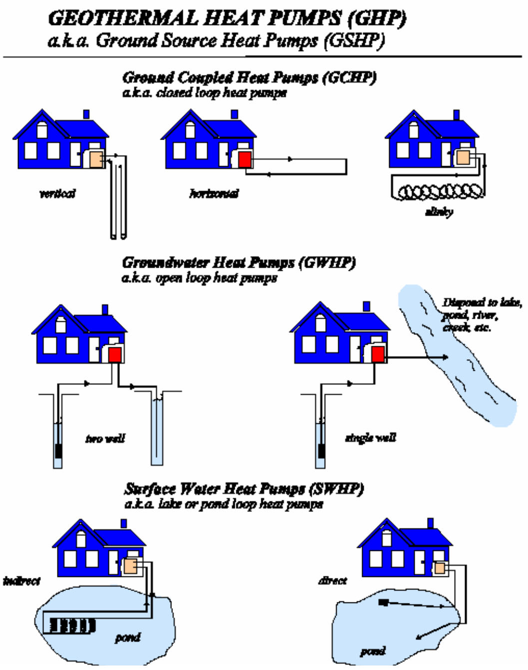

Figure 11, Heat pump configurations, Lund 2002.

Heat can be extracted or returned via a horizontal heat exchangers array, vertical bores or from pumped wells (See Figure 11). While a single family house will require a single heat pump and a horizontal loop, single vertical bore or a pumped well, commercial or institutional building(s) or complexes may require multiple vertical bores or pumped wells and either a single large central heat pump or multiple distributed heat pumps.

At the present time approximately 50,000 geothermal heat pumps are installed in the United States annually with a total capacity of approximately 600,000 kWt. Geothermal heat pumps are also popular in many European countries with Sweden, Switzerland, Germany and France being some of the leaders in using this technology. Many of the heat pumps in Europe are, however, used only in heating mode while most of those installed in the United States provide both heating and cooling and are most often sized to meet the cooling load since cooling demand often exceeds peak heating demand.

Geothermal heat pumps have been found to be an extremely attractive alternative to conventional electric or fossil fuel space conditioning equipment, often providing a cost advantage on first cost basis as well as in operation and maintenance (Bloomquist 2001).

Geothermal heat pumps are also an important component of some district heating systems. One of the most significant of these systems is the one in Lund, Sweden where over 50 MWt is provided by two large industrial heat pumps (20 and 30 MWt respectively)(Lunds Energiverk, 1985). Four production wells provide ca 23°C geothermal water. The heat pump boosts the temperature to approximately 80°C for supply to the municipal district heating system. The spent geothermal fluid is returned to the aquifer via four injection wells.

Summary

Space heating and to a lesser extent space cooling can be provided directly, through district energy networks or through the use of heat pump technology. The earliest recorded district space conditioning system dates back to 14th century France, and now space heating accounts for over 75% of all direct use geothermal space heating applications.

Increased demand for space cooling and recent technological advances as well as growing research into low temperature absorption cooling can be expected to result in a rapid growth in the use of geothermal energy for space cooling.

References

Bloomquist, R. Gordon, Svend Strunge & Vicki Van Blaricum, 2002. *Computer Modeling for District Energy - HEATMAP, TERMIS, & HEATER.* IDEA 93rd Annual Conference & Trade Show, Baltimore 2002.

Bloomquist, R. Gordon, 2001. *The Economics of Geothermal Heat Pump Systems for Commercial and Institutional Buildings*. Proceedings of conference, "Geothermal Energy in Underground Mines" in Ustron, Poland, 2001.

Bloomquist, R. Gordon, 2000. *Geothermal District Energy System Analysis, Design and Development.* Presented at the World Geothermal Congress 2000.

Bloomquist, R. Gordon & Steve Wegman. 1998. *Municipal Water-Based Heat Pump Heating and/or Cooling Systems*. Washington State University Energy Program Contract No. DE-FG07-97ID13480.

Electric Ideas Clearinghouse, 1993. "Geothermal Heat Pumps."

IEA, 1992. "Heat Pumps, an Opportunity for Reducing the Greenhouse Effect," IEA Heat Pump Centre, The Netherlands, 12 pp.

Lund, J.W., 2002. *Direct Heat Utilization of Geothermal Resources*, Geothermal Energy Resources for Developing Countries. Chandrasekharam & Bundschuh, eds., pp.129-147.

Lund, Lienau & Lunis, 1991. Geothermal Direct-Use Energy Guidebook.

Lunds Energiverk, 1985. *Geothermal Energy*, Trollebergsvagen 5, Box 1726, S-221 01 LUND, Sweden.