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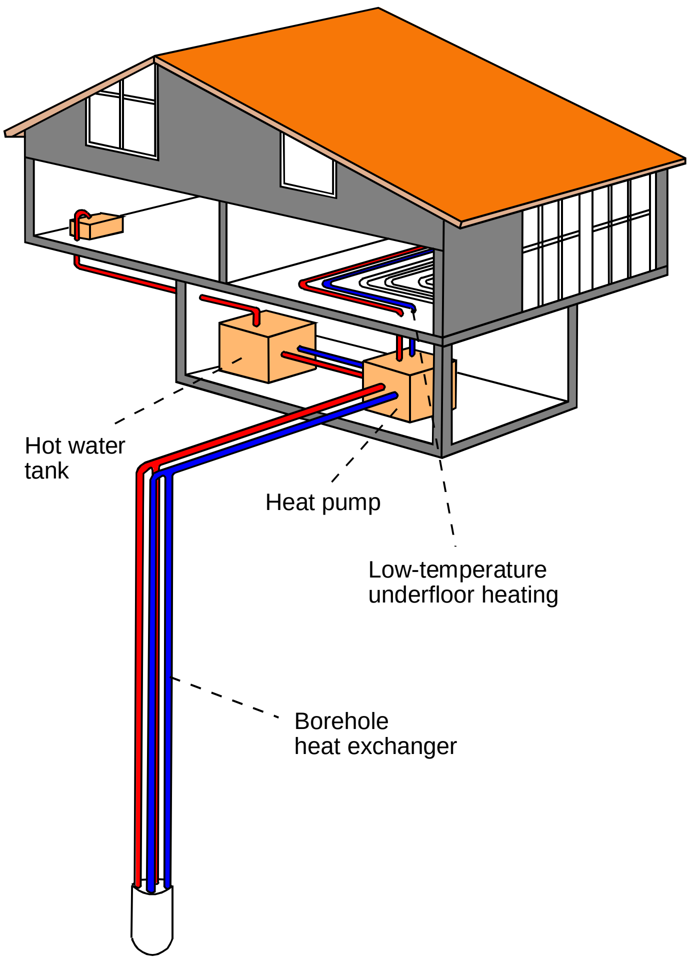
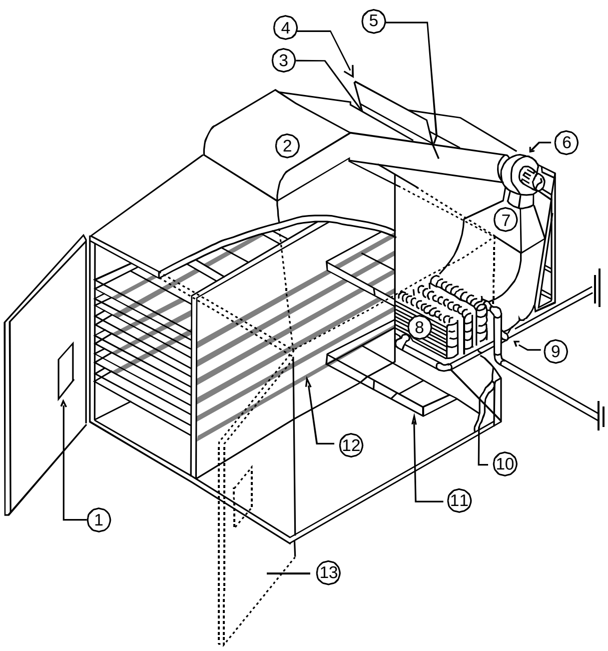


GEOTHERMAL (GROUND SOURCE) HEAT PUMP

100 YEARS OF GEOTHERMAL POWER



CHILI AND GARLIC DEHYDRATION

Vol. 25, No. 3 September 2004

GEO-HEAT CENTER QUARTERLY BULLETIN

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

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Cover: See individual articles for explanation of these figures and photograph.

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GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS
A WORLD OVERVIEW

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INTRODUCTION

Geothermal (ground-source) heat pumps (GHP) are one of the fastest growing applications of renewable energy (see discussion at the end of this article) in the world, with annual increases of 10% in about 30 countries over the past 10 years. Its main advantage is that it uses normal ground or groundwater temperatures (between about 5 and 30°C), which are available in all countries of the world. Most of this growth has occurred in the United States and Europe, though interest is developing in other countries such as Japan and Turkey. The present worldwide installed capacity is estimated at almost 12,000 MWt (thermal) and the annual energy use is about 72,000 TJ (20,000 GWh). The actual number of installed units is around 1,100,000, but the data are incomplete. Table 1 lists the countries with the highest use of GHPs.

Table 1. Leading Countries Using GHP

Country	MWt	GWh/yr	Number Installed
Austria	275	370	23,000
Canada	435	600	36,000
Germany	640	930	46,400
Sweden	2,300	9,200	230,000
Switzerland	525	780	30,000
USA	6,300	6,300	600,000

GHPs use the relatively constant temperature of the earth to provide heating, cooling and domestic hot water for homes, schools, government and commercial buildings. A small amount of electricity input is required to run a compressor; however, the energy output is of the order of four times this input. These "machines" cause heat to flow "uphill" from a lower to higher temperature location- really nothing more than a refrigeration unit that can be reversed. "Pump" is used to described the work done, and the temperature difference is called the "lift"-- the greater the lift, the greater the energy input. The technology isn't new, as Lord Kelvin developed the concept in 1852, which was then modified as a GHP by Robert Webber in the 1940s. They gained commercial popularity in the 1960s and 1970s. See Figure 1 for diagrams of typical GHP operation.

GHPs come in two basic configurations: ground-coupled (closed loop) and groundwater (open loop) systems,

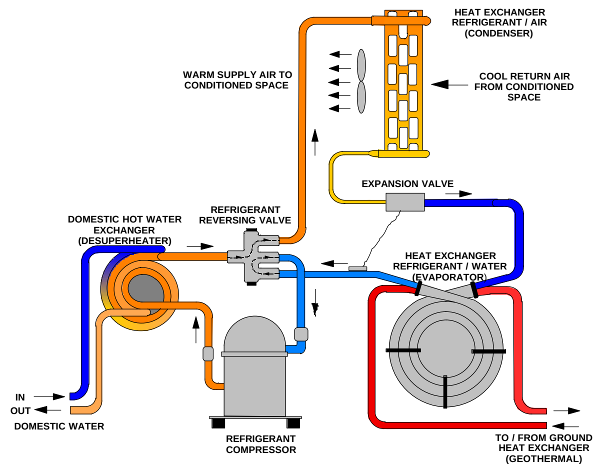


Figure 1a. GHP in the heating cycle (source: Oklahoma State University).

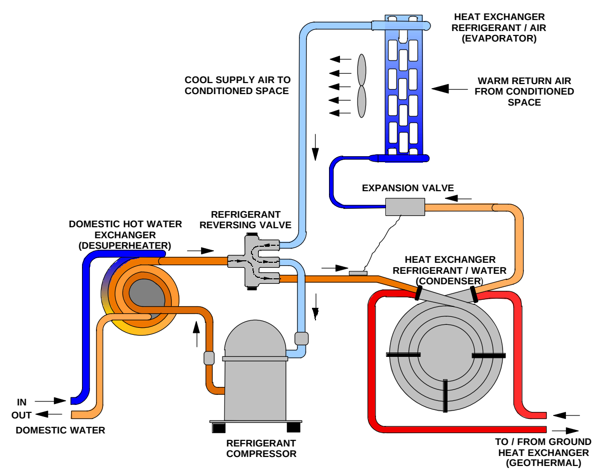


Figure 1b. GHP in the cooling cycle (source: Oklahoma State University).

which are installed horizontally and vertically, or in wells and lakes. The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled economically or is already on site. See Figure 2 for diagrams of these systems. As shown in Figure 1, a desuperheater can be provided to use reject heat in the summer and some input heat in the winter for the domestic hot water heating.

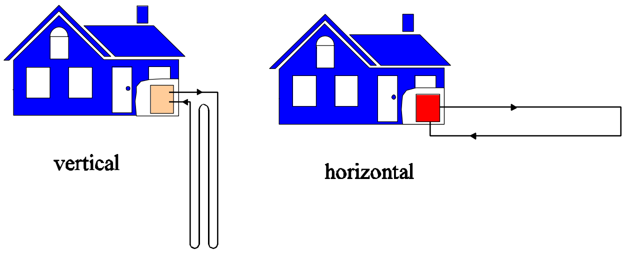


Figure 2a. ***Closed loop heat pump systems (source: Geo-Heat Center).***

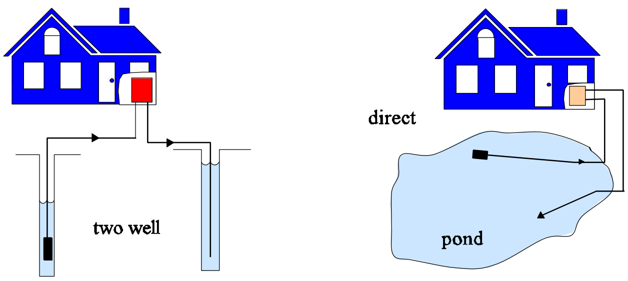


Figure 2b. ***Open loop heat pumps systems (source: Geo-Heat Center).***

In the ground-coupled system, a closed loop of pipe, placed either horizontally (1 to 2 m deep) or vertically (50 to 100 m deep), is placed in the ground and a water-antifreeze solution is circulated through the plastic pipes to either collect heat from the ground in the winter or reject heat to the ground in the summer (Rafferty, 1997). The open loop system uses groundwater or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (say for irrigation), depending upon local laws.

The efficiency of GHP units are described by the Coefficient of Performance (COP) in the heating mode and the Energy Efficiency Ratio (EER) in the cooling mode (COP_h and COP_c, respectively in Europe) which is the ratio of the output energy divided by the input energy (electricity for the compressor) and varies from 3 to 6 with present equipment (the higher the number the better the efficiency). Thus, a COP of 4 would indicate that the unit produced four units of heating energy for every unit of electrical energy input. In comparison, an air-source heat pump has a COP of around 2 and is dependent upon backup electrical energy to meet peak heating and cooling requirements. In Europe, this ratio is sometimes referred to as the "Seasonal Performance Factor" ("Jahresarbeitszahl" in German) and is the average COP over the heating and cooling season, respectively, and takes into account system properties.

UNITED STATES EXPERIENCE

In the Unites States, most units are sized for the peak cooling load and are oversized for heating (except in the northern states), and thus, are estimated to average only 1,000 full-load heating hours per year. In Europe, most units are sized for the heating load and are often designed to provide just the base load with peaking by fossil fuel. As a result, the European units may operated from 2,000 to 6,000 full-load hours per year, with an average of around 2,300 annual full load hours. Even though the cooling mode rejects heat to the earth, and thus is not geothermal, it still saves energy and contributes to a "clean environment." In the United States, GHP installations have steadily increased over the past 10 years with an annual growth rate of about 12%, mostly in the mid-western and eastern states from North Dakota to Florida. Today, approximately 80,000 units are installed annually, of which 46% are vertical closed loop systems, 38% horizontal closed loops systems and 15% open loop systems. Over 600 schools have installed these units for heating and cooling, especially in Texas. It should be noted at this point, that in the United States, heat pumps are rated on tonnage (i.e. one ton of cooling power--produced by a ton of ice) and is equal to 12,000 Btu/hr or 3.51 kW (Kavanaugh and Rafferty, 1997). A unit for a typical residential requirement would be around three tons or 10.5 kW installed capacity.

One of the largest GHP installations in the United States is at the Galt House East Hotel in Louisville, Kentucky. Heat and air conditioning is provided by GHPs for 600 hotel rooms, 100 apartments, and 89,000 square meters of office space for a total area of 161,650 square meters. The GHPs use 177 L/s from four wells at 14EC, providing 15.8 MW of cooling and 19.6 MW of heating capacity. The energy consumed is approximately 53% of an adjacent similar non-GHP building, saving $25,000 per month.

One of the recent converts to this form of energy savings is President George W. Bush, who installed a geothermal heat pump on his Texas ranch during the election campaign (Lund, 2001). Even though he is not known as an environmentalist, he referred to his system as "environmentally hip." This vertical closed loop installation cuts his heating and cooling cost by 40%.

EUROPEAN SITUATION

Ground-source heat pumps (GSHP) can offer both heating and cooling at virtually any location, with great flexibility to meet any demands. In western and central European countries, the direct utilization of geothermal energy to supply heat through district heating to a larger number of customers so far is limited to regions with specific geological settings. In this situation, the utilization of the ubiquitous shallow geothermal resources by decentralized GSHP systems is an obvious option. Correspondingly, a rapidly growing field of applications is emerging and developing in various European countries. A rapid market penetration of such systems is resulting; the number of commercial companies actively working in this field is ever increasing and their products have reached the "yellow pages" stage.

More than 20 years of R&D focusing on GSHP in Europe resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. A typical GSHP with borehole heat exchanger (BHE; a "vertical loop" in U.S.-terms) is shown in Figure 3. These systems require currently for each kWh of heating or cooling output 0.22 - 0.35 kWh of electricity, which is 30 - 50% less than the seasonal power consumption of air-to-air heat pumps, which use the atmosphere as a heat source/sink.

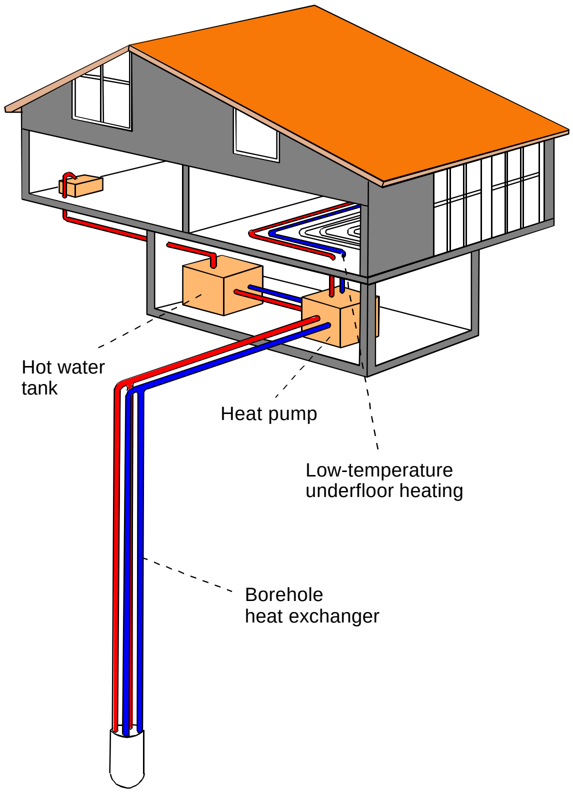


Figure 3. ***Typical application of a BHE / heat pump system in a Central European home, typical BHE length $100 m.***

The climatic conditions in many European countries are such that by far the most demand is for space heating; air conditioning is rarely required. Therefore, the heat pumps usually operate mainly in the heating mode. However, with the increasing number of larger commercial applications, requiring cooling, and the ongoing proliferation of the technology into southern Europe, the double use for heating and cooling will become of more importance in the future.

It is rather difficult to find reliable numbers of installed heat pumps in Europe, and in particular for the individual heat sources. Figure 4 gives some recent data for the number of installed units in the main European heat pump countries. The extremely high number for Sweden in 2001 is the result of a large number of exhaust-air and other air-to-air heat pumps; however, Sweden also has the highest number of GSHP in Europe (see Table 1). In general it can be concluded, that market penetration of GSHP still is modest throughout Europe, with the exception of Sweden and Switzerland.

On the field of technical optimization, some developments of recent years should be mentioned:

- Thermal Response Test to determine the thermal parameters of the underground in situ;
- Grouting material with enhanced thermal conductivity; and
- Heat Pumps with increased supply temperatures for retrofit purposes.

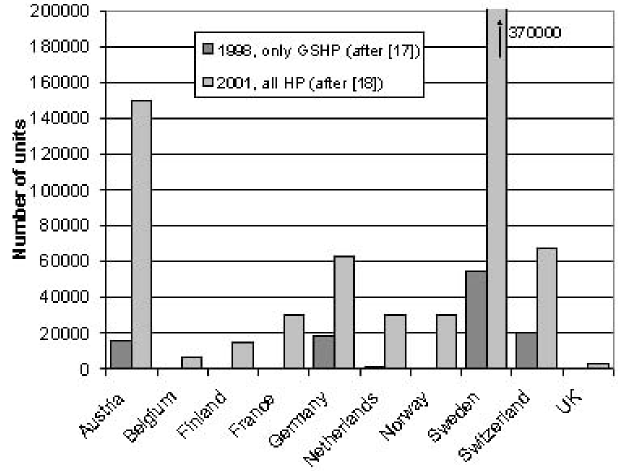


Figure 4. ***Number of installed heat pump units in some European countries (after data from Sanner, 1999; and Donnerbauer, 2003).***

For a thermal response test, basically a defined heat load is put into the BHE and the resulting temperature changes of the circulating fluid are measured (Figure 5) (Eugster and Laloui, 2002). Since mid-1999, this technology is in use in Central Europe for the design of larger plants with BHE, allowing sizing of the boreholes based upon reliable underground data. Thermal response testing was first developed in Sweden and USA in 1995, and now is used in many countries worldwide. Together with reliable design software (Hellström and Sanner, 2001), BHE can be made a sound and safe technology also for larger applications.

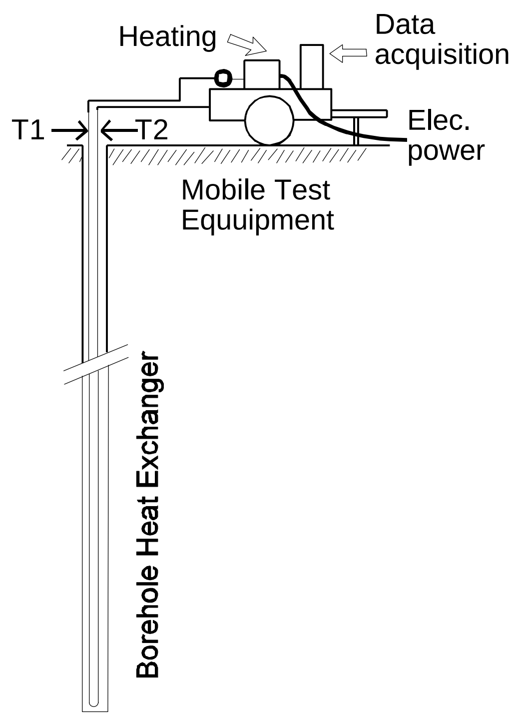


Figure 5. ***Schematic of a Thermal Response Test.***

Thermally enhanced grouting material has been available in USA for more than 10 years. Meanwhile, in Europe such material is also on the market, optimized for the relevant drilling habits and ground situation. The advantage of its use is a significant reduction in the borehole thermal resistance, which governs the temperature losses between the undisturbed ground and the fluid inside the BHE pipes. The table in Figure 6 gives some values for typical BHE; the effect could meanwhile also be demonstrated in situ, using the Thermal Response Test on BHE with different grouting materials.

Type of BHE	? grout	r_b
single-U, PE	0.8 W/m/K	0.196 K/(W/m)
	1.6 W/m/K	0.112 K/(W/m)
double-U, PE	0.8 W/m/K	0.134 K/(W/m)
	1.6 W/m/K	0.075 K/(W/m)

Figure 6. ***Table with data for r_b for different grouting materials.***

Up to now, the upper temperature limits encountered in commercially available heat pumps limit their application to low temperature heating systems. However, traditional heating systems already installed in older buildings in Germany require higher supply temperatures. To allow for retrofit of such systems with a heat pump, development of heat pumps allowing for 65EC and more are under way.

GERMAN EXPERIENCE

Since 1996, the statistics for heat pump sales in Germany allow the distinction of different heat sources (Figure 7). Within the last years, sales of GSHP have shown a steady increase, after the all-time low in 1991 with less than 2,000 units shipped. The share of GSHP (ground and water), which was less than 30% in the late-1980s, has risen to 78% in 1996 and 82% in 2002. Also from 2001 to 2002, when the building market in Germany was shrinking due to the poor economic situation, GSHP sales numbers still had a slight increase. There is still ample opportunity for further market growth, and the technological prospects endorse this expectation.

The application of GSHP in Germany is larger in numbers in the residential sector, with many small systems serving detached houses (Photo 1), but larger in installed capacity in the commercial sector, where office buildings requiring heating and cooling dominate. In most regions of Germany, the humidity in summertime allows for cooling without de-humidification (e.g. with cooling ceilings). These systems are well suited to use the cold of the ground directly, without chillers, and they show extremely high efficiency with cooling COP of 20 or more. The first system with BHEs and direct cooling was built already in 1987 (Sanner, 1990); meanwhile, the technology has become a standard design option. Some recent examples of GSHP systems in Germany can be found in Sanner and Kohlsch (2001).

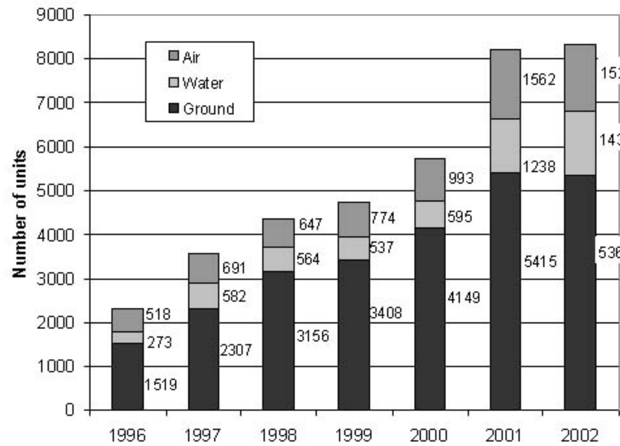


Figure 7. ***Number of annual heat pump sales in Germany, according to heat sources (after data from IZW e.V., Hannover and BWP e.V., Munich; heat pumps used for hot tap water production only are not included).***

Photo 1. ***Installation of borehole heat exchanger at a small house in Bielefeld, Germany, using a small, powerful Rotomax drilling rig.***

In Germany, the GSHP has left the R&D & D-status way behind, and the emphasis nowadays is on optimisation and securing of quality. Measures like technical guidelines (VDI 4640), certification of contractors, quality awards, etc., are beginning to be set into force to protect the industry and the consumers against poor quality and insufficient longevity of geothermal heat pump systems.

THE GEOTHERMAL HEAT PUMP BOOM IN SWITZERLAND

Geothermal heat pump (GHP) systems have spread rapidly in Switzerland, with annual increases up to 15%. At

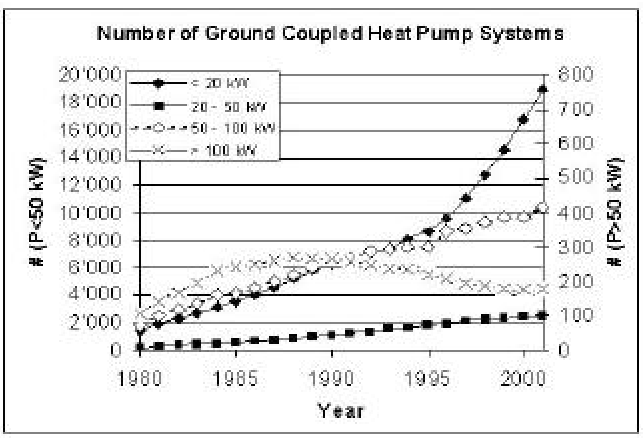
present there are over 25,000 GHP systems in operation. The three types of heat supply systems used from the ground are: shallow horizontal coils (<5 % of all GHPs), borehole heat exchangers (100 - 400m deep BHEs; 65%), and groundwater heat pumps (30%). Just in 2002 alone, a total of 600 kilometers of boreholes were drilled and equipped with BHEs.

GHP systems are ideally suited to tap the ubiquitous shallow geothermal resources. The reliability of long-term performance of GHP systems is now proved by theoretical and experimental studies as well as by measurements conducted over several heating seasons (Eugster and Rybach, 2000). Seasonal performance factors >3.5 are achieved.

The measurements and model simulations prove that sustainable heat extraction can be achieved with such systems (Rybach and Eugster, 2002). The reliable long-term performance provides a solid base for problem-free application; correct dimensioning of BHE-coupled GHPs allows widespread use and optimisation. In fact, the installation of GHPs, starting at practically zero level in 1980, progressed rapidly and now provides the largest contribution to geothermal direct use in Switzerland.

The installation of GHP systems has progressed rapidly since their introduction in the late-70s. This impressive growth is shown in Figures 8 and 9.

Figure 8. ***Development of geothermal heat pump***



installations in Switzerland in the years 1980 - 2001. From Kohl et al., (2002).

The annual increase is remarkable: the number of newly installed systems increase with an annual rate >10%. Small systems (< 20 kW) show the highest growth rate (>15% p.a., see also Figure 1). In 2001, the total installed capacity of GHP systems was 525 MWt, the energy produced about 780 GWh. A large number of wells (several thousand) have been drilled in 2002 to install double U-tube borehole heat exchangers (BHE) in the ground (Photo 2). Average BHE drilling depth is now around 150-200 m; depths >300 m are becoming more and more common. Average BHE cost (drilling, U-tube installation incl. backfill) is now around 45 US$ per meter. In 2002, a total of 600 km of BHE wells were drilled.

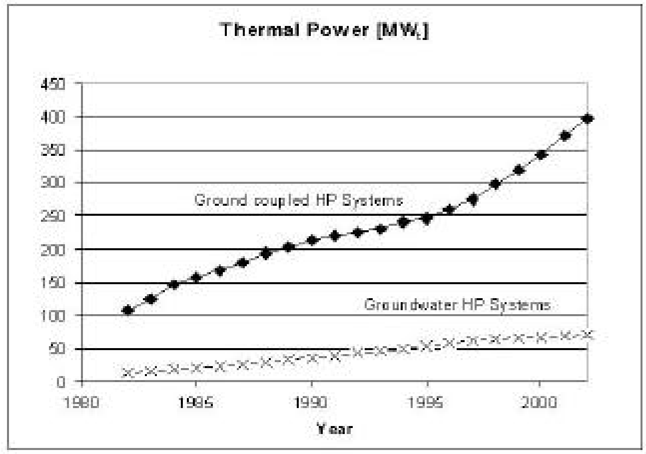


Figure 9. ***Development of installed capacities (MWt) of BHE-coupled (top) and groundwater-based (bottom) geothermal heat pumps in Switzerland during the years 1980 – 2001 (from Kohl et al., 2002).***

The Reasons of Rapid Market Penetration in Switzerland

The main reason for the rapid market penetration of GHP systems in Switzerland is that there is practically no other resource for geothermal energy utilization other than the ubiquitous heat content within the uppermost part of the earth crust, directly below our feet. Besides, there are numerous and various further reasons: technical, environmental, and economic.

Photo 2. End of double U-tube BHE (Geowatt).

<u>Technical Incentives</u>

- Appropriate climatic conditions of the Swiss Plateau (where most of the population lives): Long heating periods with air temperatures around 0^0C, little sunshine in the winter, ground temperatures around 10 - 12^0C already at shallow depth;
- The constant ground temperature provides, by correct dimensioning, a favourable seasonal performance factor and long lifetime for the heat pump;
- The GHP systems are installed in a decentralized manner, to fit individual needs. Costly heat distribution (like with district heating systems) is avoided;

- Relatively free choice of location next to (or even underneath) buildings and little space demand inside; and
- No need, at least for smaller units, for thermal recharge of the ground; as the thermal regeneration of the ground is continuous and automatic during period of non-use (e.g. summer).

Environmental Incentives

- No risk with transportation, storage, and operation (e.g. with oil);
- No risk of groundwater contaminations (as with oil tanks); and
- The systems operate emission-free and helps to reduce greenhouse gas emissions like CO_2.

Economic Incentives

- The installation cost of the environmentally favorable GHP solution is comparable to that of a conventional (oil based) system (Rybach, 2001);
- Low operating costs (no oil or gas purchases, burner controls etc. as with fossil-fueled heating systems);
- Local utility electricity rebates for environmentally favorable options like heat pumps; and
- A CO_2 tax is in sight (introduction foreseen for 2004).

A further incentive and reason for rapid spreading of GHP systems is "Energy Contracting" by public utilities. The latter implies that the utility company plans, installs, operates, and maintains the GHP system at own cost and sells the heat (or cold) to the property owner at a contracted price (cents/kWh).

Outlook in Switzerland

Whereas the majority of GHP installations serve for space heating of single-family dwellings (± sanitary water warming), novel solutions (multiple BHEs, combined heat extraction/storage {e.g., solar energy}, geothermal heating/cooling, "energy piles") are rapidly emerging. With over one GHP units every two km^2, their areal density is the highest worldwide. This secures Switzerland a prominent rank in geothermal direct use (for installed capacity per capita among the first five countries worldwide). It is expected that the GHP boom in Switzerland will prevail for quite some time.

GEOTHERMAL HEAT PUMPS IN THE UK

While the UK can lay claim to the efforts of Lord Kelvin in developing the theory of the heat pump, the adoption of heat pumps for heating buildings has been inexorably slow. The first documented installation of a ground-source heat pump comes from the 1970s (Sumner, 1976). Another pioneer championed the installation of small closed loop systems in houses in Scotland during the early-90s. It then took time to discover why the adoption of this technology in the UK was so far behind the burgeoning activity in northern Europe and North America. The primary reasons are a relatively mild climate, poor insulation levels of the housing stock, lack of suitable heat pumps, and competition from an extensive natural gas grid. (Curtis, 2001)

In the mid-1990s, geothermal heat pumps slowly began to evolve–with lessons being learned from practices adopted in Canada, America and northern Europe. It has taken time to identify the appropriate technology to be used in UK housing stock and to overcome issues that are unique to the UK. An additional complication is the complexity of the geology of the UK within a relatively small geographical area.

In the last two years, geothermal heat pumps have been officially recognised as having a role to play in several UK initiatives–for example the affordable warmth program, renewable energy and energy efficiency targets.

The little known fact about these systems in the UK, is the dramatic reduction in carbon dioxide emissions that can be achieved compared to conventional systems. A geothermal heat pump connected to the UK electricity grid will lead to overall reductions in CO_2 emissions of between 40 and 60%--immediately. As the UK generating grid (presumably) gets cleaner over the years to come, so the emission levels associated with long-lived geothermal heat pumps will continue to fall even further. Architects and developers are also finding that new assessment criteria for buildings are beginning to take account of the carbon performance of new properties.

From very small beginnings, geothermal heat pumps are now beginning to appear at locations all over the UK, from Scotland to Cornwall. Self-builders, housing developers and housing associations are now customers of these systems. Domestic installations ranging in size from 25 kW to 2.5 kW, using a variety of water-to-water or water-to-air heat pumps are now operational employing several different ground configurations.

A recently announced funding scheme (the Clear Skies programme) will assist in giving the technology official recognition, and will establish credible installers, standards and heat pumps that are suitable for the UK domestic sector. Together with a 1,000-house program launched last year by a major UK utility (Powergen), it is expected that there will be significant growth in interest and many successful installations of geothermal heat pumps in the domestic sector throughout the UK over the next few years.

Another important area of activity is the application of geothermal heat pumps to commercial and institutional buildings where heating and cooling is required. In 2002, the IEA Heat Pump Centre commissioned the first of a series of country studies into the contribution that heat pumps could make to CO_2 reductions (IEA, 2002). The first of these was carried out on the UK, and the conclusions were that the largest contribution that geothermal systems could make is in the office and retail sector. The first non-domestic installation, at only 25kW, was for a health centre on the Isles of Scilly. This was rapidly followed between 2000, and today with installations growing in size and sophistication up to 300kW. The applications range through schools, single and multi-storey office blocks, and several visitor/exhibition centers. Notable examples are the National Forest Visitor Centre, in Derbyshire, office blocks in Chesterfield, Nottingham, Croydon, and Tolvaddon Energy Park in Cornwall (Photo 3). A large installation has just been commissioned at a new IKEA distribution center in Peterborough. These installations use a variety of heat pump configurations, ranging from simple heating only of underfloors, reverse cycle heat pumps delivering heating or cooling, and sophisticated, integrated units delivering simultaneous heating and cooling. Stand-alone and hybrid configurations have been used, with some applications using large horizontal ground loop arrays, and others employing grids of interconnected boreholes

Photo 3. ***Drilling for a GSHP installation in progress in Cornwall, UK (Geoscience).***

GEOTHERMAL HEAT PUMPS IN SWEDEN

Ground-coupled heat pumps gained popularity in Sweden in the early-1980s and by 1985, about 50,000 units had been installed. Then lower energy prices and quality problems deflated the heat pump market, and during the next 10 years, an average of about 2,000 units were installed per year. In 1995, the public awareness and acceptance of ground-coupled began to grow due to strong support and subsidies from the Swedish state. In 2001 and 2002, about 27,000 ground-coupled heat pumps were installed (see Figure 10) according to the sales figures from the Swedish Heat Pump Organization (SVEP), which is believed to cover about 90% of the residential market. The total number of installation is, therefore, estimated to be about 200,000.

Heat pumps are now the most popular type of heating device for small residential buildings with hydronic systems in Sweden; where, the heat pump replaces oil burners because of current oil prices, electric burners because of expected electricity rates, and wood stoves because of convenience. Conversion from direct electric heating goes much slower. In addition to the residential sector, there are also some large-scale installations (closed and open-loop) for district heating networks. The average heat output of all heat pump units is estimated to be about 10 kW.

Swedish ground-coupled heat pump installations are usually recommended to cover about 60% of the dimensioning load, which results in about 3500-4000 full-load hours per year. Electric heaters integrated in the heat pump cabinet cover the remaining load. There is a trend to increase the heat pump load fraction to 80 - 90%. It is estimated that about 80% of all installations are vertical (boreholes). In the residential sector, the average depth of vertical installations is about 125 m and the average loop length of horizontal installations is about 350 m. Single U-pipes (polyethylene tubes, diameter 40 mm, pressure norm 6.3 bars) in open, groundwater-filled are used in almost all installations. Double U-pipes are sometimes used when heat is injected into the ground. Thermal response tests have demonstrated that natural convection enhances the heat transfer in groundwater-filled boreholes compared with sand-filled (and grouted) boreholes. The popularity of ground-coupled heat pumps has raised concerns of long-term thermal influence between neighbouring boreholes.

Larger systems for multi-family dwellings are becoming more popular. Free cooling from vertical installations is marketed but still finds little interest in the residential sector. The increasing interest of cooling in the commercial and industrial sector opens up a new market for ground-coupled heat pumps.

Technical development of heat pumps involves a trend where piston compressors are slowly replaced by scroll compressors, which are valued for the relatively quiet operation and compact design. There is also an interest in variable capacity control such as using one small and one large compressor in the same machine, so that domestic hot water can be produced with the smaller compressor in the summer. Most of the imported heat pumps use refrigerant fluid R410A. Swedish manufacturers still use R407C, but there is a trend to use more R410A and there is also an interest in propane. Research is ongoing to construct heat pumps with very low volume of refrigerant. Some manufacturers are marketing heat pumps that utilize exhaust air and ground as a heat source. The exhaust air can be used for preheating the heat carrier fluid from the borehole or for recharging of the ground when the heat pump is idle.

In larger borehole systems, the heat balance of the ground has to be considered in order to ensure favorable long-term operational conditions. If the heat load dominates, the ground may have to be recharged with heat during the summer. Natural renewable sources such as outside air, surface water, and solar heat should be considered. At Näsby Park (close to Stockholm), there is an installation under construction with 48 boreholes to 200 m depth; where, a 400-kW heat pump is used for base heat load operation during 6,000 hours per year. The boreholes are recharged with warm (15-20°C) surface water from a nearby lake during the summer.

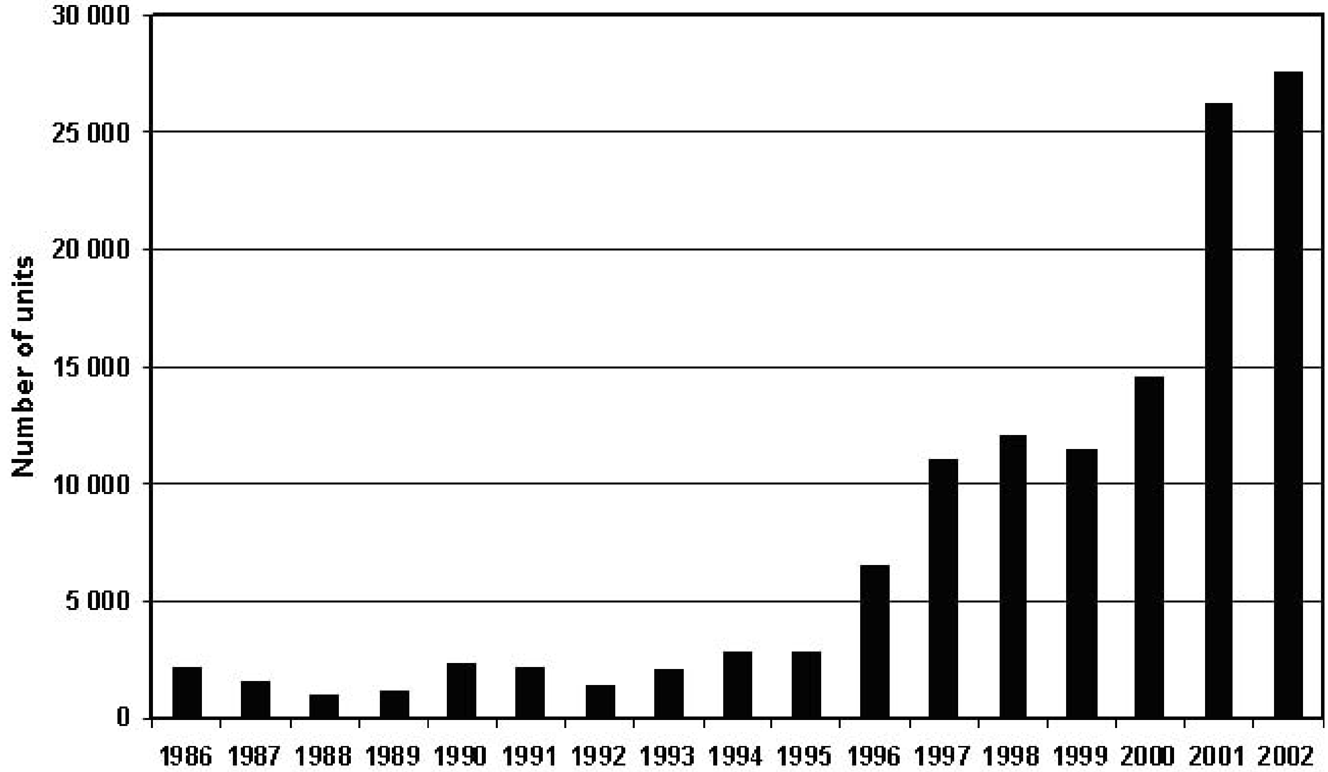


Figure 10. ***Number of annual heat pump sales in Sweden (after data from the Swedish Heat Pump Organization (SVEP)).***

EXAMPLE FROM NORWAY

In Nydalen, Oslo, 180 hard rock wells will be a key factor in providing heating and cooling to a building area of close to 200,000 m^2. The project is the largest of its kind in Europe (Photo 4)

Photo 4. ***The well field for the Nydalen GSHP in Oslo, Norway; the station will supply several buildings.***

An energy station will supply the emerging building stock in Nydalen with heating and cooling. By using heat pumps and geothermal wells, heat can both be collected from and stored in the ground. In the summer, when there's a need for cooling, heat is pumped into the ground. Bedrock temperature may then be increased from a normal of 8EC up to 25EC. During the winter season, the heat is used for heating purposes. The output is 9 MW heating and 7.5 MW cooling. Annual energy purchase is to be reduced by an anticipated 60-70 percent, compared to heating by electricity, oil or gas. The combined heating and cooling secures a high utilization of the energy station.

The most unique aspect of the project is the geothermal energy storage. Each of the 180 wells has a depth of 200 metres, providing 4 - 10 kW. The total bedrock area of thermal storage has a volume of 1.8 million m^3, located below the building area. Plastic tubes in closed circuits are used for transferring the heat.

Total cost of the project is NOK 60 million (7.5 million Euro). This is about NOK 17 million more than the cost of a conventional solution (i.e. without the energy wells and the collector system). However, with an anticipated reduction in annual energy purchases of close to NOK 4 million, the project will be profitable. The project has received a total financial support of NOK 11 million from the government owned entity Enova SF and the Energy fund of the Municipality of Oslo.

Start-up of the energy Station was planned for April 2003, including about half of the wells. The remaining wells will most probably be connected to the station in 2004.

You can read more about the project at www.avantor.no (project owner) and www.geoenergi.no (thermal energy storage).

CONCLUSIONS: THE RENEWABLE ARGUMENT FOR GEOTHERMAL HEAT PUMPS

While installations of these systems have been quietly growing, there has been limited recognition that they make a contribution to the adoption of renewable energy. This is partly because they are purely associated with the provision of heating and cooling, and therefore, do not figure in renewable electricity considerations. However, there are two other factors--a question mark over the sustainability of the energy from the ground, and a widespread notion, based on air source heat pumps, that there is no net gain in energy output--and that they are, therefore, only an energy efficiency technology.

During the 1950s and 60s when air-source heat pumps came in to vogue, electricity was being generated in central station fossil fuel plants with efficiencies approaching 30%. Air-source heat pumps of the time delivered SPFs (COPs) (seasonal performance factors) ranging between 1.5 and 2.5 typically. While Table 2 shows that at the point of delivery in the building, 60% of the energy is extracted from the air, only 75% of the original energy used to generate the electricity has been recovered as useful heat. Thus, while renewable energy from the air has been used to deliver thermal energy efficiently, no net gain has resulted. The second column of Table 2 demonstrates today's figures. New co-generation or combined cycle generating plant can deliver electricity with efficiencies exceeding 40%. Ground-coupled heat pumps are demonstrating SPFs in excess of 3.5. This results in an apparent "efficiency" of 140%, with 71% of the final energy now coming from the ground. More importantly there is an excess of 40% over and above the original energy consumed in generating the electricity.

Table 2. Energy and Efficiency Comparisons

	Old (Air-Source +Old Fossil Fuel)	New (Water-Source + New Fossil Fuel)
Electric generation efficiency	0.3	0.4
COP or SPF	2.5	3.5
Delivered energy/consumed energy	0.75	1.4
Delivered renewable energy	60%	71%
"Excess" renewable energy	-25%	40%

It is this combination of the efficiency of ground coupled water-source heat pumps, with new electrical generation efficiency that results in the liberation of an excess of renewable energy.

If the electricity can be generated from renewable sources in the first place, then all of the delivered energy is renewable. There are suggestions that it in order to maximize the delivery of renewable energy, it makes economic sense to couple expensive renewable electricity to ground coupled heat pumps as quickly as possible.

While the energy argument may be contentious, the reduction in CO_2 emissions is easier to demonstrate. The coupling of ground-source heat pumps to the current UK electricity grid, for example, can lead to reductions in overall CO_2 emissions of over 50% compared to conventional space heating technologies based on fossil fuels. This arises from the current generation mix on the UK grid. As the amount of CO_2 emitted by electricity generation falls, so the reduction in CO_2 emissions through the use of ground-source heat pumps will increase. With the use of renewable-derived electricity there need be no CO_2 emissions associated with the provision of heating (and cooling) of a building.

If one looks at the worldwide savings of TOE (tons of oil equivalent) and CO_2 for the current estimated installed capacity of geothermal (ground-source) heat pumps, several assumptions must be made. If the annual geothermal energy use is 65,000 TJ (18,000 GWh) and comparing this to electricity energy generation using fuel oil at 30% efficiency, then the savings are 35.8 million barrels of oil or 5.4 million TOE. This is a savings of about 16 million tonnes of CO_2. If we assume savings in the cooling mode at about the same number of operating hours per year, these figures would double.

FURTHER INFORMATION

- International Ground Source Heat Pump Association, Oklahoma State University, Stillwater, OK (www.igshpa.okstate.edu).
- Geothermal Heat Pump Consortium, Washington, DC (www.geoexchange.org).
- IEA Heat Pump Centre, Sittar, the Netherlands (www.heatpumpcentre.org).
- European Geothermal Energy Council (www.geothermie.de/egec_geothernet/menu/frameset.htm).
- European Heat Pump Association (www.ehpa.org).

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REFERENCES

Curtis R H., 2001. "Earth Energy in the UK." *Proc. International Geothermal Days Conference*, Bad Urach, Germany, Sept. Also in the *Geo-Heat Center Quarterly Bulletin*, Vol 22, No 4, Klamath Falls, Oregon, USA, Dec 2001.

Donnerbauer, R., 2003. Neuer Trend: Vom Boden an die Wand. – VDI-Nachrichten 16/2003, p. 11, Düsseldorf

Eugster W. J. and L. Laloui, L, (eds.), 2002. Geothermische Response Tests, 130 p., GtV, Geeste, ISBN 3-932570-43-X

Eugster, W. J. and L. Rybach,, 2000. "Sustainable Production from Borehole Heat Exchanger Systems." *Proc. World Geothermal Congress 2000*, Kyushu-Tohoku, Japan, p. 825-830.

Hellström, G. and B. Sanner, 2001. "PC-Programs and Modeling for Borehole Heat Exchanger Design." *Proc. IGD 2001 Bad Urach, Supplement*, ISS Skopje / GtV Geeste, available at http://www.uni-giessen.de/~gg1068/html/literatur.html

IEA, 2002. "Reducing Carbon Emissions with Heat Pumps, the UK Potential." HPC-AR-15. IEA Heat Pump Centre, November, Netherlands, 2002.

Kavanaugh, S. P. and K. Rafferty, 1997. *Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings*, American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), Atlanta, GA (can be ordered at: www.ashrae.org)

Kohl, Th.; Andermatten, N. and L. Rybach, 2002. "Statistik Geothermische Nutzung in der Schweiz für die Jahre 2000 und 2001." Report to Swiss Federal Office of Energy Bern, 25 p.

Lund, J. W., 2001. "Geothermal Heat Pumps – An Overview." *Geo-Heat Center Quarterly Bulletin*, 22/1 (March), Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR (available at: http://geoheat.oit.edu).

Rafferty, K., 1997. "An Information Survival Kit for the Prospective Geothermal Heat Pump Owner." Geo-Heat Center, Klamath Falls, OR (available at: http://geoheat.oit.edu).

Rybach, L., 2001. "Design and Performance of Borehole Heat Exchanger/Heat Pump Systems." *Proc. European Summer School of Geothermal Energy Applications*, Oradea/Romania (CD-ROM).

Rybach, L. and W. J. Eugster, 2002. "Sustainability Aspects of Geothermal Heat Pumps." *Proc. 27th Workshop on Geothermal Reservoir Engineering*, Stanford University, California/USA (CD-ROM).

Sanner, B., 1990. "Ground-Coupled Heat Pump Systems, R&D and Practical Experiences in FRG.: *Proc. 3rd IEA Heat Pump Conference*. Tokyo 1990, pp. 401-409, Pergamon Press, Oxford.

Sanner, B., 1999. "Prospects for Ground-Source Heat Pumps in Europe." *Newsletter IEA Heat Pump Center*, 17/1, pp. 19-20, Sittard.

Sanner, B. and O. Kohlsch, 2001. "Examples of GSHP from Germany." *Proc. IGD 2001 Bad Urach, Supplement*, ISS Skopje / GtV Geeste, available at http://www.uni-giessen.de/~gg1068/html/literature.html

Sumner J., 1976. Domestic Heat Pumps. Prism Press, ISBN 0 904727 09 2, 1976.

VDI 4640, 2002. "Thermal Use of the Underground, Guideline of the German Association of Engineers (Verein Deutscher Ingenieure, VDI)." 4 parts, 2000-2002, Beuth Verlag, Berlin

100 YEARS OF GEOTHERMAL POWER PRODUCTION

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INTRODUCTION

Electricity from geothermal energy had a modest start in 1904 at Larderello in the Tuscany region of northwestern Italy with an experimental 10 kW-generator. Today, this form of renewable energy has grown to 8771 MW in 25 countries producing an estimated 54,793 GWh/yr. These "earth-heat" units operate with an average capacity factor of 71%; though, many are "on-line" over 95% of the time, providing almost continuous base-load power. This electricity production is serving an equivalent 60 million people throughout the world, which is about one percent of our planet's population. The development of worldwide geothermal power production can been seen in Figure 1. The large downward spike in the production is the result of the destruction of the Italian field at the end of World War II–discussed later. Since WWII, geothermal power has grown at a rate of 7.0% annually. Electric power from geothermal energy, originally using steam from resources above 150°C, is now produced from resources down to 100°C using the organic Rankine cycle process in binary power units in combination with a district heating project.

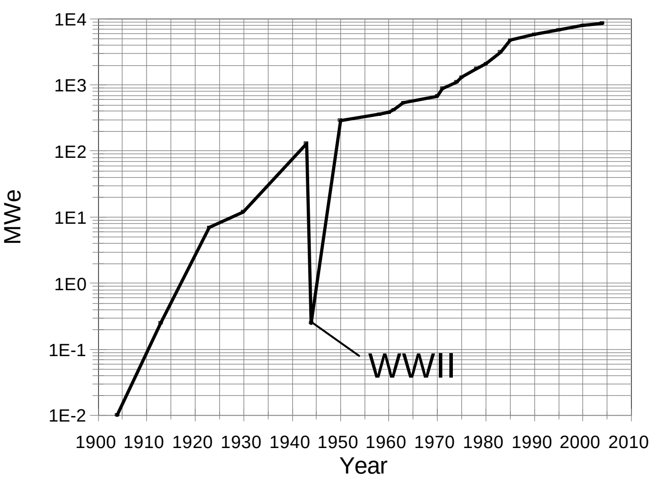

Figure 1. World geothermal power production 1904-2004.

THE EARLY YEARS – DRY STEAM DEVELOPMENT

Geothermal energy was not new to the Larderello area in 1904, as sulfur, vitriol, alum and boric acid was extracted from the hot spring areas, and marketed at least since the 11th century. In the late 18th century, boric acid was recognized as an important industry in Europe, as most was imported from Persia. Thus, by the early-1800s, it was extracted commercially from the local borate compound using geothermal heat to evaporate the borate waters in *lagoni* or *lagone coperto*--a brick covered dome (Figure 2). Wells were also drilled in the early-1800s in the vicinity of fumaroles and natural hot pools to access higher boron concentrations.

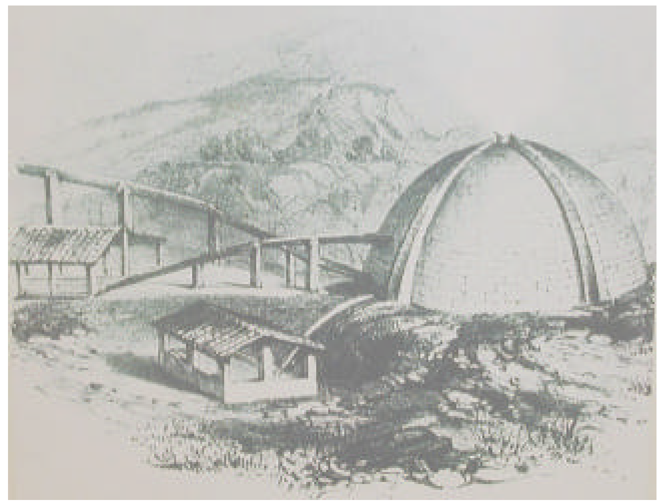

Figure 2. Covered lagoon ("lagone coperto"), Larderello, Italy, 1904 (courtsey of ENEL), 18th century.

In the beginning of the 19th century, the Larderello chemical industry came under the direction of Prince Piero Ginori Conti. He experimented with the use of geothermal steam as an energy source for electrical production. He carried out his investigations for several years and was rewarded with success in 1904, when five light bulbs were lighted using geothermal power. He used a piston engine coupled with a 10-kilowat dynamo; the engine was driven by pure steam produced in a small heat exchanger fed with wet steam from a well near Larderello (Figure 3). This engine used an "indirect cycle"–that is the geothermal fluid heated a secondary pure water to produce steam that moved the piston generator set. This was the first binary cycle–using a secondary working fluid. The "indirect cycle" protected the piston from the potential harmful affects of chemicals in the geothermal fluid.

Encouraged by the results from this "first" experiment, Prince Conti developed the "first" prototype of a geothermal power plant, which went into operation in 1905. This Cail reciprocating engine connected to a 20-kilowatt dynamo along with a Neville Reciprocating engine coupled to a second 20-kilowatt dynamo in 1908 enabled the electrification of Larderello's most important industrial plants and the main residential buildings. In 1913, the "first" commercial power plant, named Larderello 1, was equipped

Figure 3. Prince Ginori Conti and the 10-kW experimental power plant, Larderello, Italy, 1994 (courtesy of ENEL).

with a turbine generating 250 kilowatts of electricity (Figure 4). It was designed and built by the Tosi Electromechanical Company to operate with wellhead fluid pressures of up to three atmospheres. The turbine was driven with pure steam obtained from a heat exchanger supplied by geothermal fluids from two wells at 200 to 250ºC. The energy from this plant was fed into a network serving all the chemical production plants and the main buildings of Larderello, and the villages of the region.

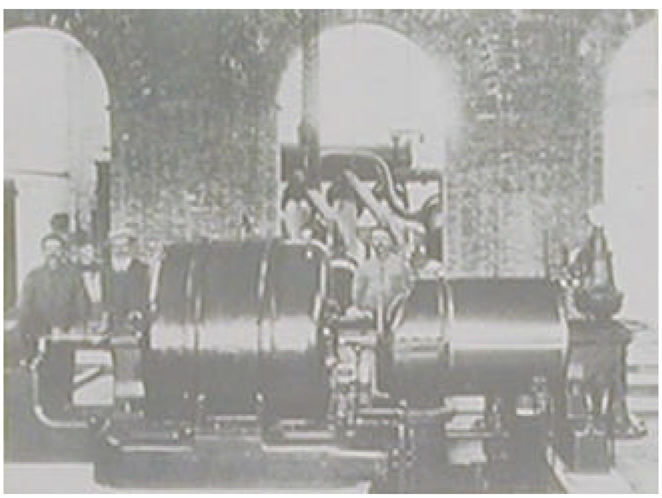

Figure 4. First commercial geothermal power plant, 250 kW, Larderello, Italy, 1913 (courtesy of ENEL).

By 1923, two 3.5-megawatt turbo alternators units using the "indirect cycle" were installed, equaling most of the world's installed hydroelectric and thermal power plants of the time. The "first" pilot turbine fed directly with natural steam produced from the wells or "direct cycle," with a capacity of 23 kilowatts was installed at Serrazano in 1923 (Figure 5). Other "direct cycle" plants at Castelnouovo (600 and 800 kW) and at Larderello (3.5 MW) followed in the late-1920s. Thus by 1930, the installed capacity of this Boraciferous region was 12.15 MW of which 7.25 MW used the "indirect cycle" and 4.90 MW the "direct cycle." The "indirect cycle" plants remained popular, as the natural steam produced by the wells at Larderello was more valuable to extract valuable chemical by-products.

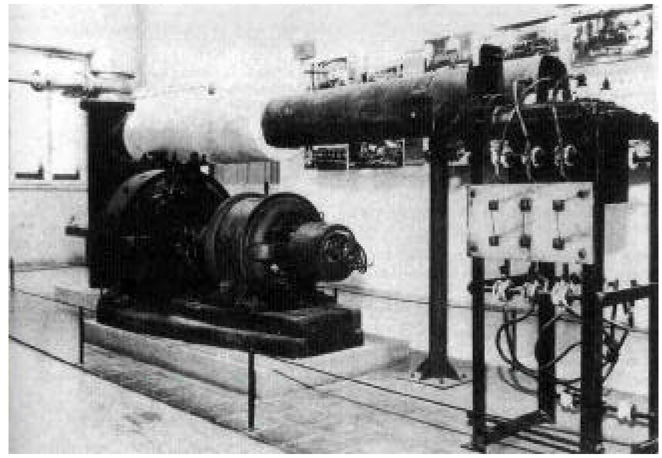

Figure 5. First "direct cycle" power plant, Serrazzano, Italy, 1923 (courtesy of ENEL).

At the end of 1943, the total installed capacity in the Boraciferous region was 132 MW of which 107 MW used the "indirect cycle." The others were exhausting-to-atmosphere units or "direct cycle." Unfortunately in 1944, the Larderello region was directly involved in World War II. The Larderello power plants were strategically important because they provided electricity to the whole railway network of central Italy. In the spring of 1944, not far from Larderello, the retreating armies then in Italy formed the "Gothic Line' which separated the two warring groups. All the geothermal power stations and chemical plants in the area were heavily bombed and destroyed (Figure 6), and almost all the production wells were blown up by charges placed at the base of the master valve. Only the 23-kW "direct cycle" plant survived–which has been used at the company school to train technical personnel since 1925.

Figure 6. Geothermal plant at Larderello, destroyed in WWII, 1944 (courtesy of Ian Thain).

With hard work, the capacity of the region was reconstructed and reached almost 300 MW by 1950, and has continued to increase over the years to the present installed capacity of 790.5 MW (699 MW operating capacity) producing 5.3 billion kWh in 2003. Many of these earlier plants have natural draft cooling towers that dominated the landscape. However, the newer plants are designed to have a low profile with forced draft cooling towers and are architecturally pleasing in appearance (Figure 7). Most of these plants are supplied by "dry steam" wells that produce only high-temperature steam–thus, eliminating the need to separate steam from water.

Figure 7. Geothermal power plant at Larderello today (courtesy of ENEL).

THE NEXT STAGE – WET STEAM DEVELOPMENT

A major geothermal resource with surface manifestations occurs at Wairakei, in the volcanic region of North Island of New Zealand. Thus, during World War II, New Zealand government scientists arranged for army engineers serving with the British 8th Army in the Italian campaign, to visit, inspect and report on the Larderello geothermal power development. Unfortunately, when they got to the plant in June 1944, it had been total destroyed.

Further interest in the development of the Wairakei field came in 1947 from severe electricity shortages following two dry years which restricted hydro generation and a desire by the government for the New Zealand electricity supply to be independent of imported fuel. Thus in 1948, New Zealand engineers were again sent to Larderello; where, they found rebuilt power plants producing over 140 MW and another 142-MW station under construction.

These observations of the power plants and geothermal use at Larderello were important; however, the New Zealand engineers faced a more complicated problem. Whereas, the Larderello resource was of the "dry steam" type, Wairakei was a "wet steam" resource. This meant that New Zealand technology had to be developed to separate the steam from the high-temperature hot water, produced at 13.5 barg (approximately 200ºC). Thus, encouraged by the enthusiasm of the Italian engineers for geothermal power production, New Zealand decided to proceed with the development of Wairakei.

Drilling started in 1949, with some spectacular results (Figure 8), and 20 MW of power was proven by 1952. The initial plans for Wairakei was a combined power station and a heavy water plant. Conceptual designs in 1954 provided for a 47-MW power plant and production of 6 tonnes per year of heavy water. However, the heavy water plant idea was abandoned in 1956 and thus, the electric power station, Wairakei "A," was redesigned for two high pressure (HP) units of 6.5 MW, two intermediate pressure (IP) units of 11.2 MW, and three low pressure (LP) condensing units of 11.2 MW, giving a total installed capacity of 69 MW. The HP units used flashed steam at the wellhead of 13.5 barg, the IP units used 4.5 barg, and the LP units used a pressure of just above one barg. Due to increased output from the wells, two addition HP units of 11 MW and one LP unit of 11 MW were added to Wairakei "A" Station. Additional generating capacity was added through a "B" Station, which brought the entire development to 192.6 MW.

Figure 8. Drilling a Wairakei, New Zealand, 1950s (courtesy of Ian Thain).

In November of 1958, the first turbine-generator sets in "A" Station were synchronized to the national grid– the first geothermal electrical development in the world using "wet steam." High-temperature and pressure well water of five HP and two IP wells was fed into a flash plant; where, the pressure was reduced and a fraction of the water (15 to 20%) is flashed to steam in successive stages. The Wairakei Separator was developed for this task, which used a tangential entry bottom outlet tank. The center of the production field is approximately 3.5 km from the power station, and the steam is transmitted to the power station via three 760 mm and five 508 mm diameter pipelines (Figure 9). The power station is located adjacent to the Waikato River; where, the water is used for the direct contact condensers (Figure 10). Condensing the steam with river water exiting from the turbine reduces the pressure to a vacuum, thus increasing the pressure drop across the turbine, which in turn increases the output efficiency by as much as 100% compared to atmospheric exhaust plants.

With time, both double flash and triple flash turbines were installed to take advantage of the three-pressure levels of steam. Due to steam decline, the HP systems were derated and only IP and LP steam are only used today. Other fields at Ohaaki, Rotokawa, Mokai, Kawerau and Ngawha have been added to the geothermal power generating network with a total installed capacity of 453 MW (334 MW operational) of which 162 MW are at Wairakei. These plants operate with a capacity factor of 90 to 95%, providing the country with about 5% of its installed electricity capacity and 6% of the energy generated.

Figure 9. Wairakei, New Zealand geothermal field.

Figure 10. Wairakei power plant with Waikato River in background, New Zealand.

EARLY DEVELOPMENTS IN THE AMERICAS

United States

The surface geothermal manifestations at The Geysers geothermal field in northern California, was used by Indians who cooked with the steam and hot water at thermal features, and basked and bathed for pleasure and cures. In the mid-1880s, European settlers "discovered" the area and referred to them as the "Gates of Hades." The area was then developed for tourists with the construction of The Geysers Hotel. By the 1880s, the hotel had earned an international reputation as a resort and spa. By the early-1920s, the resource was being considered for electrical power generation. Well No. 1 was drilled in 1921 and at a shallow depth "…the well blew up like a volcano." A second well, also called No. 1, was drilled in 1922 and controlled, but not before it blew out "…mud, tools, rocks, and steam"--the world's first successful geothermal well drilled for electrical power generation outside of Larderello. Steam was found at about 60 meters–a second "dry steam" field. Well No. 2 was completed in 1923 to a depth of 97 m with a temperature of 153ºC and 4 barg pressure.

John Grant constructed the first power plant at The Geysers in the early 1930s near wells No. 1 and 2 (Figure 11). It was a 35-kilowatt power plant containing two reciprocating, steam-engine-driven turbine generators from General Electric. Various metal alloys were heated to determine the best composition for the turbine blades–as the steam was used directly in the turbine–unlike the early "indirect steam" plants at Larderello. A contract was signed to sell the energy to nearby Healdsburg City; however, an oil glut hitting the West Coast of the U.S., made electricity generated from this fuel more attractive. The contract was cancelled in 1934 and at least one of the two original generators was moved to The Geysers Resort. Here, electricity was generated for the hotel, cottages, bathouse and grounds into the 1950s.

Figure 11. First power plant at The Geysers, USA, early-1930s (courtesy of Geothermal Resources Council).

B.C. McCabe, who had created Magma Power Company, drilled the first modern well, Magma No. 1, in 1955. Dan McMillan Jr. created Thermal Power Company in 1956, and together these two companies began drilling five wells over the next two years--the deepest at 427 meters. In 1958, Pacific Gas & Electric Company (PG&E), a major public utility in Northern California, signed a contract to purchase steam from the Magma-Thermal venture, the first modern commercial agreement for geothermal electrical power generation in the United States. PG&E built power plant Unit 1 and began operating in 1960–the first modern power plant to generate electricity from geothermal steam in the U.S.

By 1968, the capacity of the field increased to 82 MW and wells reach to depths of 600 meters. In 1967, Union Oil Company of California became the field operator. By

1989, twenty-nine units had been constructed with an installed capacity of 2,098 MW. Today, Calpine Corporation and Northern California Power Agency (NCPA) operate the field with a gross capacity of 936 MW from 22 units (Figure 12). The reduction in capacity is due to the dismantling and retirement of a number of units, a reduction in steam production due to "too many straws sucking from the reservoir" and only about 20% of the produced fluid being injected back into the reservoir. This reduction is being reversed in several units by the Southeast Geysers effluent recycling system (SEGEP). This project and the more recent one from the city of Santa Rosa injects recycled wastewater into the reservoir to recover more steam for power production. A total of 820 liters/second is being injected through two large pipelines. To date, the inject water from SEGEP has brought back 77 MW and another 100 MW increase is expected from the Santa Rosa project.

Figure 12. Modern 110-MW plant at The Geysers, California.

The total installed capacity in the U.S. is now about 2400 MW (2020 operating) generating about 16,000 GWh/yr for a capacity factor of 90%.

Mexico

Another "dry steam" field was developed at Pathé in central Mexico. It was the first geothermal zone explored in the country between 1950 and 1955. In 1955, the first exploration well was drilled. Over 24 wells, to depths of 195 to 1288 meters, were drilled over the next four years, with three successful ones used to supply steam to a geothermal power plant of 3.5 MW in 1959. The geothermal plant, the first commercial one on the American Continent was operated until 1972, when it was abandoned and dismantled.

Later fields at Cerro Prieto, just over the U.S. border near Mexicali, and at Los Azufres, between Mexico City and Guadalajara were developed. They, with two other smaller fields, now have an installed capacity of 953 MW producing 6,282 GWh/yr (2003) for a capacity factor of 75%.

DEVELOPMENTS IN ASIA

Japan

Small geothermal test plants were made in Beppu (1925) and Otake (1926) geothermal fields on the southern island of Kyushu. These tests were based on the idea that "… volcanoes have enormous heat energy as seen in volcanic explosions." However, these trials were not successful.

The first commercial power plant was put online at Matsukawa on northern Honshu in 1966. This 23-MW condensing power plant uses a "dry steam" resource. Like Larderello and The Geysers, this is one of the few sites in the world where "dry steam" is available. This plant is the result of drilling in 1953 in the hope of discovering a source of hot water to supply a health spa. Instead, many of the wells produced steam at a depth of 160 to 300 meters. Before the power station was constructed, tests were run for 18 months on a 450-kW atmospheric exhaust (back-pressure) turbine to assess the corrosion effects on various materials from exposure to geothermal steam and its condensate. Five wells now provide superheated steam at a pressure of 4.4 barg and temperatures ranging from 153 to 190ºC. A natural draft tower, the only one of its type in Japan, provides water for the direct-contact condenser (Figure 13).

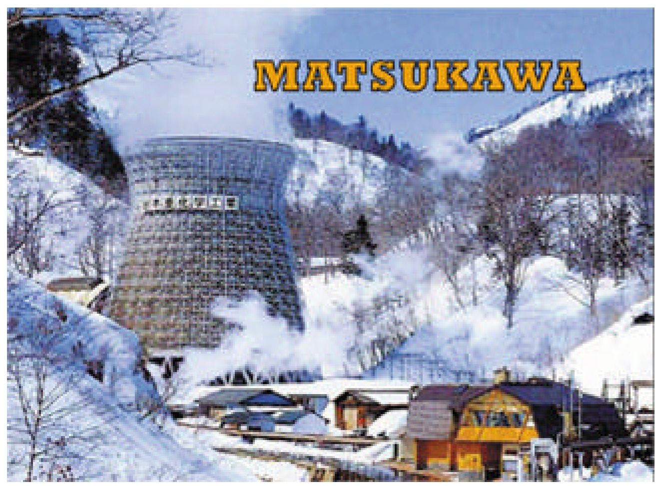

Figure 13. First power plant in Japan, 23-MW "dry steam" at Matsukawa.

Japan now has an installed capacity of 535 MW with plants distributed over 14 fields producing 3470 GWh/yr (1999-2000) for a capacity factor of 74%.

Russia

The Paratunka geothermal power plant, located on the Kamchatka peninsula in eastern Siberia, was an attempt to provide cascaded energy for use in both electric power generation and direct-use. The power plant began operation in 1967 (Figure 14), and was the first to use an organic binary fluid in the power cycle, R-12 refrigerant, as the working fluid heated so that it vaporized by geothermal water at 81ºC–which is the lowest geothermal fluid temperature recorded for electric power generation!

Figure 14. ***First binary plant using 81°C water at Paratunka, Kamchatka, Russia, 1967.***

The power from the plant served a small village and several Soviet state farms. The geothermal water, after leaving the plant, was cooled to 45°C and used to heat the soil in a series of greenhouses. Finally, the cooling water leaving the condensers of the power plant was used to water the plants in the greenhouse, as the water from the local river was too cold to use. The power plant has since be shut down and dismantled, mainly due to leaks in the refrigerant piping.

A second plant at Pauzhetka in the same region was also put into production in 1967. This plant is a flash steam type using a cyclone separator, consisting of two units combining to 5 MW capacity. Nine wells are used to supply the plant, providing 2 to 4 barg pressure at 127°C. Another 11 MW have been added at Pauzhetka, along with 12 MW at the Severo-Mutnovka field. A 50-MW plant, consisting of two 25-MW units, at Mutnovsky was recently completed. Several smaller plants have been constructed on the Kuril Islands producing about 11 MW of power.

The total installed capacity of geothermal power plants in Russia, all located in the Kamchatka and Kuril Islands area, is 100 MW. These plants are critical, as all power in this area has to be produced for local plants. Due to heavy snowfalls in the area, the new plant at Mutnovsky, is designed to be remotely operated.

Peoples Republic of China

In the early-1970s, recognizing the importance of geothermal energy as an alternative source of electrical power, small experimental power units were established along the east coast of China at Fengshun in Guangdong Province in 1970 (0.3 MW flash steam), followed by small binary plants, around 0.3 MW capacity, using temperatures between 80 and 100°C at Wentang and Huailai in 1971, Huitang in 1975 and Yingkou in 1977. It was found that these units were too small and the efficiency too low due to the low temperature of the geothermal water, and all have been shut down. In 1977, a geothermal power plant was put online at Yangbaijing in Tibet supplying power to Lhasa. The installed capacity was 3 MW using 202°C fluid of which 5 to 20% was flashed to steam. Today, the installed capacity, all located in Tibet, is 32 MW supplying over 50% of the electric power to Lhasa.

ICELAND

The first geothermal power plant was placed online in 1969 at Namafjall in northern Iceland (also known as Kisilidjan). This 3-MW non-condensing (back-pressure) plant was purchased second-hand from England to reduce construction time (Figure 15). The energy is supplied to a diatomaceous earth drying plant located next to Lake Myvatn. Diatomaceous earth, with moisture contents at 80%, is dried in rotary drum driers and shipped to Germany to be used as a filter in beer production. Since it is a non-condensing plant, the efficiency is quite low, estimated around 14%; however, it is still in operation today.

Figure 15. ***First geothermal plant in Iceland at Namafjall, 1969, 3-MW non-condensing plant.***

More recently, a combined heat and power plant has been built at Svartsengi in southwestern Iceland. The plant using 240°C fluid, provides 45 MW of electricity (8.4 MW of which is from binary units) and 200 MW of thermal energy to the surrounding community. The waste brine, high in silica content, is run into the adjacent lava field, sealing the bottom, thus providing a large heated pond. This pond today is famous as the Blue Lagoon, used by locals and tourists (Figure 16).

Figure 16. ***Combined heat and power plant at Svartsengi, Iceland–Blue Lagoon on right (courtesy of Haukur Snorrason, Reykjavik, Iceland).***

RECENT DEVELOPMENTS

With the successes through the 1960s and early 1970s, geothermal power plant construction took off:

1975 – 30 MW at Ahuachapan, El Salvador
1980 -- plants in Indonesia, Kenya, Turkey, the Philippines and Portugal (Azores) were online.
1985 -- plants in Greece (Milos), France (Guadeloupe) and Nicaragua online.
1990 -- plants in Thailand, Argentina, Taiwan and Australia online – the plant in Greece shut down.
1995 -- plant in Costa Rica online.
2000 -- plants in Austria, Guatemala and Ethiopia online – the plant in Argentina shut down.
2004 -- plants in Germany and Papua New Guinea online.

Binary cycle plants using the organic Rankin cycle, became more popular–as they can use lower temperature water –down to 100°C. Since efficiencies are low and economics questionable (high parasitic loads) at these temperatures, these plants are often constructed in concert with a district heating system. These plants are also modular, generally in sizes less than one megawatt; thus, allowing for rapid installation. Examples of these new installations are as follows:

Austria

A one-megawatt binary unit at Altheim using 106°C fluid at 100 liters/second from a 2,270-meter deep well, also supplied 10 megawatts of thermal energy to the local district heating network (Figure 17). A second power plant-district heating project is at Bad Blumau in eastern Austria providing 250 kW of electric power from a binary plant using 110°C water, and then supplies 2.5 MW of thermal power with the waste 85°C water to the hotel and Spa Rogner.

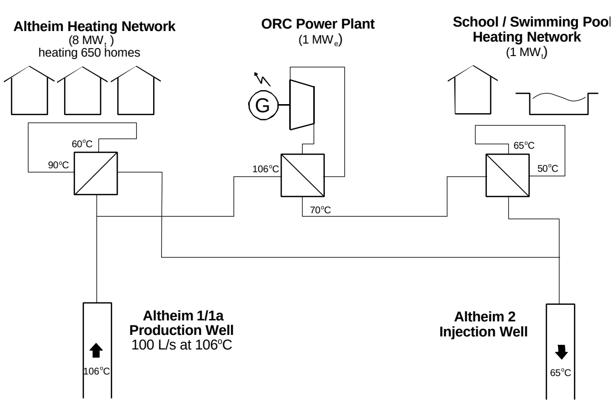

Figure 17. Combined heat and power plant at Atlheim, Austria.

Thailand

A 300-kW binary plant using 116°C water provides power to the remote village of Fang (Figure 18). In addition hot water is also used for refrigeration (cold storage), crop drying and a spa. The power plant provides electric energy at a rate of 6.3 to 8.6 US cents per kWhr, replacing a diesel generator that cost 22 to 25 US cents per kWhr.

Figure 18. Binary power plant, 300 kW, at Fang, Thailand (courtesy of ORMAT).

Germany

At Neustadt Glewe in north Germany, a well at 100°C provides energy for a 210-kW binary plant and 11 MW thermal to a district heating system (Figure 19). This is the lowest temperature binary plant operating in the world at present.

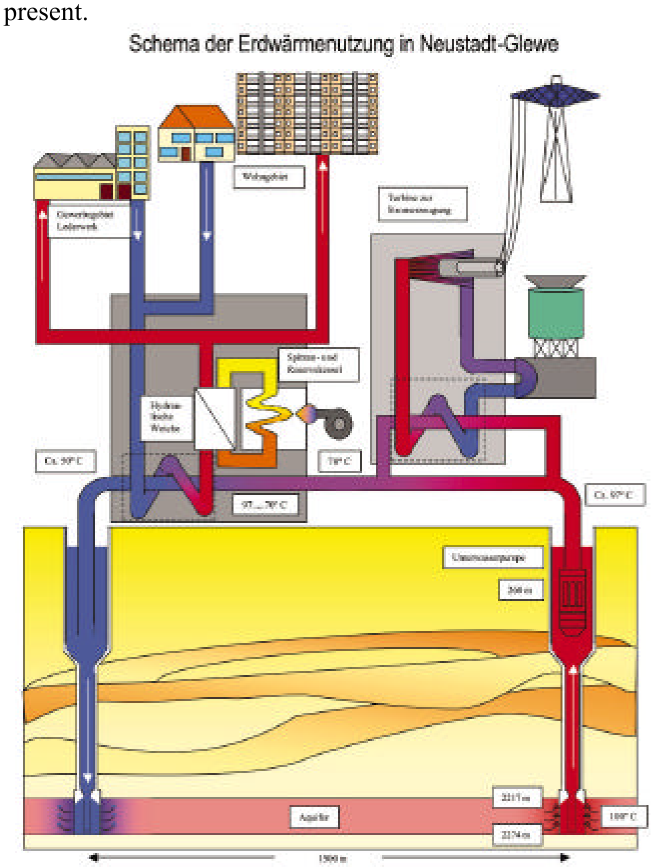

Figure 19. Combined heat and power plant at Neustadt Glewe, Germany.

Mexico

In the northern state of Chihuahua, an isolated village, Maguarichic, relied on a 90-kW diesel generator to provide electricity for only three hours in the evening. The villagers rarely had meat, cheese or milk, and they were not aware of national events since no television was available. The federal government in 1997 provided a 300-kW binary plant using 150ºC water for US$3000/kW (Figure 20). The villagers now have street lights, refrigerators and have established a small cottage industry using electric sewing and tortilleria machines. Best of all, the children now have ice cream!

Figure 20. 300-kW binary plant at Maguarichic, Mexico (courtesy of CFE).

United States

Near Susanville in northern California, two 375-MW binary plants operated by Wineagle Developers provide a net power output of 600 kW (Figure 21). The plants used 63 liters per second of 110ºC waters. The plant is completely automated. The entire plant, including the well pump, is controlled by either module. By pushing one button on the module control panel, the plant will start, synchronize to the power line and continue operation. If the power line goes down, the module and downhole pump immediately shut down, since no power is available for its operation. When the power line is re-energized, the modules restart the downhole pump, and then bring themselves on line. Operation can be monitored remotely, with a service person alerted by an alarm system.

Figure 21. Wineagle binary plant of 2x375 kW in northern California, USA.

SUMMARY

The following figures are based on reports from the World Geothermal Congress 2000 (Japan) and from preliminary reports for the World Geothermal Congress 2005 (Turkey). The figures for capacity is the installed number, as the operating capacity may be less, and the energy produced, in many cases are estimated, as little data are available.

CONCLUSIONS

With 100 years of experience, reservoir engineers, and plant operators have learned the importance of giving more attention to the resource, including the injection of spent fluids. With proper management, the resource can be sustained and operated for many years. Geothermal fields have been operated for over 50 years and probably can be for over 100 years. The cost of power has been declining and in many cases, is competitive with fossil fuel plants at 4 to 5 U.S. cents per kWh.

Table 1. Installed (gross) Geothermal Power Worldwide (2004).

Country	Installed MW	Est. Energy Produced (GWh/a)
Argentina	(1)	not operating
Australia	<1	3
Austria	<1	5
China	32	100
Costa Rica	162	1,170
El Salvador	105	550
Ethiopia	7	30
France (Guadalupe)	4	21
Germany	<1	2
Greece	(2)	not operating
Guatemala	29	180
Iceland	200	1,433
Indonesia	807	6,085
Italy	790	5,300
Japan	535	3,470
Kenya	127	1,100
Mexico	953	6,282
New Zealand	453	3,600
Nicaragua	78	308
Papua New Guinea	30	100
Philippines	1,931	8,630
Portugal (Azores)	8	42
Russia	100	275
Taiwan	3	15
Thailand	<1	2
Turkey	21	90
United States	2,395	16,000
TOTAL	**8,771**	**54,793**

Binary cycle plants are becoming more popular, as they can use lower temperatures–down to 100ºC–and the economics of the system is improved if the wastewater is used in a direct-use project such as district heating. Modular units are available in both binary and flash steam models, which allows for rapid installation. This will allow geothermal power to be extended to many "low-temperature" geothermal resource countries. I predict, that in the next 20 years, we will see 25 new countries added to the list of geothermal power producers.

Finally, the importance of geothermal power production in some countries is significant in contributing to the electrical energy mix as presented in Table 2.

Table 2. National Geothermal Contribution to the Electric Power Utilization

Country	% of Natural Capacity (MW)	% of Natural Energy (GWh/yr)
Philippines	16.2	21.5
El Salvador	15.4	20.0
Kenya	15.0	20.0
Nicaragua	17.0	17.2
Iceland	13.0	14.7
Costa Rica	7.8	10.2
New Zealand	5.1	6.1
Indonesia	3.0	5.1

ACKNOWLEDGMENT

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REFERENCES

Burgassi, P. D., 1999. "Historical Outline of Geothermal Technology in the Larderello Region to the Middle of the 20th Century," Chapter 13 in: *Stories from a Heat Earth – Our Geothermal Heritage* (R. Cataldi, S. F. Hodgson, and J. W. Lund, editors), Geothermal Resources Council, Special Report 19, Davis, CA, pp. 195-220.

DiPippo, R., 1980. "Geothermal Energy as Source of Electricity." U.S. Department of Energy, U.S. Government Printing Office, Washington, DC.

Gutiérrez-Negrin, L. C., A; Garduño-Monroy, V. H. and Z. Casarrubias-Unzueta, 2000. "Tectonic Characteristics of the Geothermal Zone of Pathé, Mexico," *Proceedings of the World Geothermal Congress 2000*, International Geothermal Association, Pisa, Italy, pp. 1189-1193.

Hodgson, S. F., 1997. "A Geysers Album - Five Eras of Geothermal History," California Department of Conservation, Division of Oil, Gas and Geothermal Resources, Sacramento, CA.

Kononov, V.; Polyak, B. and B. Kordov, 2000. "Geothermal Development in Russia: Country Update Report 1995-1999," *Proceedings of the World Geothermal Congress 2000,* International Geothermal Association, Pisa, Italy, pp. 261-275.

Lund, J. W., 2003. "The USA Geothermal Country Update," *Geothermics,* Vol. 32 (4/6), Elsevier Ltd., Oxford, UK, pp. 409-418.

Sato, K., 1970. "The Present State of Geothermal Development in Japan," *Proceedings of the United Nations Symposium on the Development and Utilization of Geothermal Resources,* Geothermics, Pisa, Italy, pp.155-184.

Thain, I. A., 1998. "A Brief History of the Wairakei Geothermal Power Project," *Quarterly Bulletin*, Geo-Heat Center, Klamath Falls, OR, pp. 1 – 4.

Draft Country Update papers for the World Geothermal Congress 2005 from Russia, Japan, Mexico, New Zealand, USA and Italy.

ON TOP OF THE WORLD: ARCTIC AIR BASE WARMED WITH HEAT PUMP TECHNOLOGY

Helge Underland
Norwegian Defense Estates Agency

The Arctic city of Bodø, Norway, population 41,000, looks out on the Atlantic Ocean and the island of Langegode. The city's civilian airport is shown in the foreground. Images of the air base are proprietary.

The Main Air Station in Bodø, Norway, has the distinction of being the northermost F-16 base in the world. At 66.5 degrees north, it sits above the Arctic Circle on rugged Atlantic coastline, vulnerable to some of the harshest, most changeable weather on the planet. Snowy conditions and freezing rain during much of the year require Royal Norwegian Air Force pilots to have an extra measure of skill to safely control their planes in the air and on the ground.

Built during World War II, Bodø Air Station grew in strategic importance–and size–during the Cold War. As NATO's northernmost front with Warsaw Pact forces, it became famous in the early-1960s as a base for U2 surveillance missions. Today, its two F-16 fighter squadrons still stand ready to scramble. Nearly 800 people work on site.

To support Bodø's continued key role in national defense, the Norwegian Defense Estates Agency enlarged the air station's facilities, most notably during the 1950s. The expansion included infrastructure renovations, equipping buildings (sometimes in groups of two or three) with oil-fired hot water heating systems. During the 1990s, the decision was made to construct a district heating operation on base, using a heat pump as the main energy source. Currently, that system is efficiently warming barracks, workshops, hangars and other buildings at Bodø Air Station, tapping the nearby seawater for heat energy.

FUEL VERSATILITY

With rivers, waterfalls and lakes in abundant supply, Norway relies on hydroelectric power for almost all of its electricity. The country produces approximately 120 TWh (400 TBtu) of hydroelectricity each year. It imports and exports electricity with Russia, Finland, Sweden and Denmark. Electric boilers are in widespread use and relied on in periods when electricity is cheap (approximately \$0.01/kWh). But when the weather gets colder and the price increases, we can switch to oil-fired boilers. Electricity tariffs are less expensive if we can stop the electricity boilers in 60 minutes or less when we change over to oil.

After many years of heating Bodø Air Station with oil-fired boilers, the Norwegian Defense Estates Agency developed a new energy plan for various military bases during the 1980s. The plan recommended eventual construction of district heating systems that could rely on a variety of energy sources–oil, electricity, biofuels or heat pumps.

The original oil-fired boilers were capable of handling 100 percent of the load, with redundant electrical boilers that could handle 60 percent. Since 1990, heat pumps or biofuel boilers, which cover approximately 40 to 60 percent of the load, have been installed in many locations. These various boilers provide backup options and allow the switch between boilers to use whatever fuel is cheapest. Where we have installed a heat pump, it serves the main load, with oil-fired boilers for peak load and backup.

The Bodø Air Base's district heating system started up in 1992, serving approximately 40 buildings. The design heating load in the buildings varied from 72 kW (69 Btu/sec) to 940 kW (890 Btu/sec), totaling 5,400 kW (5,120 Btu/sec). Because of differences in the consumption patterns of various buildings–depending on occupancy, demand at different times of day, etc.–the actual total load was calculated at 3,800 kW (3,600 Btu/sec), and the total energy consumption was projected to be 11 GWh (36.8 GBtu).

This reflects a decrease in heat demand with the conversion of all buildings to district heating. All told, the old heating system previously used 13 GWh (43.4 GBtu). Since district heating has been installed, however, the actual consumption has been 8 GWh (26.7 GBtu) per year.

HEAT PUMP PRINCIPLES

The heat pump was clearly a suitable energy source for the Bodø system, given the area's 274-day heating season, mean temperature of 4.6ºC (40.3ºF) and design temperature (lowest mean temperature of three days) of minus 13.5ºC (7.7ºF). For a heat pump to be economical, it needs to run for a long duration in weather that is not too frigid.

A heat pump can be compared to a refrigerator; where, heat is transported from the inside to the outside–from low temperature to a higher temperature. The four main components of a heat pump: the evaporator, compressor, condenser and expansion valve–are all connected to a closed circuit. The evaporator is where a liquid boils and evaporates under low pressure. Low-temperature energy, in the form of seawater at 7ºC, is added. The vapor is compressed to a higher pressure and higher temperature in the compressor. The hot vapor enters the condenser; where, it is condensed and the heat is transferred to a heating system.

Finally, a high-pressure refrigerant is expanded through the expansion valve, which regulates between high and low pressure. In this way, the temperature in a liquid can be increased by adding high-quality energy (electricity) in small amounts and low-quality energy, in the form of seawater or ambient air, in large amounts. In general, approximately one part electricity is added to three parts low-quality energy.

When planning began on the Bodø district heating system, it was known that chlorofluorocarbon-based refrigerants would be banned, so alternatives were considered. The new refrigerants had not yet been sufficiently tested, so the old well-known ammonia (NH_3), R-717, was chosen. Although it had been widely used in refrigerating plants, it had not previously been used in a heat pump. NH_3 has very good thermodynamic properties. It does not damage the ozone layer or harm the environment in any way. In a certain mixture with air, however, it is explosive and toxic.

Compressors in refrigeration plants typically are built for a pressure of 25 bar (363 psi), with a condensation temperature of approximately 50ºC (122ºF). For the district heating system, however, we wanted a higher temperature. The design temperature of the heating systems in the buildings on the system was 80ºC (176ºF). Therefore, we needed a compressor of approximately 40 bar (580 psi).

ENERGY FROM THE SEA

Bodø central heating plant consists of two heat pumps of 2 MW (1,896 Btu/sec), one electric boiler and two oil-fired boilers at 3.8 MW (3,600 Btu/sec) (Figure 1). The central heating plant is located close to the beach, approximately 200 m (656 ft) away. Seawater is drawn from a depth of 170 m (558 ft); where, the temperature is constantly 7ºC (44.6ºF) throughout the year. The seawater drains into a 7-m deep basin (19.7-ft); where, two submerged pumps are located. Their total capacity is 180 m^3/hr (47,600 gal/hr).

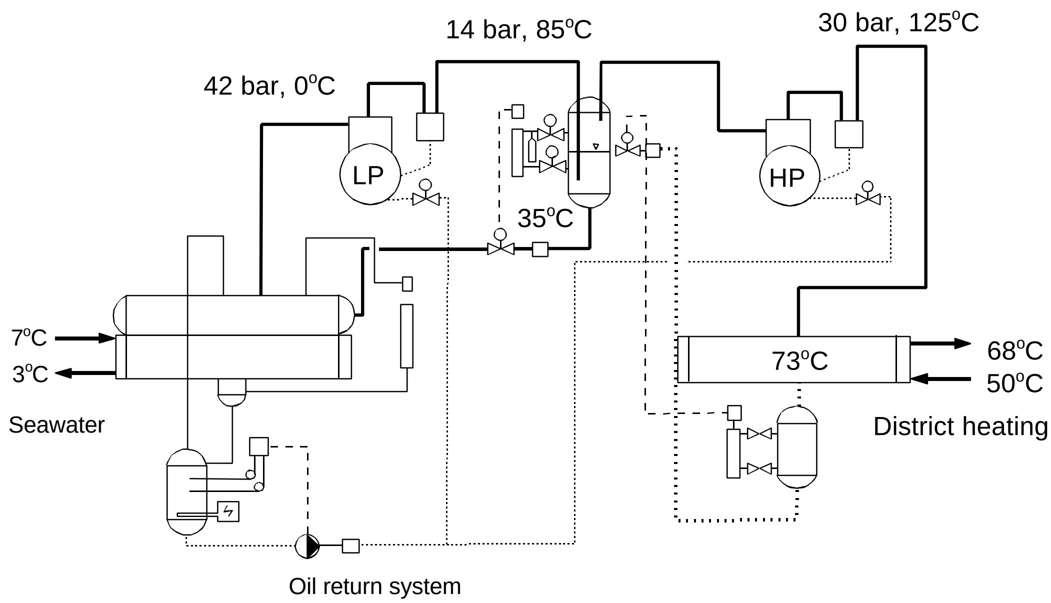

Figure 1. ***The Bodø, Norway, Main Air Station District Heating System. Since it began in 1992, this system has relied on heat pump technology as its main energy source.***

The heat pump consists of two separate aggregates with shell-and-tube condensers and evaporators. Each has a two-stage piston compressor with "inter-stage" receivers. (An inter-stage receiver is similar to an inter-cooler for a two-stage air compressor; it is necessary to reduce gas temperature between the low-pressure and high pressure compressors.) The compressors consist of a low-pressure compressor with 16 cylinders and a high-pressure compressor with six cylinders (Table 1). The two-stage compressor is preferred because it needs less power than a one-stage compressor, and therefore, performs better. Given the pressure, temperature and the use of NH_3, it is necessary to use a two-stage compressor to prevent the oil from decomposing.

The NH_3 is heated with seawater and boils in the evaporator at 4 bar (58 psi) and minus 0.7°C (33.3°F). The low-pressure compressor compresses the vapor to 14 bar (203 psi), 100°C (212°F). The hot vapor enters the inter-stage receiver. The high-pressure compressor compresses the vapor from 14 bar, 38.7°C (102°F) to 30.7 bar (445 psi), 108°C (226°F). The hot vapor enters the condenser; where, it is cooled to 74°C (165°F), and the condensation heat is transferred to the district heating system. The fluid enters the inter-stage receiver through the expansion valve, and from the inter-stage receiver to the evaporator through the second expansion valve.

The two aggregates are connected in series. The water in the district heating system enters the first aggregate (the "master"), which is always running, at 60°C (140°F) and leaves at 64°C (147°F). It enters the second aggregate (the "slave"), which runs only if necessary, at 64°C and leaves at 68°C (154°F). The heat factor is 3.4 at the master and 3.2 at the slave.

PERFORMANCE TRACK RECORD

In the nearly 12 years since Bodø's district heating system began operating, the Norwegian Defense Estates Agency has been pleased with the installation's efficiency and positive environmental benefits (Table 2).

The project cost a total of 38 million NOK ($5.5 million). It was originally decided that the system would be built as a prototype demonstration plant and as such, it received economic support from the Norwegian Water Resources and Energy Directorate. The agency granted 1.2 million NOK ($175,000) for instrumentation for follow up in the run-in and test period.

The heat pump installation has had a positive influence on the environment by reducing air pollution. Since startup of the new system, carbon dioxide emissions have been cut each year by 3,048,700 kg; sulfur dioxide by 4,760 kg; nitrous oxides by 2,830 kg; and sulfur by 2,300 kg. In total, these emissions are the equivalent of 400 cars each driving 15,000 km per year.

Recently, six more buildings have been connected to the Bodø district heating system, further optimizing the heat pump's performance.

In general, the Norwegian Defense Estates Agency is quite satisfied with its large heat pump installations around the country. There are, for example, two systems in Bergen, at Sjøkrigskolen and Haakonsvern, which use seawater as the heat source, and an ambient air-based system in Stavanger. Those use R-134a as a refrigerant. Other systems also use groundwater as a heat source.

In Oslo, the agency is evaluating the heating and distribution system of the landmark Akershus Fortress, a medieval castle and museum. The design heating load for this

Table 1. Compressor Technical Data, Bodø Air Base Heat Pump System

	Low-Pressure Compressor	High-Pressure Compressor
Manufacturer	SABROE	SABROE
Model	SMC 116 S	HPC 106 S
Rotational Speed RPM	1475	1475
Max. Shaft Power	155 kW (147 Btu/sec)	124 kW (118 Btu/sec)
Piston Displacement	905 m^3/hr (239,000 gal/hr)	330 m^3/hr (87,200 gal/hr)

Table 2. Bodø Air Station District Heating System Statistics 2003

Maximum Output	2 MW (1,896 Btu/sec)
Delivered Quantity of Energy	8 GWh/yr (26.7 GBtu)
Used Quantity of Energy to Run the Heat Pump	2.5 GWh/yr (8.4 GBtu)
Coefficient of Performance	3.4
Total Cost for the District Heating System and the Heat Pump	38 million NOK ($5.5 million)
Extra Cost for the Heat Pump	8 million NOK ($1.2 million)
Payback for the Heat Pump	6 years

In the Bodø district heating system, vapor enters this low-pressure compressor and then the barrel-like "inter-stage receiver," where temperature is reduced before the vapor continues into the high-pressure compressor.

The Bodø system's heat pump consists of two separate aggregates with shell-and-tube condensers and evaporators.

is 6 MW (5,700 Btu/sec). A heat pump system using NH_3 is under consideration for this facility.

Heat pump technology is a sustainable method of heating. Its use reduces consumption of oil and gas, decreasing air pollution. To obtain the best performance, it is important to have a continuous heat source. It is also important to balance the distribution systems and design them with the lowest possible operating temperature. This will reduce the input energy to the compressor and increase the coefficient of performance.

In the long term, only those technologies that are sustainable can address the dual challenge of protecting the ozone layer and containing adverse climate effects. In the experience of the Norwegian Defense Estates Agency at Bodø and other sites, ammonia-based heat pumps are a good choice and right for the future.

ACKNOWLEDGMENT

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CHILI AND GARLIC DRYING BY USING WASTE HEAT RECOVERY FROM A GEOTHERMAL POWER PLANT

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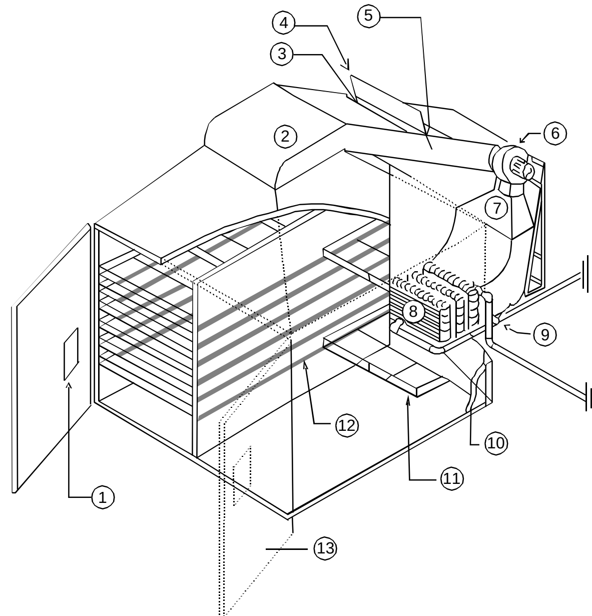
INTRODUCTION

In Thailand, natural sun drying is one of the most common ways to preserve agricultural products. Many agricultural products are spread on the ground to be dried by sun and wind. During the drying, these products are neither protected against dust and rain, nor against rodents, birds and insects. This results in poor quality products due to contamination and high loss caused by uneven or incomplete dehydration. In order to meet the food requirements of the growing population and moreover to provide high quality products, Thailand is developing dryers that respond to such demand. In addition, to overcome the dependence on solar energy which is the most common energy source for drying, different sources of energy are envisaged. Geothermal is one with relatively high potential at industrial scale. In fact, Thailand has more than forty medium-enthalpy geothermal resources scattered throughout the country, particularly in the north. In Fang district, Chiang-Mai province, the Electricity Generating Authority of Thailand (EGAT)(EGAT, 1995) has installed a geothermal power plant. It is a binary cycle system with a total generating capacity of 300kW$_e$. The rejected temperature of hot water is about 80ºC. Hence, the idea of using this waste heat for drying of chili and garlic.

Chili and garlic are important products for Thailand's economy. They are popular for Thai people in both forms: fresh and dry. Chili and garlic drying by using hot water from geothermal power plant is a new undertaking which has better performance for drying the product and does not cause any pollution. The purpose of the investigations in the paper are, first to design an industrial dryer and second, to find out the appropriate drying conditions using hot water from the geothermal power plant. The evaluation of the economic feasibility and cost analysis of the drying system is also conducted.

METHODOLOGY

Chili (Pairintra, et al.,1996) and garlic (Asasujarit, et al., 1996) drying in this study is similar to the general method of drying but differs in the source of energy, which comes from hot water from the geothermal power plant. Figure 1 shows the experimental design dryer (Thiebrat, 1997). The cabinet dryer of 2.1 m width, 2.4 m length and 2.1 m height has 36 trays placed in two compartments. A motor of 2 hp (1420 rpm) is used for driving the fan producing an air flow at constant rate of 1 kg/s. Likewise, controlling the temperature of drying air is made by varying the flow rate of the incoming geothermal hot water into the water-to-air heat exchanger installed at the inlet of dryer cabinet. A valve installed on the air duct between the outlet of the dryer chamber and the inlet of ambient air allows control of the rates of incoming and recycled air. At this geothermal power plant, only one dryer could be placed due to space limitation.



1 = window
2 = return air duct
3 = exhaust opening
4 = valve
5 = inlet opening
6 = centrifugal fan
7 = air duct
8 = heat exchanger
9 = hot water tap
10 = insulated walls
11 = grills
12 = shelf for putting grill
13 = door

Figure 1. Schematic view of the dryer with air/geothermal hot water exchanger.

RESULTS

Due to budget limitations, only two tests per product were made which might not be sufficient to draw final conclusions. However, general and subjective conclusions were formulated concerning the use of heat recovered from waste hot water from geothermal power plant.

Table 1. **Experimental Results for Chili and Garlic Drying**

Description of Drying	**Type of Product**			
	Chili		**Garlic**	
	Test 1	**Test 2***	**Test 1**	**Test 2**
Condition of Drying				
- Air Flow Rate (kg/s)	1.00	1.00	1.00	1.00
- Hot Water Flow Rate (kg/s)	1.00	1.00	0.09	0.04
- Average Air Temperature in the Cabinet (°C)	50.4	44.9	40.6	34.8
Average Ambient Air				
- Temperature (°C)	30.0	28.3	27.0	25.4
- Relative Humidity (%)	73.3	76.7	64.4	65.9
Conditions				
- Initial Moisture Content (%)(db/wb)	281/73	326/76	274/73	340/77
- Final Moisture Content (%)(db/wb)	16/13	10/9	127/55	132/56
- Initial Weight (kg)	467	570	245	213
- Final Weight (kg)	141	148	149	112
Energy Consumption (MJ/kf H_2O evap.)				
- Hot Water	39.52	103.10	15.36	5.97
- Electricity	1.42	2.06	8.15	9.74
- Total Energy Consumption	40.94	105.16	23.51	15.71
Drying Time (h)	46	90	76	94

* During this test, electricity was cut off for a few hours.

As indicated in Table 1, the energy consumed in the cabinet for drying is derived from two sources: electrical energy for the blower and thermal energy from geothermal hot water. Based on product quality and energy consumption, the optimum operating conditions are as follows; for chili, the flow rate of hot water is about 1 kg/s with 60% recycle of hot air leaving the dryer cabinet; whereas, for garlic, the hot water flow rate is about 0.04 kg/s without air recycle. In both cases, the air flow rate was l kg/s. The corresponding percentages were 3.5% and 96.5% for chili, and 62% and 38% for garlic.

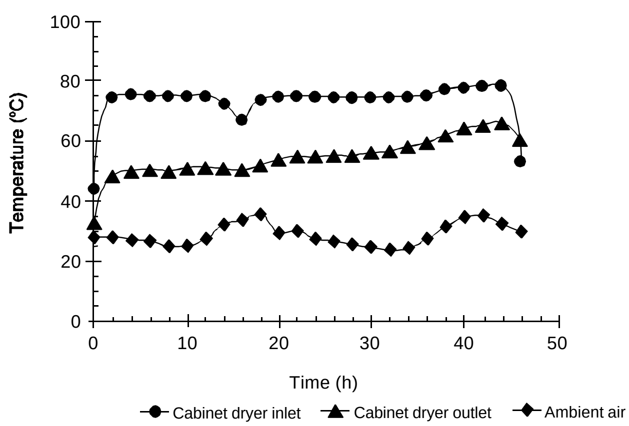


Figure 2. Evolution of air temperature for chili drying.

Figures 2 and 3 show the average temperature profile of air at inlet and outlet of the cabinet dryer and ambient for chili and garlic, respectively.

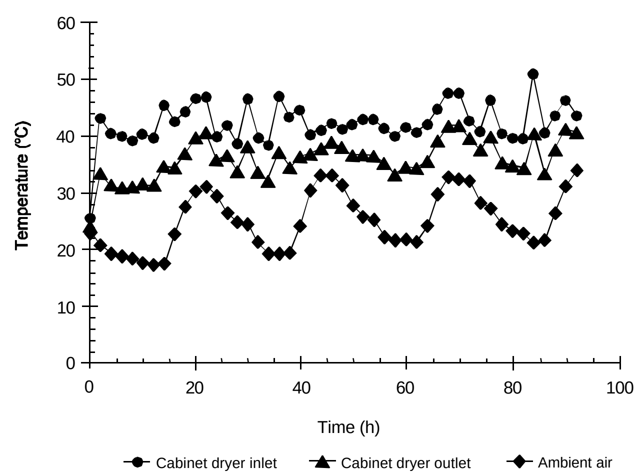


Figure 3. Evolution of air temperature for garlic drying.

To assess the economic feasibility of this drying system, a cost analysis was made under the following assumptions (Kiatsiriroat, 1994):

1. The capital cost of cabinet dryer was 40,000 Baht ($1,080);
2. The annual rate of interest for the financial year was 14.25%,
3. The economic life of the cabinet dryer was 10 years,
4. The annual operating and maintenance cost were 10% of the cabinet dryer cost,
5. The operating time for cabinet dryer was 24 hours per day; 60 days for chili and 90 days for garlic, and
6. The system can dry chili at the rate of 13,500 kg/yr and garlic at the rate of 5,635 kg/yr.

The cost of energy for motor was 8,769.18 Baht/yr ($237) and garlic at the rate of 5,635 kg/yr.

The annual cost for drying chili was 218,567 Baht ($5,907) and 104,334 Baht ($2,820) for garlic. The corresponding cost of evaporation of 1 kg of water was 23.25 Baht ($0.63) for chili and 39.22 Baht ($1.06) for garlic. The cost of drying process per kilogram of fresh product was 16.19 Baht ($0.44) for chili and 18.52 Baht ($0.50) for garlic. Finally, the cost of 1 kg of dried chili and garlic were 53.32 Baht ($1.44) and 35.07 Baht ($0.95), respectively.

SUMMARY

The objective of this research is to design a dryer that uses waste heat from a geothermal power plant. The dryer was built at the geothermal power plant in Fang district, Chiang-Mai province, Thailand. The geothermal hot water, about 80ºC, circulates through a cross-flow heat exchanger of 100 mm width, 500 mm length and 300 mm height. A 2-hp (1420 rpm) motor is used for driving the dryer blower. The outgoing air from the heat exchanger with constant flow rate (1 kg/s) is introduced into the drying chamber of 10.5 m^3 volume. The experiments were made for chili (450 kg) and garlic (220 kg).

For chili (75% wb to 13% wb), the required air temperature is about 70ºC; whereas, for garlic (75% wb to 55% wb), 50ºC is needed. The corresponding drying time and mass flow rate of hot water are about 46 hours/1 kg.s^1 for chili and 94 hours /0.04 kg.s^1 for garlic.

Thus, two sources of energy which are thermal energy from a geothermal power plant and electricity from a blower were used. The total energy consumed was 13.3 MJ or 40.94 MJ/kg H_2O evap. for chili 1.5 MJ or 15.71 MJ/kg H_2O evap. for garlic. The corresponding part of energy consumed from a waste heat geothermal plant is 96.5% for chili and 38.0% for garlic drying.

CONCLUSIONS

Drying agricultural product by using waste heat recovery from a geothermal power plant was investigated experimentally.

The air circulates through the drying installation at a constant rate. The control of temperature is made by varying the flow rate of hot water circulating through the water-to-air heat exchanger.

The design of the industrial scale dryer allows to recycle, partially or totally, the air leaving the drying cabinet. Investigation of performance of this dryer was made, basically, on product quality, drying time and energy consumption. Finally, an economic study showed that such dryer offers an interesting alternative for drying as the resulting costs are reasonable and the system operation is independent from weather conditions.

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REFERENCES

Asasujarit, S.; Hirunlabh, J.; Khedari, J.; Pairintra, R. and C. Chindaruksa, 1996. "Chili Drying by Producer Gas from an Up-Flow Gasifier," In *International Conference on Food Industry Technology and Energy Applications*, November 13-15, 1996. King Mongkut's Institute of Technology, Thonburi, Bangkok, Thailand, pp. 69-74.

Electricity Generating Authority of Thailand (EGAT, 1995). "Power Development Planning 1995-2011, February.

Kiatsiriroat, T., 1994. *Design of Thermal System*. Bangkok: King Mongkut's Institute of Technology, Thonburi Press.

Pairintra, R.; Hirunlabh, J.; Khedari, J. and S. Keereelird, 1996. "Performance of Garlic Drying by Solar Energy Combined with Producer Gas," In *International Conference on Food Industry Technology and Energy Applications*, November 13-15, King Mongkut's Institute of Technology, Thonburi, Bangkok, Thailand, pp. 293-297.

Thiebrat, S., 1997. "Chili and Garlic Drying by Using Waste Heat Recovery from Geothermal Power Plant." Master Thesis, King Mongkut's Institute of Technology, Thonburi, Bangkok, Thailand.

STAMPS IN THE NEWS

GEOTHERMAL HEAT IN ICELAND

A series of five stamps along with an informative booklet was recently issued (March 11, 2004) by the Iceland Post Office (Posturinn - www.stamps.is) (email: stamps@postur.is). The following are excerpts from this booklet (gift folder G29 with 439A-E as se-tenant stamps in one sheet which is dedicated to geothermal energy in Iceland).

Geothermal Heat in Iceland: "Iceland lies astride the Mid-Atlantic Ridge, a geologically active system of ridges and fissures forming an undersea mountain chain along a split in the earth's curst that stretches the entire length of the Atlantic Ocean. ... The meeting point of the American and European tectonic plates, runs through Iceland.... moving apart at an average rate of two centimeters per year."

What is Geothermal Warming?: "The hot water found around Iceland is rainwater that gradually seeps through the earth's surface layer until it heats up when it comes into contact with hot rock. The heated water has a lower density and rises towards the surface through faults and fissures in the form of hot water or steam."

Low-Temperature Areas: "There are around 250 low-temperature geothermal areas all around the country outside of the active fissure zones. The largest low-temperature areas are in the south and west of the country. A low-temperature geothermal area is generally defined as an area where the temperature is below 150EC (302EF) at a depth of 1000 meters (3300 ft.). Because the mineral content of hot water in these low-temperature areas is generally low as well, the water can be used directly in domestic and industrial heating systems."

High-Temperature Areas: "High-temperature geothermal areas are found only at active volcanic belts or at their edges. There are between 20 and 30 such areas in Iceland. The active volcanic belt is a broad zone stretching diagonally from northeast to southwest Iceland. The temperature of the water is not less than 200EC (392EF) at a depth of 1000 m (3300 ft.). ... Higher temperature water contains more gases and dissolved mineral than water from low-temperature areas. High-temperature water cannot be used directly for heating. Instead, utilization is mainly accomplished through heat exchangers; whereby, hot water or steam is used to heat cold water from a different source."

Exploitation of Geothermal Energy: "Geothermal energy is exploited in numerous ways and has helped improve Icelanders' quality of life throughout the ages. In earlier times, hot water was used mainly for bathing and laundry. Since the settlement of Iceland began nearly 1100 years ago, references in Icelandic Sagas and other stories have been made to hot pools for bathing. ... For centuries, the residents of Reykjavik used the warm springs in Laugardalur for washing clothes. ... The earliest confirmed use of geothermal energy for domestic heating was in 1907.... Today, more than 85% of Iceland's inhabitants enjoy domestic heating derived from geothermal energy. In thinly populated areas, schools and small villages have been built where hot water was discovered. Swimming pools are an important part of Icelandic culture, and outdoor swimming pools are open all year round --despite the country's northerly location. Iceland has more than 100 pools using naturally heated water. Horticultural greenhouses are a common sight in areas where hot springs abound. Small geothermal power stations produce electricity such as Krafla and Bjarnarflag near Myvatn, at Svartsengi and at Nesjavellir.

The Reykjavik Heating Company was established in 1930 and initially used hot water from boreholes in Laugardalur to heat one of the city's schools. This venture proved to be popular, and hot springs all around the area were soon tapped for heat. Boreholes were sunk in Reykur and Reykjahlið in the Mosfellsbær area, as well as in other places close to Reykjavik. As soon as all the hot springs were soon fully exploited, it became clear that, as the city grew, its residents would have to look farther away for sources of hot water. In 1990, the Nesjavellir energy installation began operation and hot water is now piped over 20 km into Reykjavik."

THE STAMP THAT CHANGED HISTORY

The 1900 Nicaraguan stamp depicted above (Scott #122), was instrumental in determining the location of the canal connecting the waters of the Atlantic and Pacific Oceans, or as is known today, the Panama Canal.

The United States had been interested in a canal linking the Atlantic and Pacific Oceans for many years, as more than two months were required to sail from California to New York by way of Cape Horn--a canal across Central American would reduce the voyage by 8,000 miles. France had begun a canal project in the Panama region of Colombia during the 1880s, but progress was stopped by tropical diseases, engineering problems with unstable soils, and financing. The French company, headed by Ferdinand DeLesseps, declared bankruptcy, and the receiver company attempted to sell the assets to the United States. However, their difficulties made an alternate location through Nicaragua appear more acceptable to the Americans even though it was longer, as it offered a more amenable climate and easier terrain than found in Panama. Senator John Tyler Morgan, chairman of the Senate Committee on Interoceanic Canals favored the Nicaraguan route. President Theodore Roosevelt favored the Panama route, but remained noncommittal.

On the other side, William Nelson Cromwell, an American lawyer and promoter, and Philippe Bunau-Varilla, the agent for the original French construction company set about to counter the congressional interest in Nicaragua. Senator Marcus Alonzo Hanna of Ohio, another promoter for Panama, discussed "the burning question" of igneous activity in the Caribbean region. He pointed out that Mont Pelée in Martinique had erupted the previous month killing 40,000 people, and that Panama was "exempt" from this kind of danger. Nicaragua, on the other hand, lay along a volcanic tract through which the proposed canal would traverse that was "probably the most violently eruptive of any in the Western Hemisphere." Mount Momotombo, a hundred miles from the proposed route, had blown up only two months prior to Pelée. Even as he spoke, Mount Pelée was erupting again. Later, maps and diagrams of Central American showing every active and extinct volcano most of which lined up in Nicaragua--and with Panama dot free--were exhibited in the Senate.

Finally, to cinque the argument for the Panama route, Bunau-Varilla visited stamps shops in Washington, D.C. and bought enough of the above stamp showing the erupting Mount Momotombo, to send one to every Senator. "An official witness," he typed on the envelopes, "of the volcanic activity of the Isthmus of Nicaragua." The final vote on June 19, 1902 was 76 to 6 in favor of the Panama route. Forty million dollars were subsequently approved for purchase of the French project along with $130 million in construction funds. Problems with Columbia in preventing the canal's construction, led to the revolt in the region and the formation of the country of Panama in 1903. Construction started in 1904 and was completed by 1914 at a cost of more than $360 million. It was operated by the American Panama Canal Company until the year 2000: when, it was turned over to Panama. Ironically, Momotombo erupted in 1902 and 1905, but has not erupted since. Momotombo is now the site of 77.5 MWe of installed geothermal electric power.

As an interesting recent development, Nicaragua has proposed a new waterway through the southern part of the country--a public private partnership called the Grand Canal Foundation--to cost an estimated $25 billion and take 10 years to build. It would be wide and deep enough to handle a new generation of "post-Panamax" container ships that are too big to fit through the Panama canal's locks and put an end to delays of days or even weeks as ships presently await passage. Proponents say it would turn Nicaragua into the wealthiest nation in Central America within 20 years.

MECHANICAL ENGINEER JOINS THE GEO-HEAT CENTER STAFF

Andrew D. Chiasson recently joined the Geo-Heat Center staff as Research Associate-Mechanical Engineer. He is originally from Windsor, Ontario, Canada and received B.S. and M.S. degrees in Geological Engineering at the University of Windsor (1989 and 1992). He has worked for Dragun Corporation of Farmington Hills, Michigan (1990-1996) and EnviroSolutions, Inc., of Dearborn Heights, Michigan (1996-1997) as a Geological Engineer working mainly in the ground-water flow and hydrogeological field investigations. He then attending the School of Mechanical and Aerospace Engineering at Oklahoma State University (1997-2000) as a Research Engineer/Research Assistant. The area of study was in geothermal heat pump systems under faculty associated with the International Ground Source Heat Pump Association (IGSHPA). During this time, he also designed a ground loop heat exchanger and data collection system for a bridge deck de-icing system on Interstate 40 near Weatherford, OK. After graduating with a M.S. in Mechanical Engineering, he went to work for Hardin Geotechnologies of Indianapolis, Indiana (2000-2002) as a Geothermal Engineer. He designed closed and open loop geothermal heat pump systems for buildings with this firm. Most recently, he attended the University of Wyoming at Laramie as a Research Associate, and Ph.D. student in the Department of Civil and Architectural Engineering. He worked on modeling of geothermal heat pump systems and solar engineering systems, and heat extraction systems at underground coal fire sites for cogeneration. His dissertation topic is *Hybrid Geothermal Heat Pump systems with Solar Thermal Collectors in Cold Climates*, which he plans to finish by summer 2005. He is a Registered Professional Engineer (ME) in Indiana and Michigan, a member of ASHRAE (Geothermal Energy Utilization and Solar Energy Utilization committees) and the American Solar Energy Society (ASES). He has numerous publications to his name, mainly in the area of geothermal heat pump systems. His main task at the Geo-Heat Center will be technical assistance for geothermal direct-use and heat pump projects. He was recently married to Kirstin Beach of Palo Alto, California.