Chapter 7

DIRECT APPLICATION OF GEOTHERMAL ENERGY

Kiril Popovski
Sanja Popovska Vasilevska

INTRODUCTION

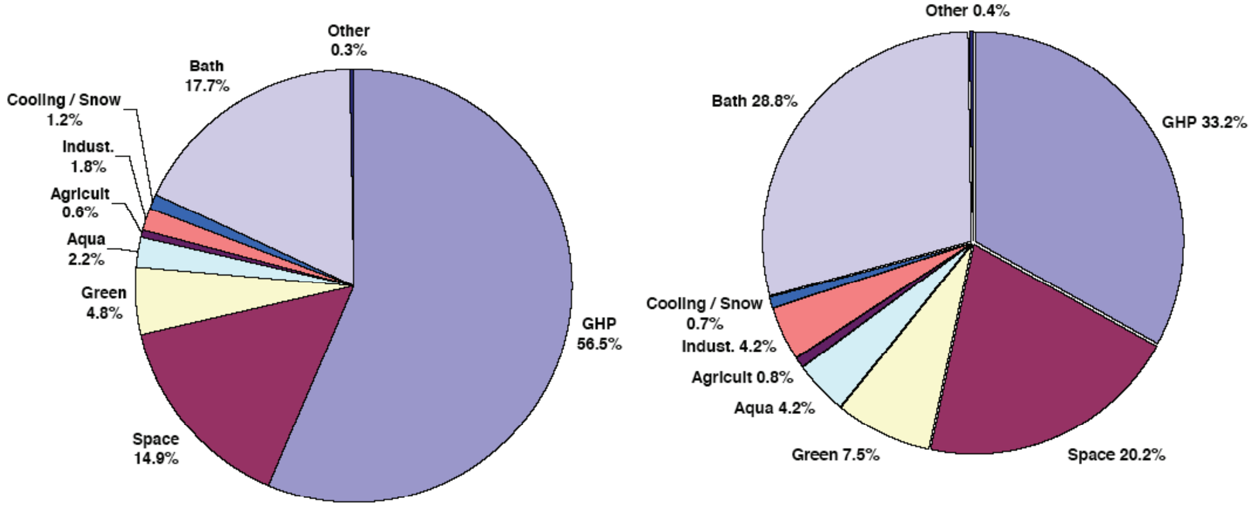
Direct application of geothermal energy relates to the low-temperature (<150ºC) hydro-geothermal resources. However, it can relate also to steam dominated ones, when the heat is extracted by means of heat exchanger and used for different non-power producing purposes. Practically, the expression "direct application" is accepted in order to make difference between the electricity ("indirect application") and other uses of geothermal heat ("direct application"), i.e. the immediate use of the consisted heat rather than to its conversion to some other form of energy.

The major areas of direct utilization (Fig.4.1) are (1) space heating and cooling including district heating, (2) agriculture applications, (3) aquaculture applications, (4) industrial processes, (5) swimming, bathing and balneology and (6) heat pumps. This chapter relates to the first four, and the last two shall be explaned in separate chapters.

Major direct utilization projects exploiting geothermal energy exist in about 65 countries, and the estimated installed thermal power is about 16,200 MWt utilizing over 64,000 kg/s of fluid (Lund, 2005). The worldwide thermal energy used is estimated to be alt least 162,000 TJ/yr (45,000 GWh/yr)-saving 11.4 million TOE/yr (Lund, 2005). The majority of this energy use is for space heating and swimming and bathing.

	Capacity, MWt			Utilization TJ/yr			Capacity Factor		
	2005	2000	1995	2005	2000	1995	2005	2000	1995
Geothermal heat pumps	15,723	5,275	1,854	86,673	23,275	14,617	0.17	0.14	0.25
Space heating	4,158	3,263	2,579	52,868	42,926	38,230	0.40	0.42	0.47
Greenhouse heating	1,348	1,246	1,085	19,607	17,864	15,742	0.46	0.45	0.46
Aquaculture pond heating	616	605	1,097	10,969	11,733	13,493	0.56	0.61	0.39
Agricultural drying	157	74	67	2,013	1,038	1,124	0.41	0.44	0.53
Industrial uses	489	474	544	11,068	10,220	10,120	0.72	0.68	0.59
Bathing and swimming	4,911	3,957	1,085	75,289	79,546	15,742	0.49	0.64	0.46
Cooling/snow melting	338	114	115	1,885	1,063	1,124	0.18	0.30	0.31
Others	86	137	238	1,045	3,034	2,249	0.39	0.70	0.30
Total	27,825	15,145	8,664	261,418	190,699	112,441	0.30	0.40	0.41

Table 7.1. Summary of the various worldwide direct-use categories, 1995-2005 (Lund, 2005)



(a) (b)

Fig.7.1. Categories of capacity and energy use in % (b), 2005 (Lund, 2005)

7.1. UTILIZATION

Historically, direct use of geothermal energy is first application by humans, after bathing and washing. Later on, it was spread to cooking and primitive heating, and now-a-days to all the life sectors where heat is necessary. Initially small scale projects, run by individuals became also very big ones, such as are the district heating (Iceland, U.S.A., Germany and France), greenhouse complexes (Hungary, Macedonia and Russia), or different industrial uses (Greece, Iceland, U.S.A.,Turkey, Romania and Serbia).

Lindal diagram (GNS Science, 2006) (Fig.7.2), indicates the temperature range suitable for various direct use activities. Typically, the agricultural and aquacultural uses require the lowest temperatures, with values from 25º to 90ºC. Space heating requires temperatures in the range of 50º to 100ºC, but 40ºC can be also useful in some cases. Cooling and industrial processing normally require temperatures over 100ºC. World leading direct user of geothermal energy, in terms of market penetration, is Iceland, where more than 86% of the population enjoys geothermal heat in their homes from 26 municipal district heating services, and where also 50% of the country's total energy use is supplied by direct heat and electrical energy derived from geothermal resources (Ragnarsson, 2000).

7.2. TECHNOLOGY

When direct application of geothermal energy is in question, not one but a chain of technologies should be applied. This chain has common composition concerning the characteristic groups, however, each group consists different technological solutions, depending on locally influencing factors and type of use. These are:

- Drilling technologies for geothermal exploration and exploitation boreholes;
- Drilling technologies for exploitation and reinjection boreholes;
- Well head completion;
- Geothermal water treatment;
- Heat exchanger complete (direct or open loop system);
- Pumping station;
- Complete for backup or covering of peak loadings;
- Water transportation from the geothermal heat source to users;
- Heat distribution systems (individual user(s) or district heating system);
- Regulation of heat supply;
- Systems for heat supply to different type of users.
- Systems for collection of effluent (used) geothermal water.
- Re-injection of the used geothermal water system completion.

This chapter is related to the parts after the well head completion and geothermal water treatment and without the waste water reinjeciton, which are treated in separate chapters.

7.2.1. Heat exchanger complete (direct or open loop system)

Normal heat carrier for direct uses is the thermal water, taken from the well. Type of its distribution depends on the requests of project in question, chemical composition, environmental considerations, economy and other locally influencing factors.

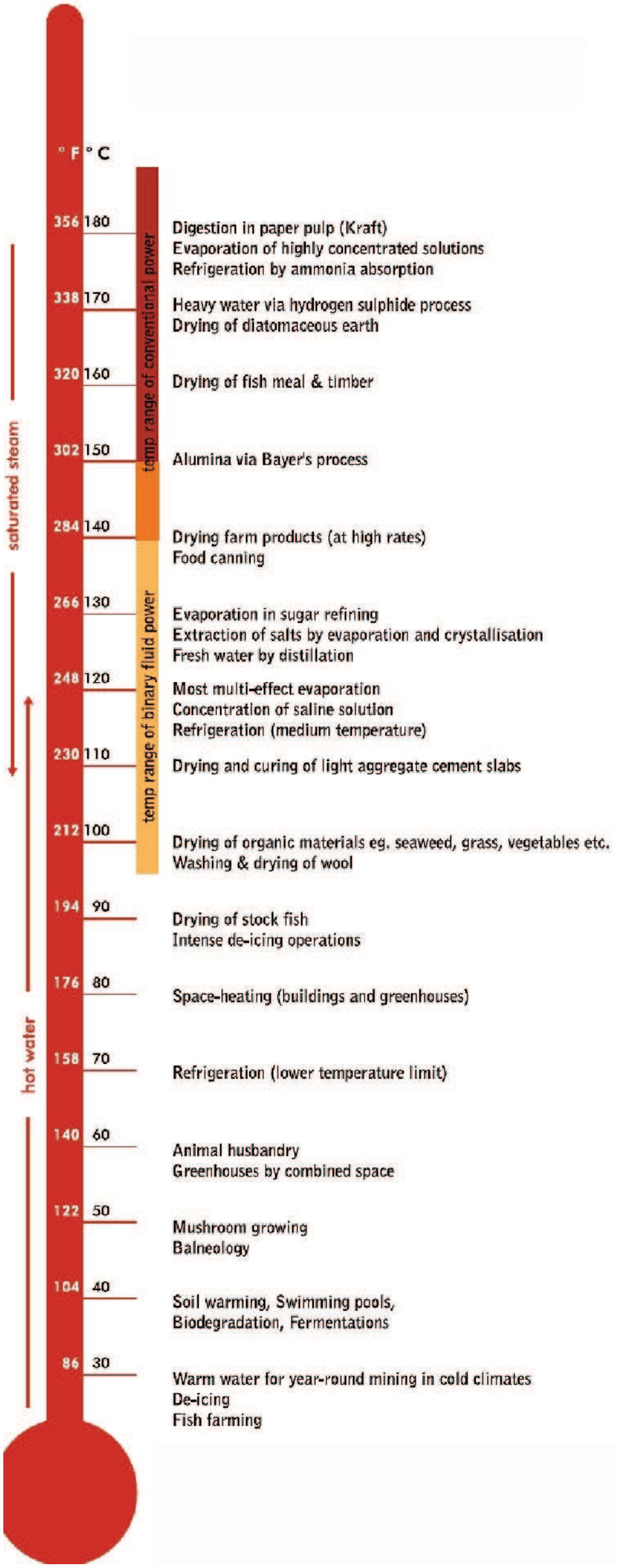


Fig.7.2. Lindal diagram (GNS Science, 2006)

7.2.1. Direct or indirect connection

Application of an open loop geothermal system, i.e. direct use of thermal water in the users heat exchangers (direct connection) is possible only when the geothermal fluid is not corrosive and with intention to scaling. However, that's extremely rare case in practice resulting with a list of complications for the users of such types of geothermal systems. Mostly, the economy reasons are the background for its quite wide use, particularly for smaller agricultural projects. When applied for bigger systems, additional control of the water chemistry is necessary, increasing significantly the exploitation costs. Much more convenient is the application of closed loop systems (indirect connection) enabling easier control of the geo-thermal water pressure and chemical com-position and, in that way, a full protection of the heating system parts, divided from the geothermal water flow by a heat exchanger (Fig.7.3).

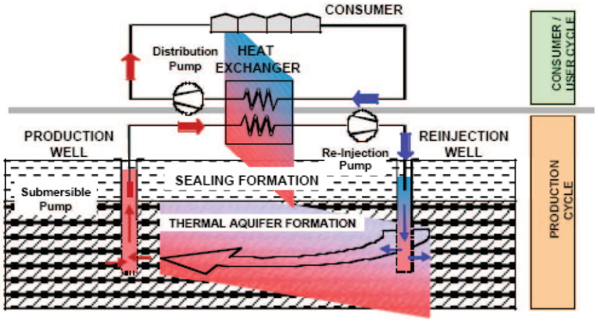


Fig.7.2. Doublet system in Kocani (Macedonia) – closed loop system (Popovski, 2003)

The principal heat exchangers used in geothermal systems are the plate, shell-and tube, plus the downhole ones.

7.2.2. Plate heat exchangers

The plate heat exchanger (Fig.7.4) consists of a series of plates with gaskets held in a frame by clamping rods. The countercurrent flow and high turbulence achieved in plate heat exchangers (Fig.7.5), provide for efficient thermal exchange in a small volume. In addition, they have the advantage when compared to shell-and-tube exchangers, of occupying less space, can easily be expanded when addition load is added, and cost 40% less.

The plates are usually made of stainless steel; although, titanium is used when the fluids are especially corrosive. Plate heat exchangers are commonly used in geothermal heating situations worldwide.

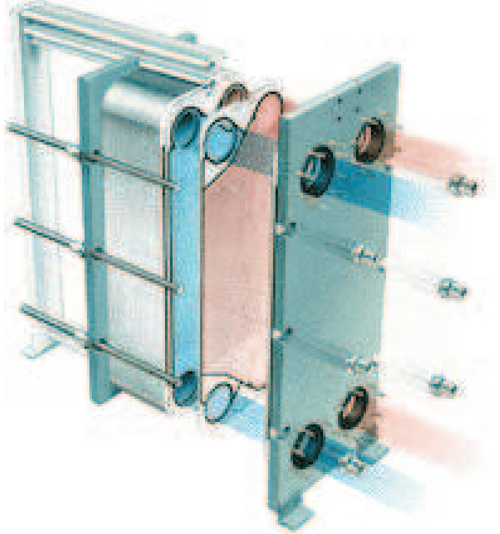


Fig.7.4. Plate heat exchanger construction

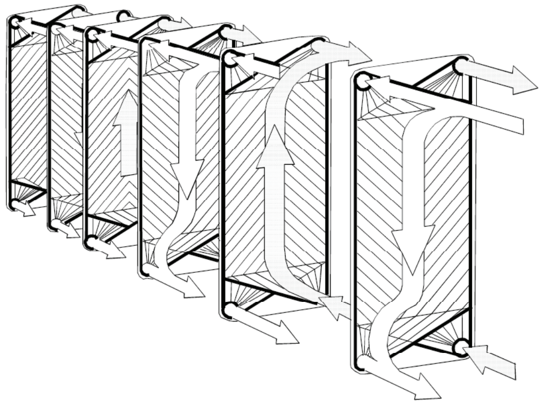


Fig. 7.5. Flows in a plate heat exchanger

7.2.3. Shell-and-tube heat exchangers

Classical shell-and-tube heat exchangers (Fig.7.6) may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (difference between incoming and outgoing fluid temperature), and the larger size.

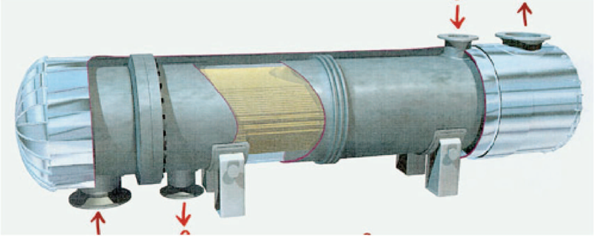


Fig.7.6. Shell-and tube heat exchanger

7.2.4. Downhole heat exchangers

Technology of the “downhole” heat exchangers use, for extracting the heat from geothermal wells, completely changes the approach to the problem of well completion and use. Except extraction of geothermal water (Fig.7.7) from the aquifer, location of the heat exchanger is in it, and enables “indirect” contact with the aquifer. In that way, absence of the pressure disturbances in it is reached, i.e. avoiding the problems of corrosion and scaling.

Technology is proven and being in a rather wide use in U.S.A. and New Zealand but not in Europe and the other parts of the world. That is mainly due to the small capacity of down hole heat exchanger’s completes, which limits their use only to heating of small private houses which is not characteristical for Europe, where normally there are not very shallow geothermal aquifers on disposal.

7.3. HEAT DISTRIBUTION AND PIPING

7.3.1. Piping

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

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

Carbon steel is now the most widely used material for geothermal transmission lines and distribution networks. Available in almost all areas, it is manufactured in sizes ranging from 10 to over 1.500 mm. Steel is the material most familiar to pipe fitters and installation crews. The joining method for small sizes (<50-15 mm) is usually threading, with welding used for sizes above this level. For under-ground installations, all joints are typically welded when unlined piping is used.

Corrosion is a major concern with steel piping. In many geothermal fluids, there are various concentrations of dissolved chemicals or gases that can result primarily in pitting or crevice corrosion. If the potential exists for this type of attack, or if the fluid has been exposed to the air before entering the system, carbon steel should be the material

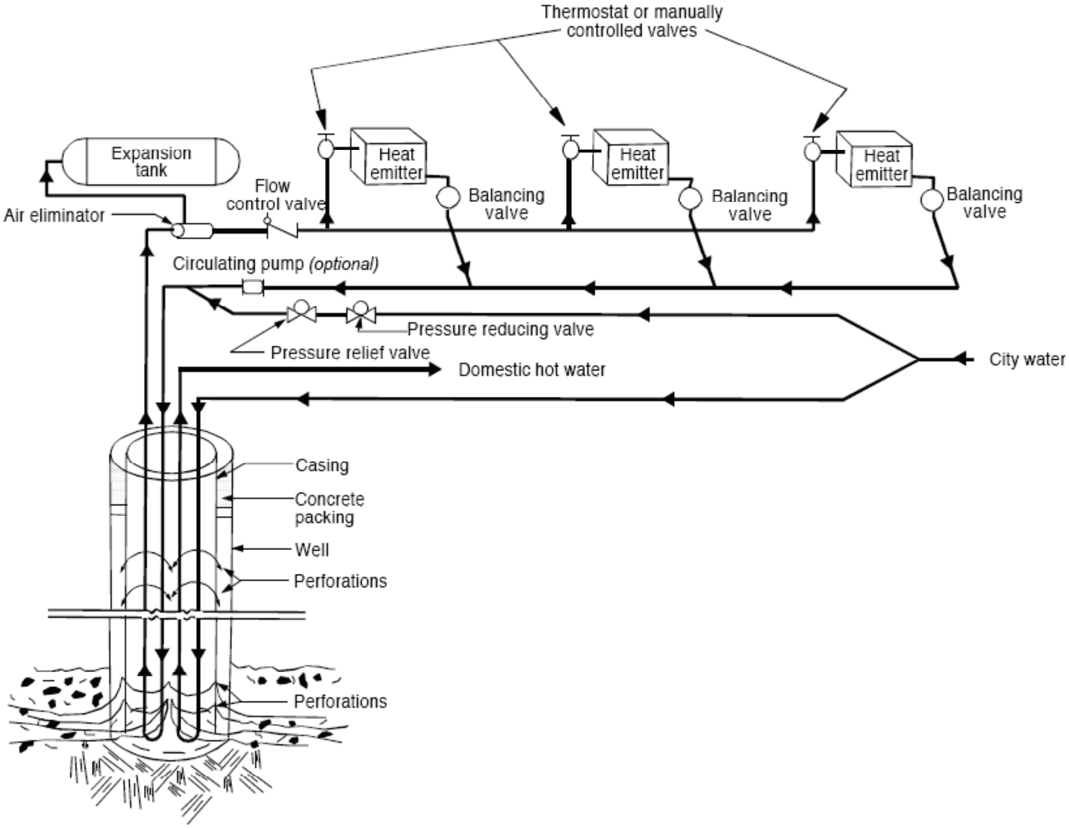


Fig.7.7. Typical hot water distribution system with downhole heat exchanger (Culver, 1989)

of last resort. Additionally, buried steel pipe is also subject to external corrosion unless protected with a suitable wrapping or cathodic protection.

Also other materials are on disposal and used in some projects due to some specific reasons.

Galvanized steel has been employed with mixed success in geothermal applications. Consideration should be given to the fact that the protective nature of the zinc coating is generally not effective above 60ºC.

Fiberglass piping, normally referred to as FRP (fiberglass reinforced plastic), is available in a wide variety of configurations. Pipe material can be compounded to be serviceable to temperatures of up to 140ºC. Regardless of the type of fiberglass material used, care must be taken to maintain operating pressure high enough to prevent flashing of hot fluids. At high temperatures (>boiling point), the RTRP systems are susceptible to damage when fluid flashes to vapor. The forces associated with the flashing may spall the fibers at the interior of the pipe surface. It is also necessary to take into account that RTRP pipes are normally produced in dimensions larger than >50mm, i.e. another material would have to be used for branch and small diameter piping of < 50 mm.

PVC is a low-temperature (maximum up to 60ºC) rigid thermoplastic material. It is manufactured in 15 to over 400 mm in diameter and is, next to steel, the most commonly available piping material.

CPVC is a higher temperature rated material with a maximum temperature rating up to 100ºC. Pressure handling ability at this temperature is very low (as is PVC at its maximum temperature) and support requirements are almost continuous.

Polyethylene is in the same chemical family (polyolefin) as polybutylene and is similar in physical characteristics. It is a flexible material available in a wide variety of sizes from 15 to 1.000 mm diameter, however its maximum service temperature is only of 40 to 50 ºC. Very high molecular weight/high density PE can be employed for low pressure applications up to temperatures as high as 80 ºC but it is significantly more expensive.

Some European district heating systems are using a cross-linked PE product for branch lines of 125 mm and under. This material is servicable to 90 ºC.

Asbestos cement pipe has been used for many years but recent concern about the carcinogenic nature of asbestos has resulted in an impact on the availability of these pipes. Manufacturers have ceased production and it is unlikely the material will be available in the future.

Buried or aboveground pipe installations are options in the system design that require evaluation.

Aboveground installations typically are supported on concrete pipe supports and rollers. This installation eliminates conflicts with buried utilities and may be easier to maintain. However, aboveground installations are more subject to damage and vandalism. Pipe supports and constraints, road crossings, venting, expansion provisions, and insulation protection are important considerations in the aboveground design.

Fig.7.8. Aboveground geothermal pipeline in Smokvica, Macedonia (Popovski, 2000)

Buried piping systems, the most common type of transmission line, are aesthetically more pleasing than aboveground installations and are deemed far superior from the standpoint of immunity to accidental or intentional damage. (Fig.7.9). Major disadvantages are external pipe corrosion and accessibility for maintenance or service connections.

Proper pipe bedding materials, grading, venting, expansion provisions, and corrosion protection should be reviewed for buried installations. Proper bedding is particularly important for the nonmetallic materials.

A method of buried installation that allows accessibility is the use of utility tunnels with removable covers or adequate crawl space and man-holes. However, this type of piping is the most expensive and also the one with the longest life expectancy and lowest maintenance cost of all pipe-lines.

Normally, pipes in district heating systems or long transmission lines carrying warm geothermal fluid require some thermal insulation. This insulation can be provided by selected backfill methods, field applied insulation or, more commonly now-a-days, a pre-insulated piping system.

Fig.7.9. Buried pipes installation

For steel, FRP, PB, PE, DUC, and PVC a variety of jacket insulation materials are available at the market (Fig.7.9). The most common one is PVC. High impact type piping is employed for this service with a minimum thickness of 120 mm. Polyethylene jacketing material is commonly used for the European steel district heating lines and is generally a minimum of 125 mm. It is also used in corrugated form for the jacketing on pre-insulated PEX pipe.

Fiberglass jacketing is used primarily with fiberglass and steel carrier material.

Most jacketed systems (except fiberglass) employ a rubber end seal to protect the insulation from exposure to moisture. On fiberglass systems, the jacketing material is tapered at the end of each length to meet the carrier pipe, thereby forming a complete encasement of the insulation.

Particularly for longer lines and higher fluid temperatures, pipe extension resulting from temperature changes should be taken into account in the piping system design, i.e. proper and controlled moving of pipes should be allowed. Adequate thrust blocking and restraints are needed to secure some kinds of pipes. Steel pipe should have expansion loops or expansion joints and thrust blocking to control the expansion and keep the pipe stress within the allowable limits. During the system layout design, a comprehensive stress analysis should be performed to determine if all sections of the system are within the allowable stress limits. The AC, ductile iron, and other types of push-on joints may allow for expansion in the joint and require only thrust blocks.

As for any system consisting circulation of fluids, design of pipelines takes into account the head loss in the system in question. As the pipe size is decreased for a given fluid flow, the head loss will increase, therefore, increasing the pump motor size and energy consumption. Head loss in a piping system is a function of the quantity circulated and the friction loss in the pipe. Pipeline head loss should be carefully calculated using the manufacturer's flow data and corrected for the temperature involved.

The successful geothermal pipeline layout should consider the topography of the system. Distribution networks and transmission mains with significant changes in elevation may require additional venting and vacuum valves. Non-condensible gasses trapped at system high points can restrict flow rates and increase pumping requirements.

If the water is drained from a pipeline without proper air venting, low pressure can be created that can cause the transmission line to collapse. Hot water has a higher vapor pressure and the problems associated with water flashing should be addressed.

Supply and distribution systems can consist of either a single-pipe or a two-pipe system. The single-pipe is a once-through system where the fluid is disposed or reinjected of after use. Such a distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system (direct connection), or for the connection of geothermal well to the heat exchanger system. In a two-pipe system, the fluid is recirculated so the fluid and residual heat are conserved (second loop in two loop systems). A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems (Fig.7.10) cost typically 20 to 30 percent more than single-piped systems.

Fig.7.10. Properly completed distribution pipelines for large complex of geothermally heated greenhouses (Kocani,Macedonia)

7.3.2. Heat supply

Main problem of the heat supply from geothermal well to the heat users is that, in most cases, heat requirements are changeable, daily and during the year. In order to follow regularly these changes, regulation of heat supply should be provided.

Type and quality of the regulation complete depends on the type of connection of heat user(s) to geothermal well, quality requests of it, and economic liability of technical solutions on disposal.

Most simple is the case with direct connection of user(s) to geothermal well. As told before, such connection is not recommended due to the resulting problems with scaling and corrosion of pipes and heating elements of the user's system. However, for very simple types of use and for relatively low mineralized waters, it is still in rather wide use. For such simple cases, it is not recommended to use expensive and sensible equipment and to apply continual accommodation of temperature of the heating fluid to the changes of user's requests. Simple on/off regulation (Fig.7.11) is normally the only one which is economically feasible.

When normal indirect connection is applied (Fig.7.12), problems with the chemistry of the heating fluid are avoided in the second loop and different types of regulation of heat supply to final users can be applied.

Both, quantitative and qualitative types of regulation are in use, depending on particular requests of the heat user(s). For instance, in Fig.7.13, an example of quality regulation is presented. By the use of a mixing valve, it is possible to follow the changeable requests of the heated room, i.e. to keep the programmed inside air temperatures. Constant volume of the heating fluid is flowing through the system but its temperature is changing depending on the values of the inside air temperature.

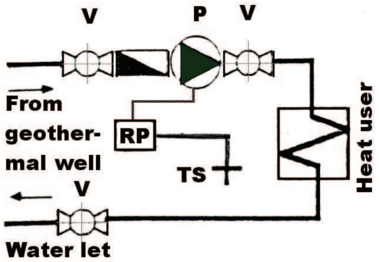


Fig.7.11. Regulation of heat supply for direct connection to geothermal well

When large systems are in question, with different regimes of heat supply, it is necessary to take into account also the influence of pumping from geothermal well to the subsurface reservoir. Then, not only the regulation of heat supply in the secondary but also in the primary loop is necessary.

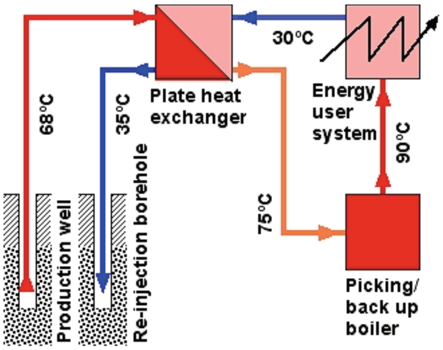


Fig.7.12. Principle of indirect connection of the user to geothermal well

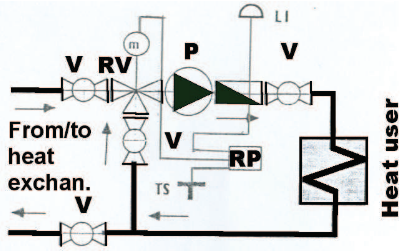


Fig.7.13. Regulation of heat supply for indirect connection to geothermal well

Normally (Fig.7.14), an "amortization" tank is installed in the geothermal location, where geothermal water from all the wells is collected. Depending on the water level in reservoir, one or more well pumps are switched "on/of" or regulated to pump more or less water in it. From the reservoir, water is pumped through the distribution line to the heat user(s) location. It is with changeable capacity, depending on the temperature of the effluent water. After that, water is transported to the final users. However (see later on), for such systems also regulation of the heat supply from the heat accumulation tank and peak boiler is necessary. When temperature of the return water from the users drops below certain value, additional hot water from the accumulator to the system is pumped. If even then it is still below the limit, the peak boiler is switched on and vice versa. In that way, heat supply is accommodated to the total needs of the system of final users.

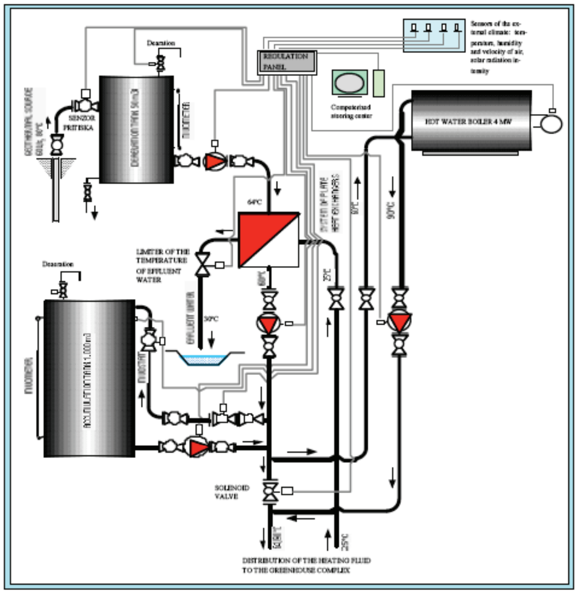


Fig.7.14. Heat supply connection of the Vinica (Macedonia) greenhouse complex to geothermal well

Final, i.e. precise regulation of heat supply to each of the final users should be made by separate connection stations (Fig.7. 15). Heating fluid flow through the systems is continual but its temperature is accommodated to the inside temperature of the heated rooms. When dropped down bellow certain limit, mixing valve let higher flow of the hot water from the system and vice versa.

It is possible to apply also some other technical solutions for regulation of heat supply, however it's necessary to take into account that precise regulation conditions application of complicated even for smaller installations (Fig.7.16). That makes them expensive and complicated for proper main-

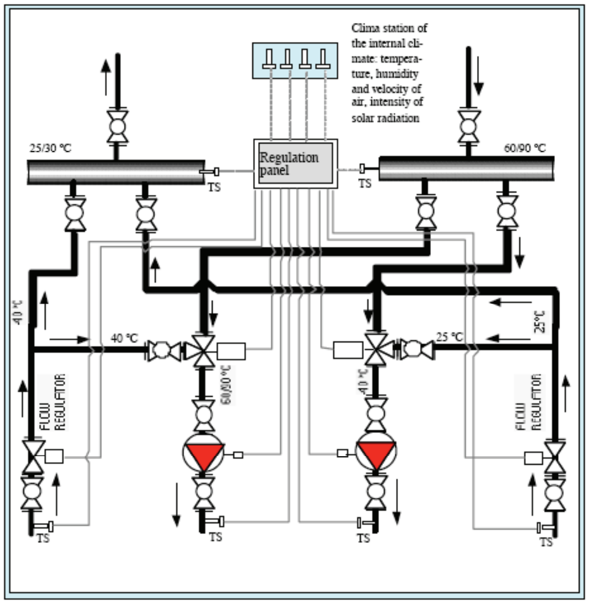


Fig.7.15. Connection of two greenhouse heating systems to the central heat distribution system

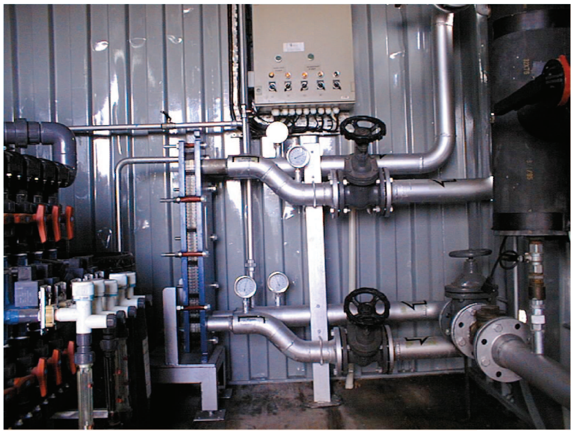


Fig.7.16. Connection station of the greenhouse complex in Ribeira Grande (Azores, Portugal)

tenance.

7.3.3. Peak loadings and backup heat source

Changeable character of the heat supply to users influences not only the technical solution of the heat supply regulation system but also the completion of heat source. For instance, annual lasting of different air temperatures in Middle European conditions can be followed in Fig.7.17. Resulting change of the heat demand of a greenhouse complex (Fig.7.18) enables to get orientation how much of the annual heat consumption can be covered by different power of the heat source (Fig.7.19). Requirements above 50% of the design ones participate less then 10% in the total annual heat consumption, 40% with les then 15%, etc.

Taking into account how expensive is to complete a geothermal energy heat source and distribution lines to the consumers location, it comes that the major part of the investment is not used economically. Therefore, it's obvious that it is economically justified to cover only the basic heat requirements by geothermal energy and to find some other solution for the peak loadings.

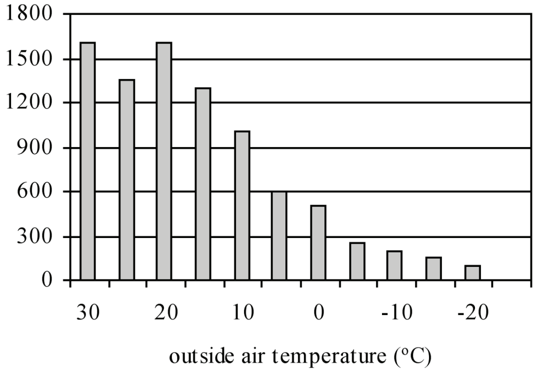


Fig.7.17. Annual temperature occurrences

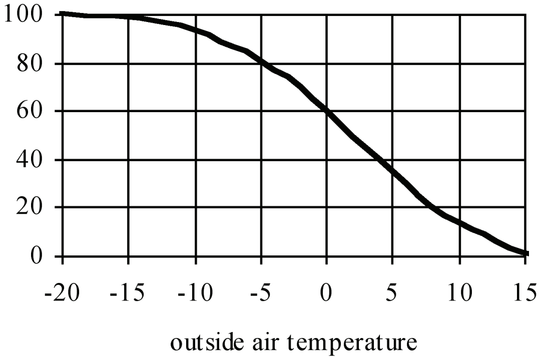


Fig.7.18. Annual heat power demand

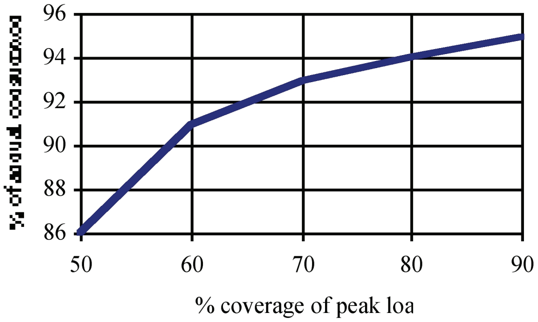


Fig.7.19. Coverage of heat requirements by different powers of the heat source

For the morning short lasting peak loadings, the most economical solutions is to apply so called heat accumulators. These are large tanks (Fig.7.22), in which hot water is pumped when the heat requirements of the users are lower than the capacity of geothermal well(s). In opposite, when they are higher, it is pumped in the system as from an additional heat source (7.14). However, during the coldest winter months, such a solution cannot cover the long lasting peak heat requirements. For such situation installation of an additional heat source, able to cover the peak demand is necessary.

There are two general approaches available to resolve the problem, i.e. to use individual unit heaters in heated rooms or to use a central peaking boiler.

Individual unit heaters have the advantage of saving cultivation space since they can be hanged to the ceiling, but in order to provide more uniform air distribution, large number of units are required making them an expensive option.

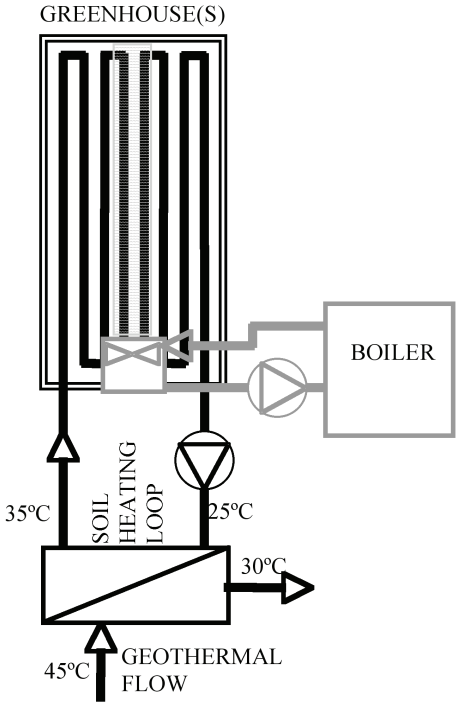


Fig.7.20. Individual arrangement

Peaking with a central boiler is more complicated. There are two common solutions: central boiler is installed as separate heating system (Fig.7.20) and, it is installed down-stream of the geothermal heat exchanger (Fig.7.21). First solution is aimed to improve the temperature of the supply water using the same heating elements, whereas the second employs two independent heating systems.

Peaking strategies of the individual unit heaters and central boiler engaging only peaking system are the same (Fig.7.20). If geothermal soil heating system is designed to cover 50% of the peak heat power needs, than the additional (peaking) installation would be designed to cover the remaining 50%. For example, if geothermal heating system at the moment covers 60% of the heat power requirements the additional 40% will be supplied by the peaking installation.

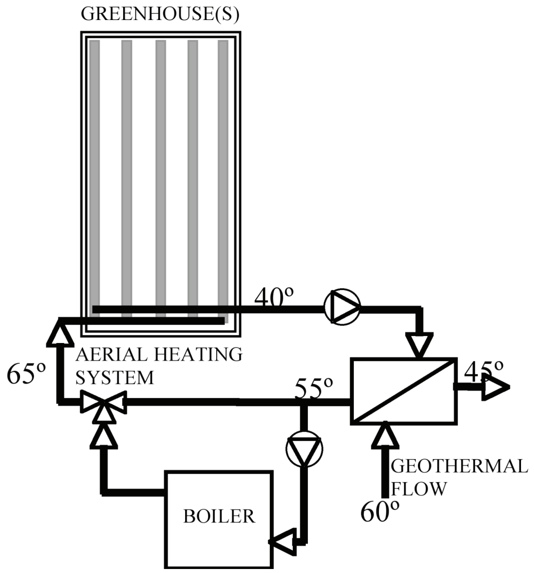


Fig.7.21. Downstream arrangement

It is entirely different situation when central boiler is installed downstream of the geothermal heat exchanger (Fig.7.21). In this case as the supply water temperature increases the capacity of the geothermal heat exchanger decreases, thus when base load geothermal system covers for example 40% of the heat power required in the moment, the central boiler would have 90% of its capacity employed or if geothermal covers 80% central boiler would employ 30%.

Annual coverage by geothermal energy can be calculated as:

$$\mathbf{C}_{geoth} = \mathbf{Q}_{geoth} / \mathbf{Q}_{demand}$$

Annual heat demand covered by geothermal energy is a product between the level of power demand and related duration of the same demand, which means that the heating system is underutilized for the most part of the season, i.e. it mainly operates in conditions different than those defined for optimal performance.

One possible approach to overcome this problem (nowadays widely accepted in practice), when application of renewable energies is in question, is to install two heating isystems – one to cover base load heating power requirements which on annual base can satisfy 60-90% of the energy needs (renewable energy requesting initial high investment but resulting with very low exploitation costs), and other for the peak and near to peak loading conditions (requesting minimal initial investment but resulting with high exploitation costs). This way both systems when are in operation work within their optimal performance range.

Fig.7.22. Heat accumulators of the Reykjavik (Iceland) district heating system

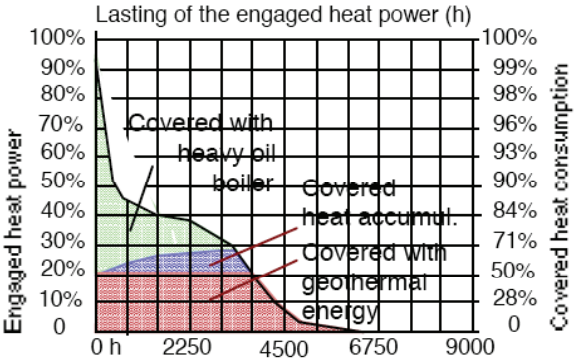


Fig.7.23. Economical organization of covering the heat requirements during the year

Then (Fig.7.21), a peak loading fossil fuel boiler is normally applied. That enables composition of a specific diagram of annual covering of users heat requirements (Fig.7.23). Division of the participation of different heat sources depends on the results of necessary economy analyses. Solution resulting with the lowest average price of heat over the year should be chosen, i.e. adequate combination of the exploitation and other running costs with the annual participation of investment in total costs. Resulting diagram of coverage the annual heat demand shall be similar to the one given at Fig.7.23

7.4. Types od Direct Use Applications

Different type of direct heat use have been technically and economically proven during the last 25 years. General data and information shall be given for all of them in the following part of this chapter.

7.4.1. Space conditioning

Under the expression "space conditioning" both heating and cooling of rooms is understood. Space heating with geothermal energy has a wide-spread application, not only of individual residencies but also of large buildings and industry.

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

Three major types of heat convectors are used for space heating:

1) forced air (forced convection systems);
2) natural air flow using hot water or finned tube radiators (natural convection systems)
3) radiant panels

Main difference for geothermal energy application is that to design a concrete heating system is not possible by using the "standard" temperatures for heat supply but the temperatures on disposal of concrete well or geothermal system.

Forced convection air systems are based on the use of a water/air heat exchanger through which the air is blown by a fan and, after taking the heat, distributed to the heated room. Simple solutions (Fig.7.24 and 7.25) are normally used in industry for heating the workshops, or for heating large rooms where good temperature distribution is not so much important and where the noise doesn't disturb the conditions for work.

This simple heating principle becomes more complicated, depending on the characteristics of the heated building and design requests of the heated rooms.

For instance, when heating of more rooms in a building is in question, or also ventilation and humidity control is needed, and air conditioning unit for supply of more rooms is necessary (Fig.7.26).

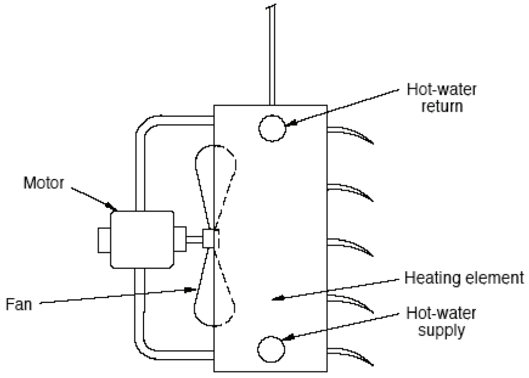


Fig.7.24. Horizontal fan-assisted convector for air heating

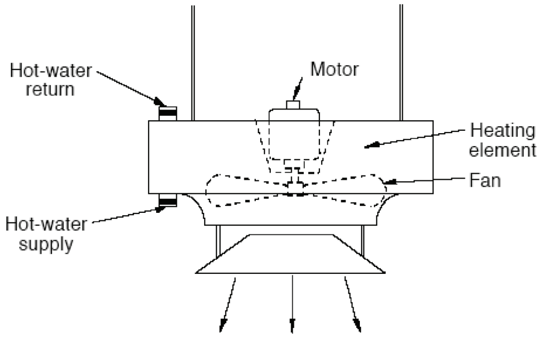


Fig.7.25. Vertical fan-assisted convector for air heating

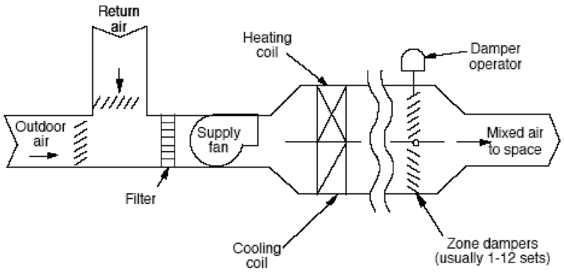


Fig.7.26. Central air conditioning unit for a building with more rooms (Bloomquist, 1987)

Main difference to the single air heating units is that consisting mixing of return and fresh air heating, enabling economy of the heat use and keeping good air conditions in the heated rooms. Difference is also that it is possible to heat more rooms by distribution of the heating air to them.

Many combinations of such centralized air heating/conditioning are possible, depending on particular requests of heat users. It's necessary to underline that such systems are more popular in U.S.A. than in Europe and other parts of the world.

In Europe, normally, heating systems with natural convection are applied. They are based on the vertical movement of the air through the heating elements, caused by the temperature difference due to the heat transfer from them to the air.

Type of the heating elements to be used depends on the characteristics of the geothermal heat source on disposal, local habits, market conditions, aesthetics and economy conditions.

Fig.7.27. Simple steel pipe heating system

The most simple system is by the use of pipes as heating elements. Two or more pipes are put one above the other along one of the walls of the room (Fig.7.23) and transferring the heat from the water streaming in them to the surrounding air. It's a cheap but aesthetically rather poor technical solution.

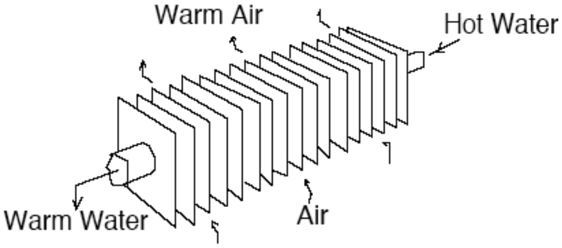


Fig.7.28. Finned convector (Lund, 1987)

Much better is the use of convectors, made of finned pipes (Fig.7.28). They have much larger heating surface per unit length of the pipe and, therefore, requesting less space for montage. However, they are quite weak for work with the heating fluids of lower temperature.

The most spread solution in use are the so called radiators. They can be made in different forms and from different materials, Most known are radiators made of steel plates (Fig.7.29), cast iron radiators (Fig.7.30) and aluminium radiators (Fig.7.31).

Radiators are a rather good technical solutions because they are traditionally in wide use. Efficiency is acceptable, even for lower temperatures of the heating fluid (up to about 40ºC), and people is used to see them as a part of the room interior.

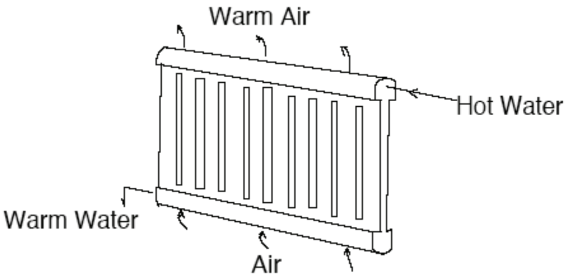


Fig.7.29. Steel plate radiator

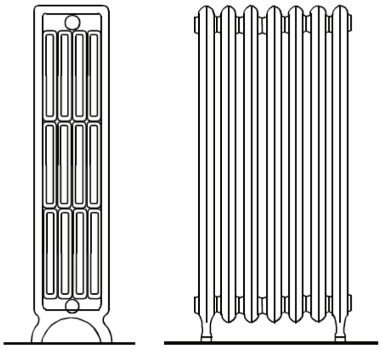


Fig.7.30. Cast iron radiator

Finned tube/convector systems, as illustrated in Fig.7.28, requires the highest heating fluid temperature of all the hot water systems. This equipment can be found in many types of buildings and frequently in conjunction with air heating systems in larger buildings. Because this system uses no fans for circulating, it relies entirely on elevated temperature to promote the air convection by which it operates. As a result, it does not perform well at temperatures less than that for which it was designed.

Fig.7.27. Aluminium radiator

The problem of weak heat transfer with the use of convectors for lower temperatures of the heating fluid can be removed by their location in a specially designed metallic masks, enabling creation of a controlled vertical air flow (Fig.7.32 and 7.33). Eventual use of a damper on the higher hole enables adjustment of the air flow and, in that way, accommodation to the available temperature of the heating fluid.

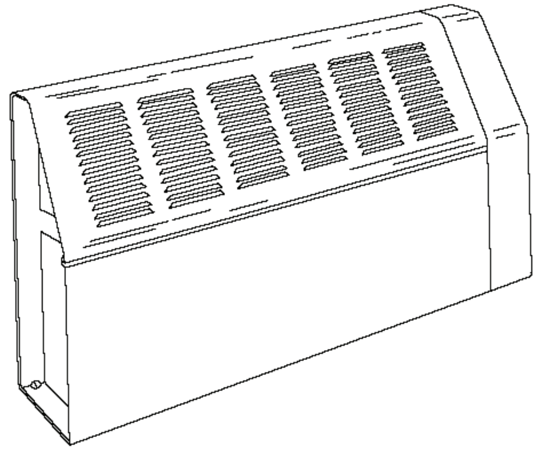


Fig.7.32. Heating element made of convector in a metallic mask

Radiant panel systems are often used today, particularly where lower temperatures of geothermal water are on disposal and as a lower part of the cascade chain of geothermal water use. This system was common in construction during the 50-ies of last century. However, they nearly disappeared after 60-ies, to reborn after the 80-ies with appearance of low temperature heating fluids with RES origin. Applications that lend themselves well to this type of system are automotive repair shops, large high ceiling manufacturing structures, hospitals and schools.

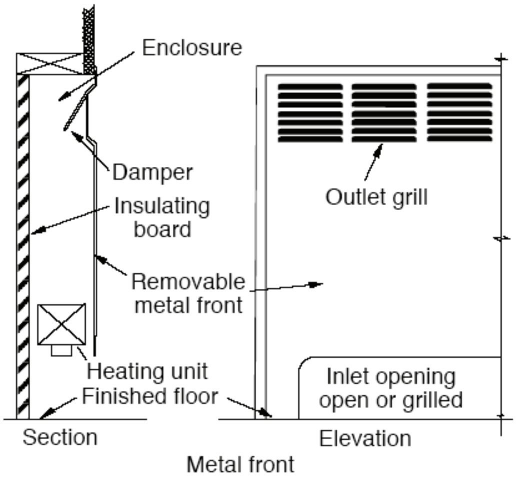


Fig.7.33. Convector in the wall construction with the mask on the front side

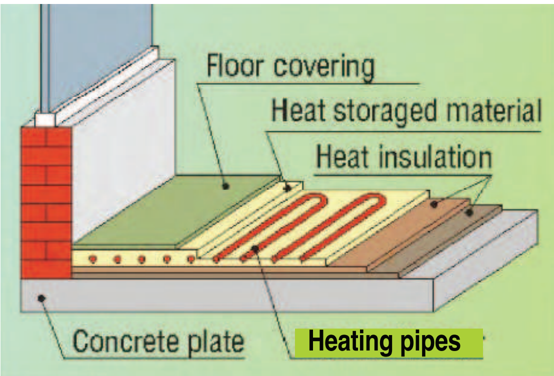


Fig.7.34. Low-temperature floor heating system

Radiant panel systems, as indicated in Fig.7.34, involve the circulation of warm water (35-45ºC) through piping that is embedded in the floor of the building. Older systems were constructed with copper or steel piping. Leaks that developed because of expansion and contraction, and corrosion resulted in expensive repair requirements. As a result, as said above, the panel system fell into disuse for many years. With the advent of new, nonmetallic piping products (primarily polybutylene) for radiant panel systems, listed difficulties has been removed, what made them very interesting nowadays.

When geothermal energy use is in question, main problem of all the heating systems is the decrease of the heat transfer coefficient for lower temperatures of the heating fluids. Most of them have been developed for the temperature regime 90/70ºC or higher (air heating systems), which is normally above the on disposal of shallow geothermal wells.

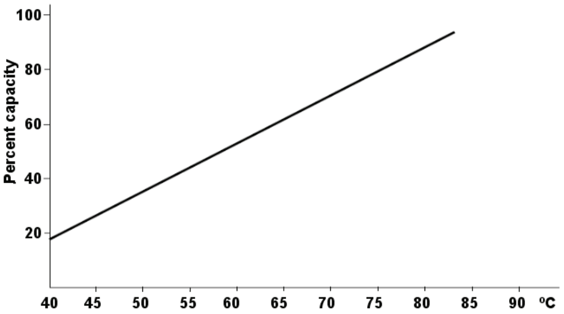


Fig.7.31. Influence of the water temperature to the heat capacity (Lund, 1983)

Resulting decrease of heat supply should be taken into account by using adequate decreasing coefficients. Fig.7.31 illustrates the average effect of reduced water temperature and Fig.7.32 of the low water velocity through the heat water/air exchangers on the heat transfer in hot water heating equipment (individual terminal equipment types respond differently). Therefore, use of the equipment with lower temperature regimes results with the need to design heating elements with larger heat exchange surface. That results with higher investments but also complications with engagement of useful space in the heated rooms.

To remove the problem, it's necessary to choose right type of the equipment, accommodated to the temperature of the heating fluid on disposal, or to cover only the basic heat requirements by geothermal energy and the peak loads by some other heat source, in order to keep the "normal" temperature regime of the heating installation (Fig.7.12).

7.4.2. Sanitary warm water preparation

Preparation of sanitary hot or warm water preparation is a quite important energy consumer for residencies, hotels, restaurants, industry the terciary sector projects. When geothermal energy is in question, it is a quite convenient heat consumer. It is, more or less, continual during all the year, and can be used as a separate user, or in combination with space heating (Fig.7.33). However, if that is economically liable is the question of a feasibility study to be made before installing it in concrete building. The decision should be based primarily upon the volume of hot water used in the building.

In general, above listed possible consumers will be characterized by sufficient domestic hot water consumption to warrant retrofit of the existing system. Buildings such as offices, retail stores, theatres, and elementary schools are unlikely to be attractive for geothermal energy use.

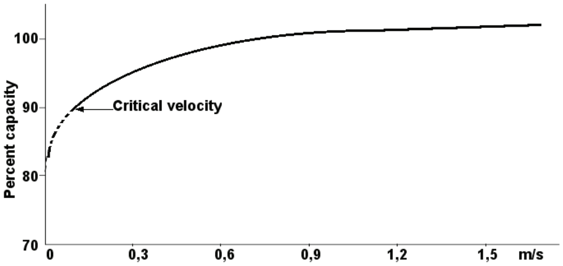


Fig.7.36. Influence of low water velocity on heat transfer in hot water heating equipment (Lund, 1983)

The preferred arrangement for domestic hot water heating is shown in the figure above. Under this design, water exiting from the space heating heat exchanger is directed to the domestic hot water heat exchanger. This scheme provides for larger temperature drop in both the end user building and in the retrofit heating system. Larger temperature drops reduce system flow rates and required piping sizes.

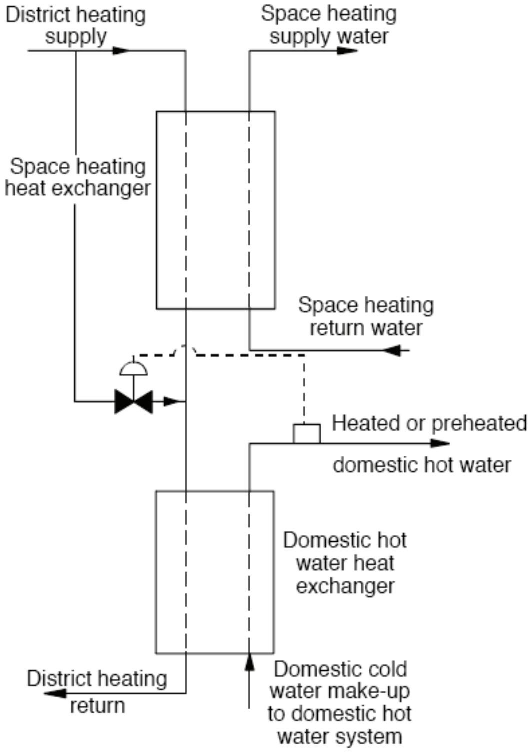


Fig.7.37. Sanitary warm water preparation with geothermal heat

Under some conditions, the flow rate from the space heat exchanger will not be sufficient to raise the domestic hot water to the required temperature. In this case, a second circuit connected to the primary hot water supply can be added to the domestic hot water heating heat exchanger. This second circuit would provide the additional boosting of the domestic hot water to the required temperature.

7.4.3. Agribusiness applications

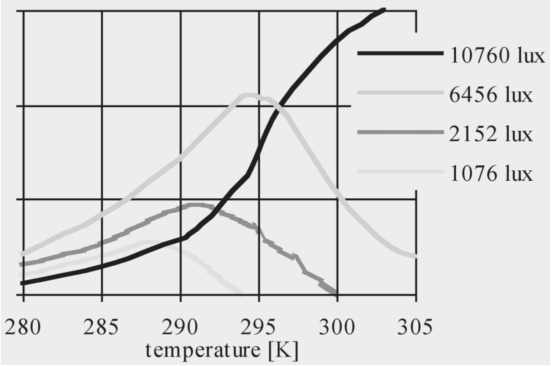
Agribusiness applications (agriculture and aquaculture) are particularly attractive due to the fact that they normally require heating at the lower end of the temperature range where there is an abundance of geothermal resources. Use of waste heat or the cascading of geothermal energy also has excellent possibilities.

A number of agribusiness applications can be considered, such as are: greenhouse heating, aquaculture and animal husbandry, soil warming and irrigation, mushroom culture, and bio-gas generation.

7.4.3.1. Heating greenhouses with geothermal energy

Most spread use of geothermal energy in agriculture is heating of greenhouses. More than 1.000 ha of glasshouses and soft plastic covered greenhouses use geothermal energy as heat source all over the world. Main reason for it is the dependence of greenhouse production of continual supply during the large part of the year. That is one of the main production costs, influencing significantly the final price of products.

The task of greenhouse construction is to create convenient environment for production of out-of-season fresh vegetable and flowers products. It enables to have products at exact dates, when market conditions are much better than during the normal production season, and products with even better quality than of the open field ones, plus with 3-4 times higher rate. By creation of an artificial climate in closed room, optimal dependence on light intensity and temperature of the plant is used to follow development of the plant. That means keeping optimal temperatures to the available solar light.



7.38. Optimal air temperature depending on available light income and photosynthesis intensity

Problematics is neither simple nor easy for handling due to list of complications, connected to keeping artificial climate in a glass or transparent plastics covered room and special requests of concrete plants, connected to their origin, shape and phase of growing, like they are velocity of movement of the air in the closed room, location of the optimal temperatures in the room with different vertical and horizontal air temperature profiles, need for constant supply of CO_2, need for maintenance of constant air humidity, etc., etc. Most of them can be resolved by a proper design of heating and ventilation systems.

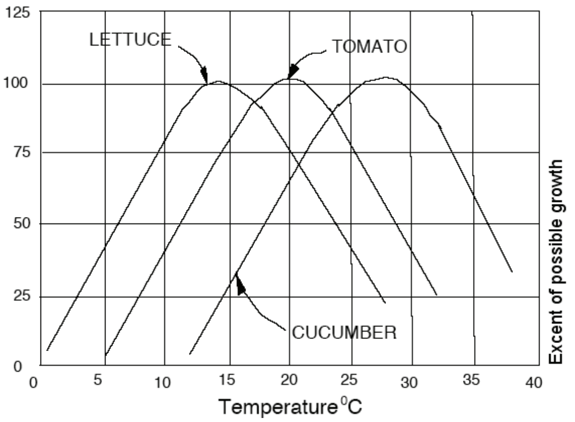


Fig.7.39. Optimum growth temperature versus light intensity for some vegetable cultures (Sammuels, 1991)

Taking into account the particular characteristics and requests of greenhouse interior, heating systems and elements for normal space heating cannot be applied. That is the reason that a list of special heating systems have been developed, enabling economical accommodation to the requests of concrete type of greenhouse construction, characteristics of local climate and requests of concrete plant. Most applied is the classification of von Zabeltits (Fig.7.40), accommodated by Popovski for geothermal energy use (Popovski, 2982).

Aerial pipe heating systems have been the most popular “universal” heating systems in the past. It is convenient because made of easy for maintenance steel pipes with different possibilities for allocation, depending on the requests of concrete culture and chosen temperature regime (Fig.7.41). It is still in wide use, particularly in combination with “vegetative” heatings (Fig.7.42).

The use of benches for growing different types of flowers requested design of heating systems accommodated to this technology.

Normally, benches are heated with the system of metallic or plastic pipes positioned bellow the bench, without or in combination with the aerial (Fig.7.43) or vegetative heating system.

Vegetative heating system is the most popular one in Mediterranean countries. It is composed of the plastic (Fig.7.45) or metallic (Fig.7.43) pipes positioned on the growing surface along the plants rows.

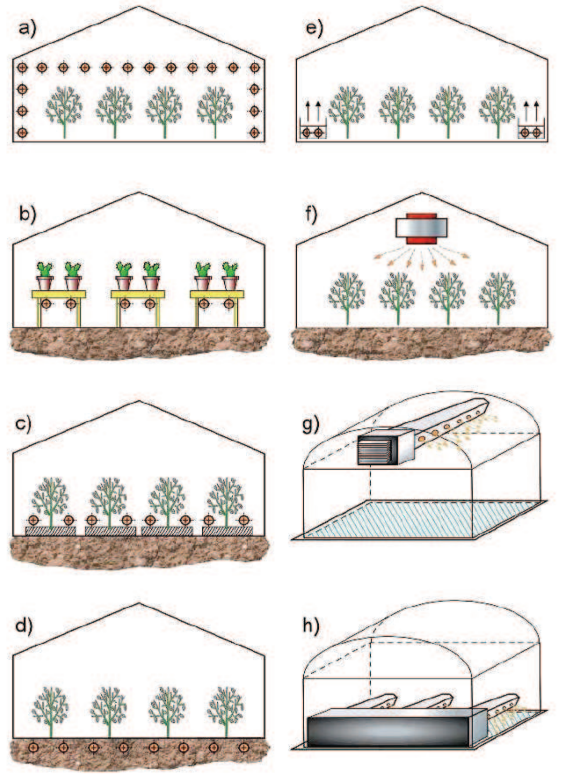


Fig.7.40. Classification of geothermal heating installations: a) Aerial pipe heating systems; b) Bench heatings; c) Vegetative heating; d) Soil heating; e) Convectors; f) Forced convection air heaters; g) Fan-jet air heating; h) Low positioned air heating (von Zabeltits, 1967, Popovski 1982)

Fig.7.41. Aerial pipe heating system

However, particular requests of some plants and use of very low temperatures of heating fluids (below 35ºC), resulted with development of different types of heating elements (Fig.7.46). Besides the single smooth or corrugated plastic pipes (a) and (b), it is possible to follow the use of special soft plastic tubes (bags), polytubes made of prefabricated system of connected pipes (d), rigid plastic plates (e) and specially prepared soft plastic tubes with perforation for positioning the plants directly above the heating system. Still, due to the problems in exploitation and maintenance of the later types, single corrugated pipes is in most wide use all over the world.

Fig.7.42. Combination of aerial and vegetative heating installation for growing roses

Fig.7.43. Bench heating

Fig.7.44. Bench heating with plastic pipes

Fig.7.45. Vegetative heating

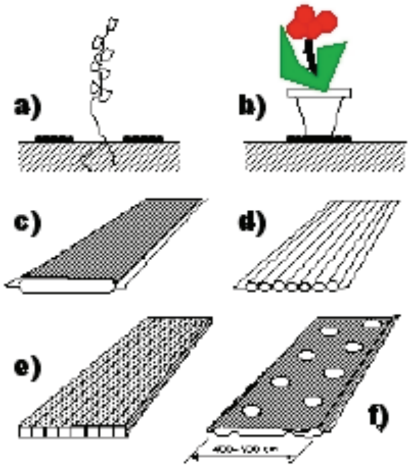


Fig.7.46. Types of heating elements of the vegetative heating system: a) Parallel pipes positioned along the plants rows; b) Pipes positioned bellow the growing pots row; c) Soft plastic black tube positioned in parallel with the plants rows; d) The same but with prefabricated connected poly-pipe lines (polutubes); e) Rigid plastic plates with channels for heating fluid flow; f) soft plastic tubes with holes for allocation of plants.

Fig.7.47. Soil heating in a greenhouse

Soil heating systems (Fig.7.47) are normally used for very low tempe-ratures of geothermal waters on disposal in mild climates and for the cultures requesting controlled temperature of the root system. Good side of it is that heating elements, i.e. plastic pipes) are positioned below the ground surface and do not disturb growing activities in the greenhouse. However, due to the limitations of possible temperature of the root system (below 25ºC) its heating performances are very poor.

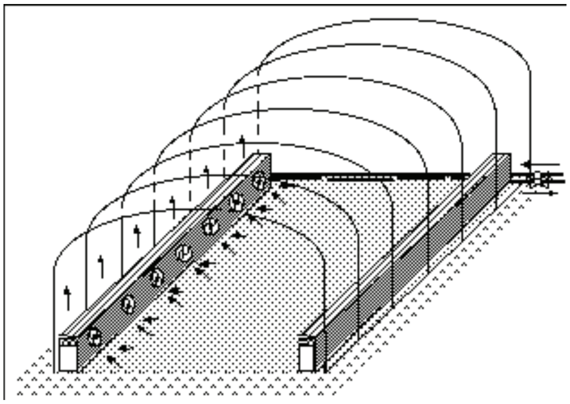


Fig.7.48. Scheme of the “hortitherm” convector heating system

Use of convectors for heating greenhouses is very rare due to the limited possibilities to use low temperature heating fluids. By incorporation of fans (Fig.118) it’s possible to improve performances of this system, however it conditions additional costs for electricity for running the fans.

Fig.7.49. Horizontal air heating units

Similarly as for heating rooms (Fig.7. 24) it is possible to use air heaters composed of water/air heat exchanger and fan for heating greenhouses, too. Fig.7.49). They are with very quick response to the changes of outside climate, however resulting vertical air temperature profile in the greenhouse interior is rather uneven and not convenient for many cultures. That is the reason for application of “dense” distribution of air heaters in greenhouse, however that increase very much the investment and exploitation costs (high electricity consumption!).

In order to remove the weak sides of the heating system with air heaters, it is possible to use a simplified system with combination of air heaters and air distribution channels made of transparent soft plastic material (Fig.7.50). In that way, a better distribution of the heating air in the greenhouse interior is enabled and all the advantages of the unit heaters kept. This, so called “fan-jet” system is very popular in U.S.A.

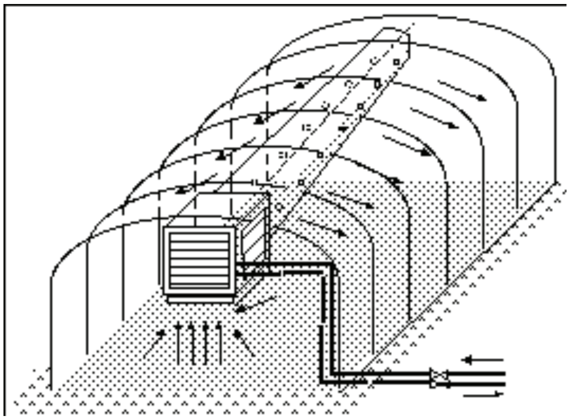


Fig.7.50. “Fan-jet” air heating system

Further improvement can be made by location of air distribution channels between the plants rows. Rather even distribution of the heating air can be reached in that way, however channels are disturbing normal work in the greenhouse, which makes this solution less popular.

One of the most important factors for making the right choice of heating system for a greenhouse with concrete plant culture in it is the resulting vertical air temperature in greenhouse interior. That influences the conditions for concrete plant growing and heat consumption of the greenhouse. The problem can be understood from the illustration in Fig.7.51. For the same reference temperature at 1.5 m height, each type of heating installation has completely different vertical air temperature profile. Depending on the location of highest temperatures, one installation can be good for certain plant but not for the other one, i.e. installations which are good for low cultures are not good for the high ones. Then, greenhouse heat consumption depends on the temperature difference between the outside and inside air. Installations resulting with high air temperatures below the greenhouse roof shall have higher heat consumption than the ones with lower temperatures.

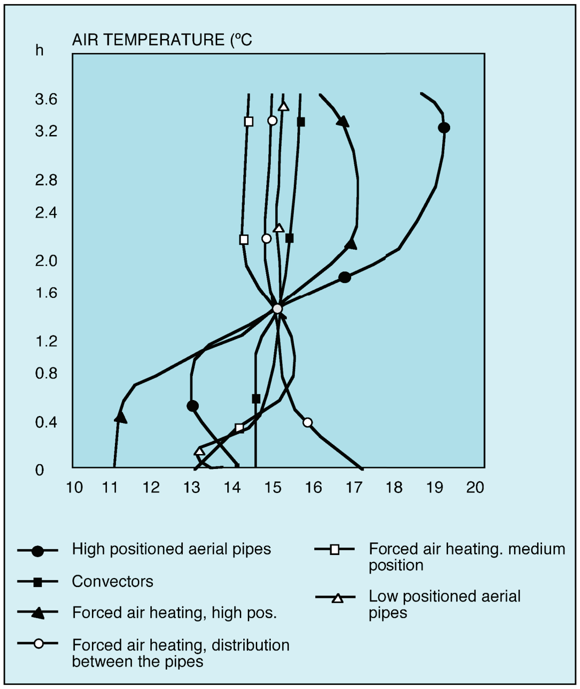


Fig.7.51. Vertical air temperature profiles in a greenhouse depending on the type of installed heating system

Taking into account the differences of requests of a culture during the process of development, it is sometimes very difficult to find the concrete type of heating installation which optimally fits its requests. Also characteristics of local climate and greenhouse construction can influence the choice. In such cases, it is sometimes necessary to make combination of two ore more heating installation in order to find the right solution (Fig.7.42 and 7.43).

In any case, geothermal energy is very good choice for heating greenhouses, which is proven both technically and economically all over the world.

7.4.3.2. Aquaculture

In difference to the animals, Different fish species have quite different rate of growing, depending on the quite small differentce of temperature of the water where living (Fig.7.52). Normally, during the cold months of the year, it is very much slowered. By growing them in warm geothermal water (if being with convenient chemical composition) or in the pools heated with geothermal energy by means of sinked heat exchangers (Fig.7.53), it is possible to create artificially convenient temperature conditions for optimal growing rate even during the winter months.

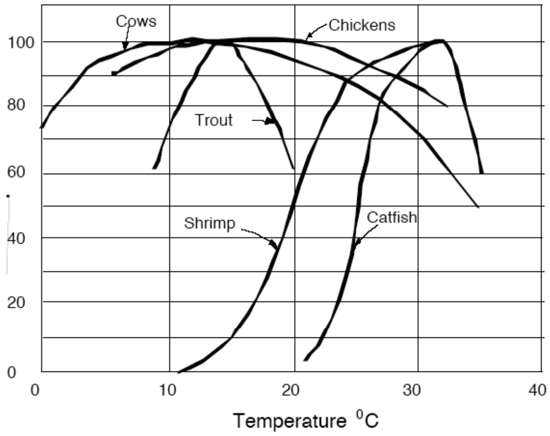


Fig.7.52. Temperature requests of different animal and fish species (Beall and Sammuels, 1991)

Fig.7.53. Geothermally heated outdoor pools containing tropical prawns in Wairakei, New Zealand (Hunt, 2005)

Some special species, prawn larves and fishes during the breeding phase are grown in special tanks with controlled deaeration (Fig.7.54).

Fig.7.54. Larval breeding tanks at Wairakei prawn farm (Hunt, 2005)

Collected experince in the raising of freshwater or marine organisms in a controlled environment to enhance production rates includes carp, catfish, bass, tilapia, frogs, clams mullet, eels, salmon, sturgeon, shrimp, lobster, crayfish, crabs, oysters, abalone, scallops and mussels.

It has been demonstrated that more fish can be produced in a shorter period of time if geothermal energy is used rather than water dependent upon the sun for its heat. When the water temperature falls below the optimal values, the fish lose their ability to feed because their basic body metabolism is affected (Johnson, 1981).

Based on experience at Oregon Institute of Technology (Fig.7.55), the most important items to consider when designing an aquaculture project for growing fishes are quality of the water and disease. If geothermal water is to be used directly, evaluation of heavy metals such as fluorides, chlorides, etc., must be undertaken to determine if the fish or prawns can survive. An aeration pond proceeding the stocked ponds will often solve the chemical problem.

Technical design process of energy installations is similar to the one for swimming pools. The ponds are normally constructed of excavated earth and lined with clay or plastic where necessary to prevent seepage loss. The long axis of the pond should be constructed perpendicular to prevailing winds to minimize wave action and temperature loss. Temperature loss can be reduced, thus reducing the required geothermal flow, by covering the pond with a plastic bubble.

A precise temperature regulation and de-aeration of the pond should be designed in order to reach good exploitation results.

Newer trends of growing fishes in “natural” environment resulted with development of “cage” growing systems. Fishes are accommodated in metallic fenced cages sinked in sea water above the horizontal heat exchanger, made of snakelike system of plastic pipes for flowing the geothermal water. Warm water above the exchager flows up through the cages and create a convenient environment for the fishes in it.

Beside fishes, also some expensive algae, like spirulina, can be grown in the water heated by geothermal energy. Better and equalized quality of product is reached in that way. Microalgal cultivation is based upon the logic of the photosynthetic process: solar energy is used for the synthesis of organic compounds out of non-organic substances.

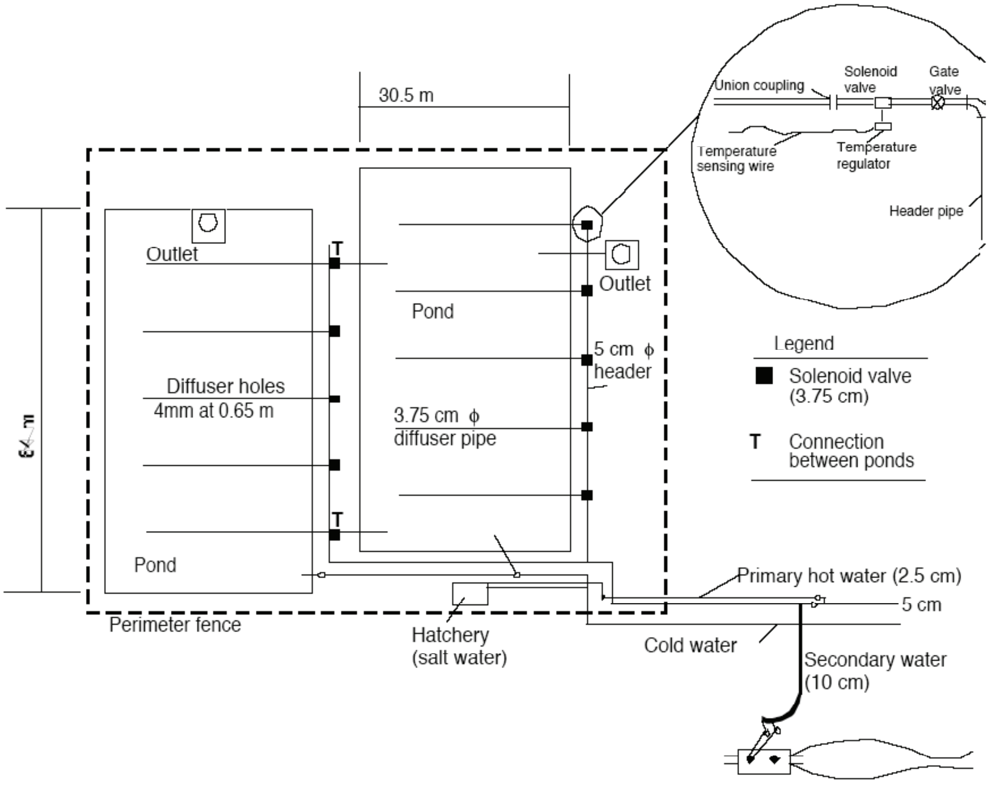


Fig.7.55. The geothermal aquaculture research project at Oregon Institute of Technology (Smith, 1981)

The amount of microalgae produced depends mainly on the genus/species, photoperiod and total amount of light, temperature, pH, rate of removal of cells from the medium, turbulence and nutrient composition of the medium, CO_2 supply and others.

The quality and quantity of the biomass produced depend on the complex relationship among the above-mentioned factors, as presented in Fig.7.56.

Different methods of algal production technology optimization by geothermal energy consist of:

1. Use of geothermal CO_2 and energy for optimizing photosynthesis.
2. Use of geothermal water for nutrition algal media preparation.
3. Use of geothermal energy for algal biomass drying.

Geothermal waters are rich in macro and micro elements and are used for preparation of nutrition media required for different algae species. Research made (Fournadzieva et al., 1993), aimed at modifying the nutrition media accounting for the minerals already present in the mineral water showed 5-10% growth increase and reduced cost for mineral salts. However, it should be emphasized that if the geothermal water contains toxic heavy metals or other components accumulating in the algal cells, such water should not be used directly for algal cultivation.

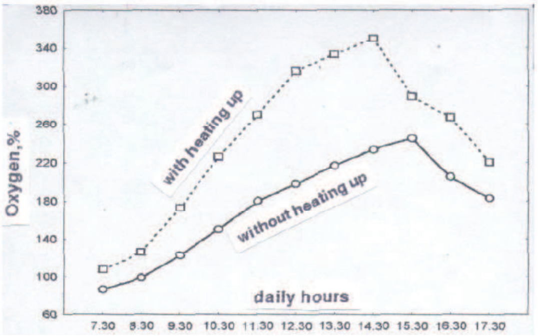


Fig.7.56. Spirulina growing rate for the same production technology – with or without heating (Fournadzieva, 2002)

Geothermal energy can be successfully used for algal biomass drying especially when algal slurry obtained after centrifugation has a high density.

Two technologies for growing spirulina in geothermal waters have been proven in practice, in open air ponds (Fig.7.57) and in protected greenhouse interior (Fig.7.58).

Fig.7.57. Open air algal cultivation (Rupite, Bulgaria)

Fig.7.58. Geothermal growing of algae spirulina (Nigrita, Greece)

7.4.3.3. Open field heating

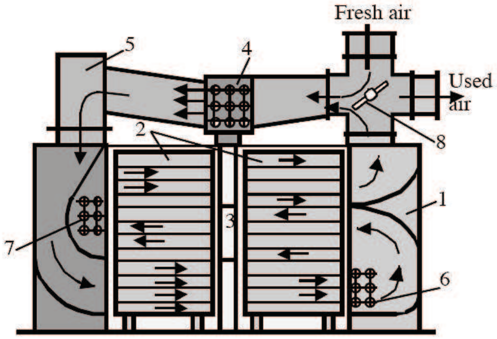
Finally, also open air fields for growing particular plants are a good opportunity for geothermal energy application in agriculture. For instance, if heating the soil below the plants with low temperature geothermal water flowing through a system of buried plastic pipes and, in that way, increasing the temperature of the root zone of the asparagus plant, it is possible to have the production during the winter and early spring months, when the price is 4-5 times higher than during the normal production months (Fig.7.59).

7.4.4. Industrial Applications

Although the Lindal diagram shows many potential industrial and process applications of geothermal energy, the world's uses are relatively few. The oldest industrial use is at Larderello, Italy, where boric acid and other borate compounds have been extracted from geothermal brines since 1790. Today, the two largest industrial uses are the diatomaceous earth drying plant in Northern Iceland and a pulp, paper and wood processing plant at Kawerau, New Zealand. However, there are a list of smaller projects confirming the feasibility of geothermal energy for different industrial uses.

Fig.7.59. Open field growing of asparagus with subsurface geothermal heating

Drying and dehydration of agricultural products are one of the most important and prospective moderate-temperature uses of geothermal energy. Various technologies enables accommodation to particular products requests and characteristics of concrete geothermal source.



1. drying chamber; 2. wagons; 3. partitions; 4,6,7-heat exchangers;5. fan; 8-flow regulating valve

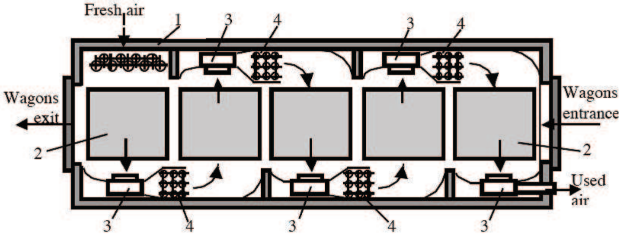
Fig.7.60. Chamber drying technology

In principle, classical drying technologies are used. The only difference is that except the use of fossil fuels for heating the drying air, a water/air heat exchanger is used. Due to the limitation of lower temperature of geothermal water on disposal, normally some corrections of drying time is necessary. It was proven in practice that such corrections do not deteriorate the quality of final products but, in opposite, they are improving it.

Chamber driers (Fig.7.60) work periodically and at atmospheric pressure. Basic part of the chamber dryer is the chamber with rectangular cross section, where the material is placed. The material is in fixed position during all the drying cycle (Fig.7.61). Loading and unloading of the material is made only from one side of the drier. They can be with: trays, compartments, hooks and with wagons. Normally, the use is for timber drying insulating plates, ceramic and silicate objects, different disperse and fibrous materials. Application is convenient for small quantities of material and in cases when precise regulation of the drying regime is required.

These dryers are characterized by low productivity and longer drying period. The drying is not even due to the uneven disposition of temperatures in the chamber, resulting from the partial flow of the air in upper layers through shorter ways (through clearances). Bad side of this type of dryers is the high need for manual work.

Fig.7.61. Timber drying chamber (Zakopane, Poland)



1. Drying chamber; 2. Wagons; 3. Fan; 4. Heat exchanger

Fig. 7.62. Tunnel dryer

Tunnel (corridor) dryers have continual principle of work. Basic part of the dryer (Fig.7.62) is the elongated drying chamber. The inter-connected wagons are slowly moving on rails along the chamber.

At the entrance and the exit the tunnel is equipped with hermetical doors. They are opened simultaneously and periodically in order to enable loading and unloading the drier with material. Drying air is moving in the same or opposite direction relative to the movement of the dried material. The circulation of the air can be natural or forced but better effect is achieved with countercurrent forced movement. Tunnel driers can work with single use of the heated air, with re-circulation or with air reheating.

In Fig. 7.63 elements of the geothermal tomato drying plant in Greece are shown. Plant works profitable and is an excellent examples for liability of geothermal energy for different vegetables and fruits drying.

Drum dryers are suitable for drying of beer and sugar refuse, grains, diary food plants and other materials. Basic part is the horizontal or leaned cylindrical drum (fig.5), with 0.5 to 0.8 turns per minute, enabling moving and mixing the disperse material.

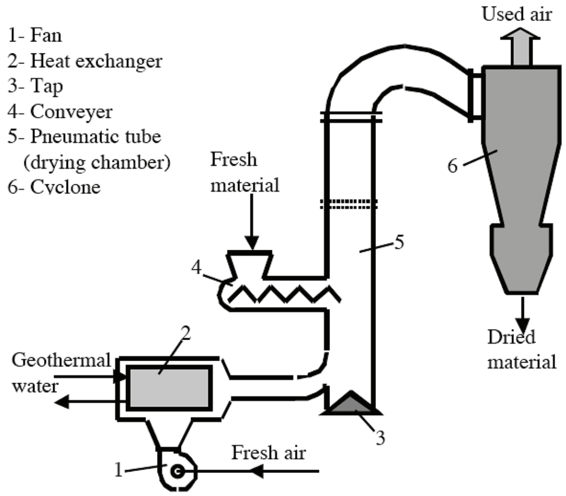


Fig. 7.64. Drum dryer

The angle of the drum relative to a horizontal line (for gradual moving of the material from one to the other end) is usually 0.5 to 3 degrees. Inside the drum and depending on the material, different kind of compartments are placed that contribute for better drying of the material.

Specific heat consumption q = 3350-5000 kJ/kg and electricity for turning and ventilation 5 to 7 kWh/1000 kg.

In Kocani (Macedonia) a rice drying unit (Fig 7.65) is in operation. Reached efficiency and economy of exploitation is competitive to any other plant of such character, using fossil fuels instead geothermal energy.

Fig.7.63. Elements of tomato tunnel drying (Xanti, Greece)

Conveyor dryers (Fig.7.66) are used for drying of cotton, wool and other fibrous materials (peaces with 5 to 7 mm thickness and 20 to 30 mm width - fruits, vegetables, tea, hemp straw, peat, etc.). These driers have continuous principle of work, by the use of a chamber, where the drying material is

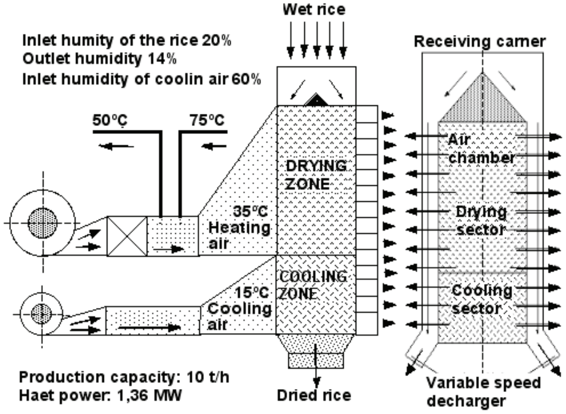


Fig.7.65. Geothermal rice drying unit (Kocani, Macedonia)

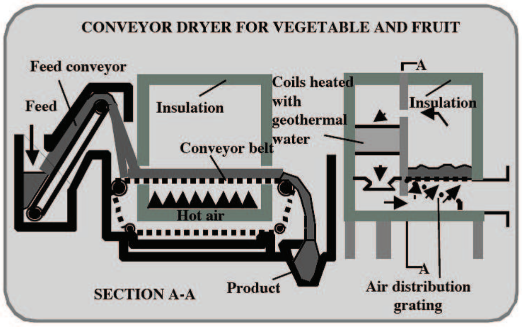


Fig. 7.66. Conveyor dryer for vegetables and fruits

placed and moves on the loading strip. The drying is performed with temperature of the air (or gas) between 70 to 170°C.

Circulation of the drying air is enabled by the use of axial fans. Dried material is collected from the strips in a basket or some other transporting device. These driers are constructed with the line width of 2 to 2.2 m and lengths of 40 m. Negative side is the uneven drying through the height of the layer, which is greatly reduced thanks to mixing when passing from one to another strip. Other negative aspect is the dirtiness coming from the particles passing through the protection screen that falls down on the heat exchanger. Specific heat consumption is q = 5000 to 7500 kJ/kg.

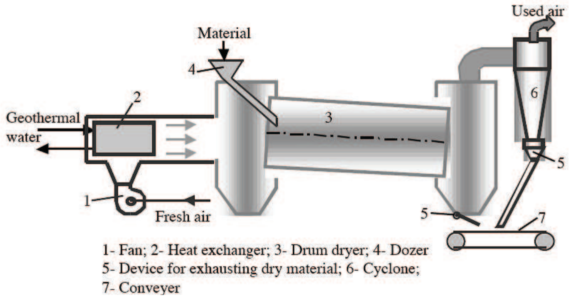


Fig.7.67. Tube-pneumatic dryer

Basic part of pneumatic (Fig.7.67) dryers is the chamber or tube in which the disperse material is dried during pneumatic transport. Velocity of the air must be higher than the velocity of particles levitation (10 to 20% than levitation velocity of the largest particles) in order to transport of the particles. It is maintained in the frame of 10 to 40 m/s depending on the particles dimensions. That requires additional electricity consumption.

Principally, the work of pneumatic dryers is continual. They are used for drying grains, chopped dairy food, vegetable leafs, etc. Passing of particles through the tube does not exceed 1 to 2 seconds, and that's why it is possible to evaporate only the superficial moisture which results with moisture content decrease of only for 6 to 10 %. q = 3800 to 6700 kJ/kg.

A new development in the use of geothermal fluids is the enhanced heap leaching of precious metals in Nevada by applying heat to the cyanide process. Using geothermal energy increases the efficiency of the process and extends the production into the winter months.

7.4.5. Desalinization

Additional and rather new application of geothermal energy is the desalinization of sea water. That is a very important problem for a list of island communities in the world.

MED-Vertical Tube distillation method is applied in the Kimolos (Greece) desalinization plant. It is based on the multieffect distillation rising film principle at low evaporation temperatures (less than 70°C –ALFA LAVAL, 1993), due to the reduced pressure (almost vacuum). The rising film principle takes advantage of the fact that the inner tube surfaces are always covered with a thin film of feed water that prevents scale formation.

The working principle is as follows (Fig. 7.68):

The vapor forms a column around the tube center which presses the feed water against the tube surface ensuring a continuous thin film of water on the tube surfaces hereby eliminating dry spots where scale may deposit. A controlled amount of sea feed water is led into the bottom of each effect and into the tubes in the heat exchanger, where the low enthalpy geothermal energy in the form of hot water of less than 70 °C, as the heating medium, heats it up.

Part of the sea-water is evaporated under vacuum, which is created by means of water ejectors connected to each effect. The vacuum makes it possible to lower the boiling temperature and thereby minimizing the amount of energy necessary for evaporating the feed water, and furthermore the low boiling temperature prevents deposits of scale inside the tubes.

The vapor generated in the first effect passes a separation compartment where the remaining feed water droplets are separated from the vapor and are extracted with the brine. The separated vapor leaves the first effect and flows through the vapor connection pipe to the heat exchanger in the second effect, and the vapor is now used as the heating medium for the second effect.

Brine extracted from the first effect is mixed with sea feed water and is brought to evaporation by means of the heat from the vapor generated in the first effect. This process is repeated in the second, third, fourth etc., when these occur.

The vapour used for heating of the se-cond, third, fourth etc. effects condenses on the outside of the heat exchanger tubes, and flows through the flash pipe in the bot-tom of the heat exchanger into the flash tank.

Separated vapour from the third effect is led into the condenser where it is condensed on the outside of the condenser tubes in which sea cooling water is flowing.

The condensate flows down into the flash tank at the bottom of the condenser. The condensate is extracted from the flash tank by the freshwater pump and is pumped into the fresh-water tank.

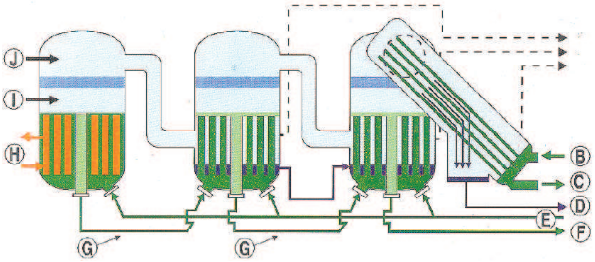


Fig.7.68. Schematic of a multiple effect distillation process: A. Vacuum chamber, B and C. Inlet and outlet of cooling sea-water, D. Distillate product, E. Feed sea-water, F. Brine outlet, G. Heat recovery from the brine, H. Condensate steam, J. Dry steam

The desalination unit can be designed in such an innovative way so that in the case that chemical composition of geothermal water allows it, it can be feasible to desalinate the low enthalpy geothermal water itself, instead of the sea-water. This would result in an increase of the energy efficiency of the unit simultaneously decreasing the required capital investments and operational costs (no heat exchangers, no sea-water pre-heating etc.).

When chemical composition is convenient, except for desalinization, it is possible to use geothermal water itself as drinking water Kocani, Macedonia).

7.4.6. Snow melting

Pavement and streets snow melting is a very important problem in many northern countries all over the world. Geothermal water can be a very good solution for such purpose because enabling significant decreease of exploitation costs, as demonstrated in several countries, including Argentina, Japan, United States and particularly Iceland. These installations include sidewalks, road-ways, bridges and runways.

Most commonly, it is done with a glycol solution, hot water or steam being circulated in pipes within or below the pavement (Fig. 7.69), using either heat pipes or geothermal fluids, however, in one instances hot water has been sprinkled directly onto the pavement. The obvious benefits of these systems (Fig.7.70) is that they eliminate the need for snow removal, provide greater safety for pedestrians and vehicles, and reduces the labor of slush removal.

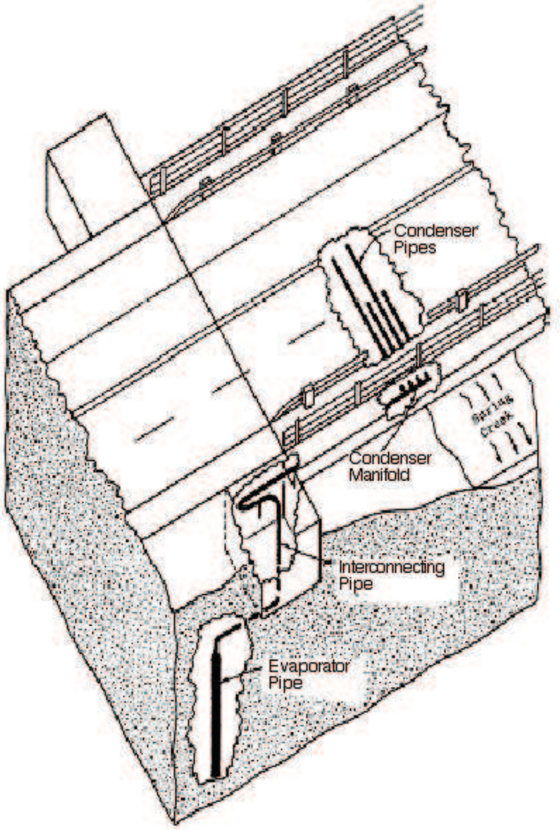


Fig.7.69. Geothermal heating of roads and pavements (Lund, 1986)

Fig.7.70. A street in Japan with snow melting installation

Chapman (Lund, 1986) classifies snow melting installation according to type as Class I, II or III. These types are described as follows:

Class I (minimum): residential walks or drive-ways; interplant ways or paths.

Class II (moderate): commercial sidewalks and driveways; steps of hospitals.

Class III (maximum): toll plazas of highways and bridges; aprons and loading area of airports; hospital emergency entrances.

Classification is related to the security measures, depending on the expected type of use.

As shown in Fig.7.69 a pipe soil heating system is normally applied, with a rather shallow allocation of the system of heating pipes.

Piping materials are either metal or plastic. Steel, iron and copper pipes have been used extensively in the past (and are still used), however, steel and iron corrode rapidly if they are not protected by coatings and/or cathodic protection. The use of salts for deicing and the elevated temperature accelerate corrosion of these materials. The corrosion rate approximately doubles for each 10ºC rise in temperature.

Present practice is to use plastic pipe with iron for the header pipe. Typical plastic pipes are of a cross-linked polyethylene (PEX). This type of pipe is lightweight and easier to handle, can be bent around obstructions or for reverse bends with radius of as little as 30-35 cm, comes in long sections, do not require expansion loops, and use mechanical compression connections. It obviously does not corrode, thus it has a life of over 50 years.

Generally, an antifreeze solution (ethylene or propylene glycol) is used in the pipes, circulated in a closed system and heated by a heat exchanger. Antifreeze solutions are necessary, as most systems will not be operated continuously in cold weather, and thus the system must be protected from freeze damage.

Portland cement concrete (PCC) or asphalt concrete (AC) may be used for snow-melting system.

The thermal conductivity of AC is lower than that of PCC, thus pipe spacing and temperatures are different. However, the main reason for not using AC pavements with pipes embedded in them, is that the hot asphalt may damage the pipes, as AC is usually placed at above 135ºC in order to get adequate compaction. Also, the compaction process may deform and even break pipes and their connections.

Geothermal energy can be supplied to the system by one of three methods:

- directly from a well to the circulating pipes;
- through a heat exchanger at the well head;
- by allowing the water to flow directly over the pavement.

All of these systems have been utilized throughout the world.

The work of the system is normally regulated by a computerized control system. It continuously receives information from various sensors and automatically activates the heating cycle when certain conditions are met.

Any of three conditions can activate the system:

- Deck surface sensor indicates snow or ice;
- Precipitation sensor indicates precipitation and deck surface temperature is below 0ºC;
- Deck surface sensor indicates wet deck and surface temperature is below 0ºC.

Either of two conditions will shut off the system:

- Deck surface sensor has indicated clear surface for more than 10 minutes
- Deck surface temperature is above 5ºC.

#

Listed examples only confirm that possibilities listed in the Lindal diagram are realistic and that is only a question of time when some different direct uses of geothermal energy shall be introduced.

7.5. DISTRICT HEATING

Composition of district heating systems is not a “geothermal invention”. They have been developed in a list of countries already before, using coal, crude oil or gas as fuel and, in later phase, so called co-generation by common production of electricity and heat.

District heating originates from a central location, and supplies hot water or steam through a network of pipes to individual dwellings or blocks of buildings. The heat is used for space heating and cooling, domestic water heating, agribusiness applications and industrial process heat.

A geothermal well field is the primary source of heat; however, depending on the temperature, the district may be a hybrid system, which would include fossil fuel and/ or heat pump peaking.

Geothermal district heating systems are in operation in at least 12 countries (Lund, 2005), including Iceland, France, Poland, Hungary, Turkey, Japan and the U.S. The Warm Springs Avenue project in Boise, Idaho (U.S.A.), dating back to 1892 and originally heating more than 400 homes, is the earliest geothermal district heating project in the World. The Reykjavik, Iceland, district heating system (Fig.7.71) is probably the biggest and most famous one. This system supplies heat for a population of around 160,000 people. The installed capacity of 830 MWt is designed to meet the heating load to about -10ºC; however, during colder periods, the increased load is met by large storage tanks and an oil-fired booster station (Ragnarsson, 2000).

Background of the successful development of district heating systems during the recent years is that they have three very important advantages in comparison with individual heatings, i.e.:

- It is possible to combine in the same system users with different day and seasonal changes of heat requirements (Fig.7.72). In that way, influence of peak loadings is decreased (Fig.7.22) and more economical use of heat source enabled (Fig.7.23);

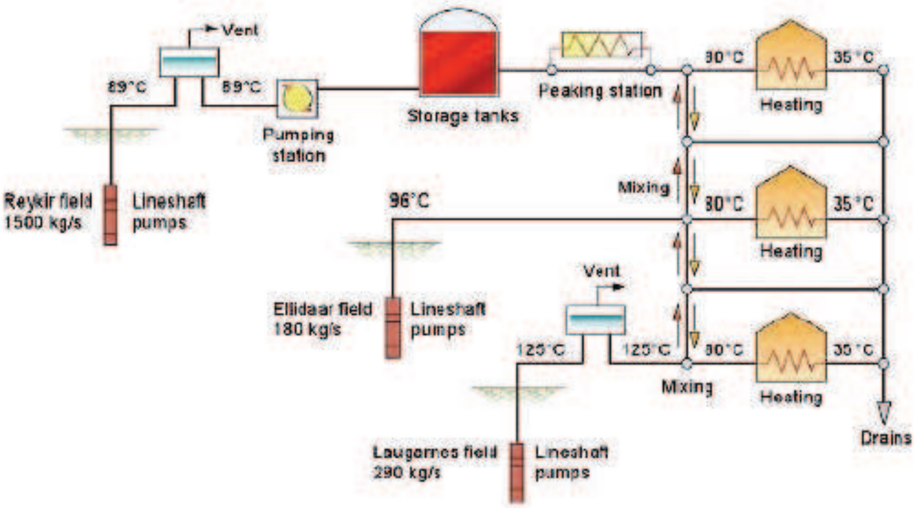


Fig.7.71. Reykjavik district heating system (prior to the Nesjavellir connection)

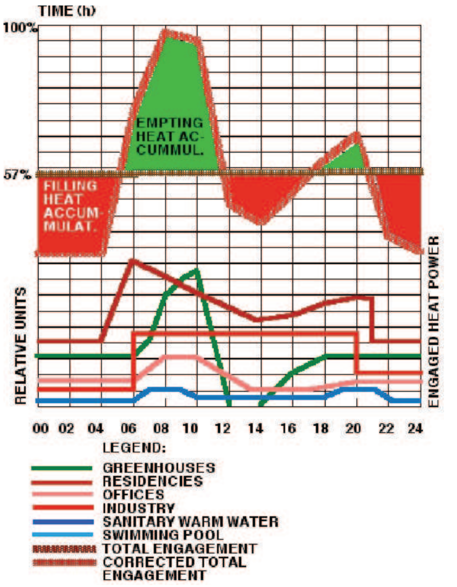


Fig.7.72. Influence of composition of users with different daily changes of heat requirements to the common one

- It is possible to compose heat users in cascades, depending on the requested temperature of heating fluid (Fig.7.73).

In that way, better use of the temperature difference of geothermal energy on disposal is enabled. Again, influence of peak loadings is decreased and more economical exploitation of the system enabled; and

- Composition of high qualified team for exploitation, maintenance and development of the system is enabled, resulting with stabile work of it and proper governing of the geothermal reservoir.

Listed advantages are proven in practice and resulted with increased interest for completion of new district heating schemes and reorientation of the existing one from fossil fuels to geothermal energy use, there where it is possible. Concrete climate conditions, composition of users and other locally influencing factors determine technical design of concrete district heating scheme.

Design procedure of a district heating scheme is quite complicated. It consists all the elaborated elements of the geothermal energy direct use chain, resulting with the need for accommodation of requests of different heat users to the characteristics of geothermal fluid on disposal. In addition, specific solutions of the distribution framework should be defined, accommodated to the distribution of heat sources and heat users.

As an example, illustrating the above said, the Paris Dogger Geothermal Distric Scheme can be used.

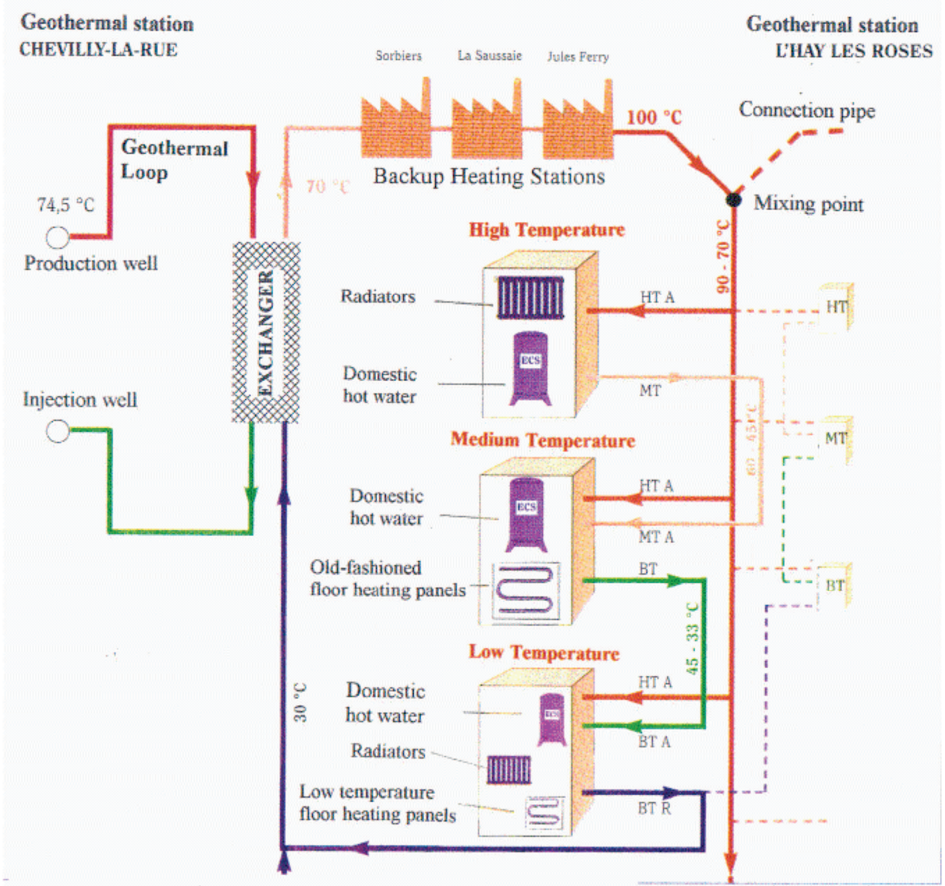


Fig.7.73. Geothermal district heating in I'Hay les Rose (France) with cascade use of geothermal water

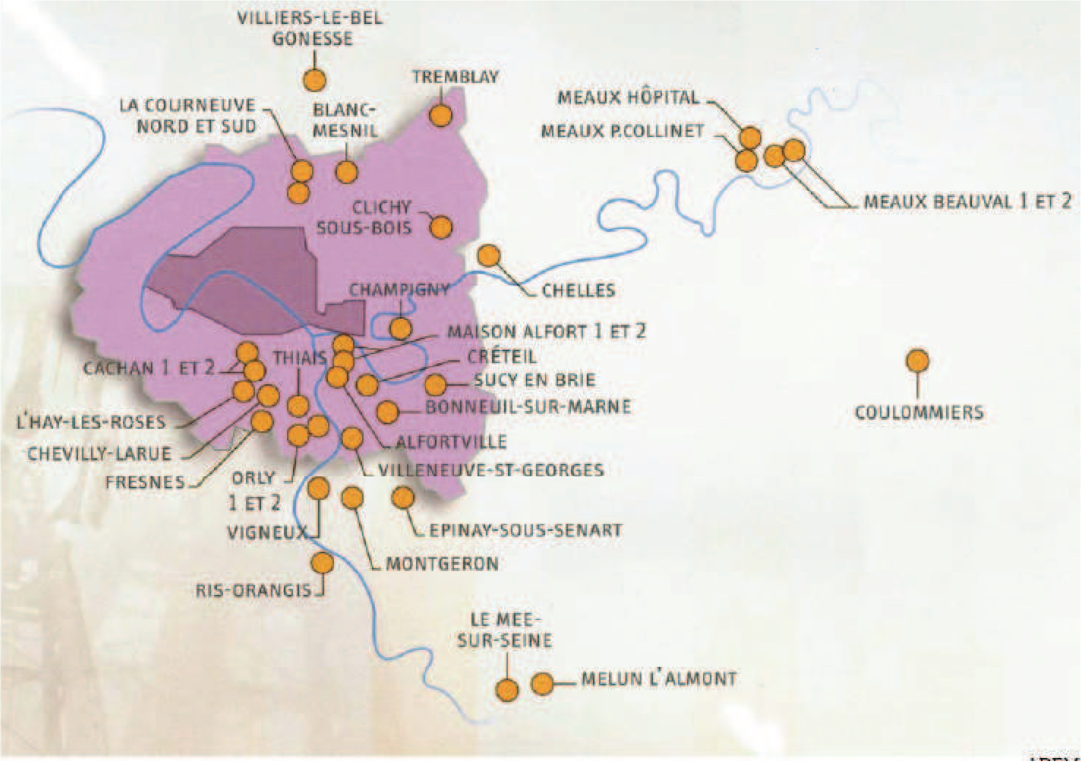


Fig.7.74. Location of Paris Basin geothermal district heating doublets (2006 status)

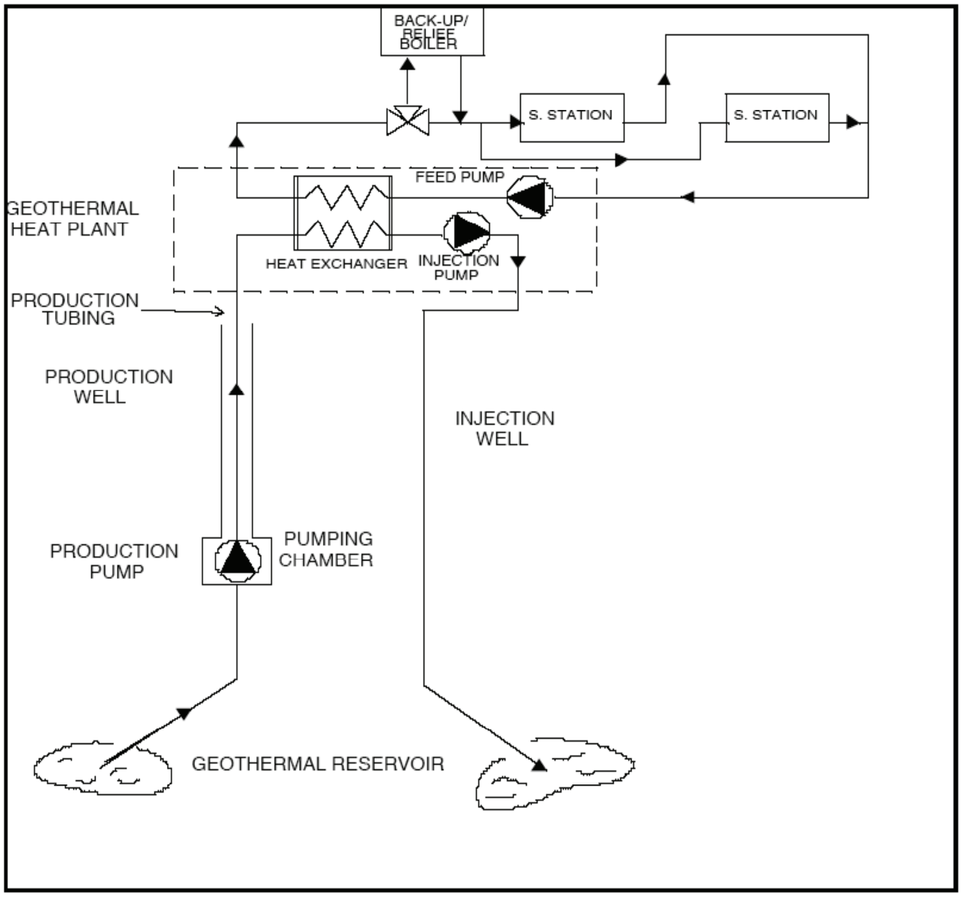


Fig.7.75. Schematics of a geothermal district heating system (Ungemach, 2005)

Paris Basin district heating has a twenty five year backup experience and thirty four heating grids operating to date.

The location of the geothermal district heating sites is shown in Fig. 7.74.

It consist of thirty four (as of year 2003) well doublets supplying heat (as heating proper and sanitary hot water, SHW) via

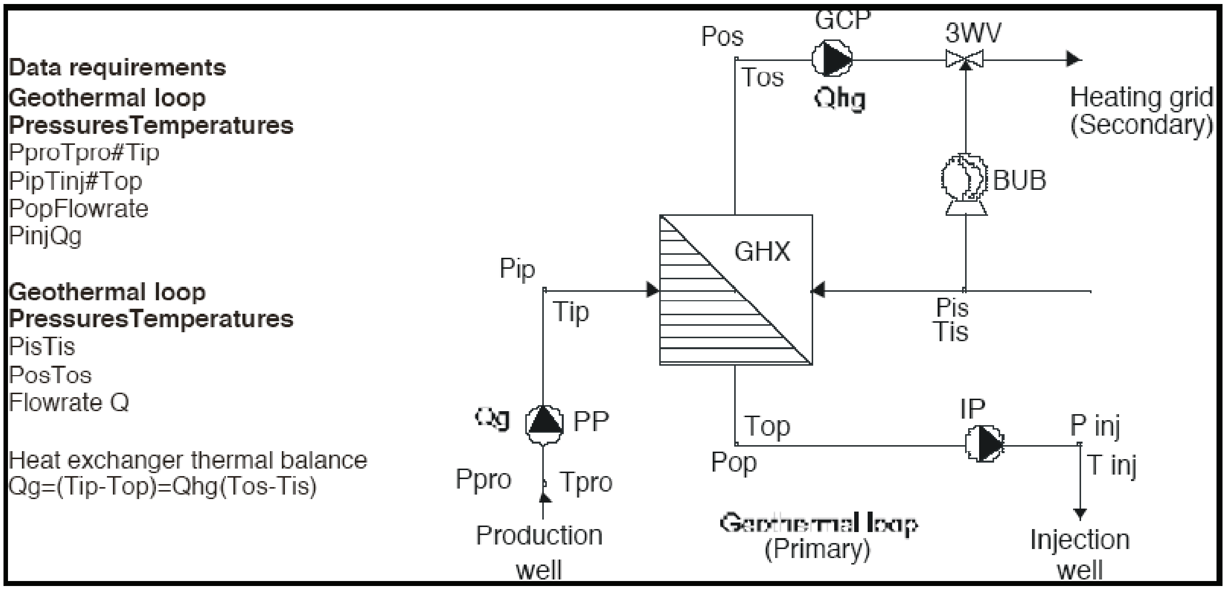
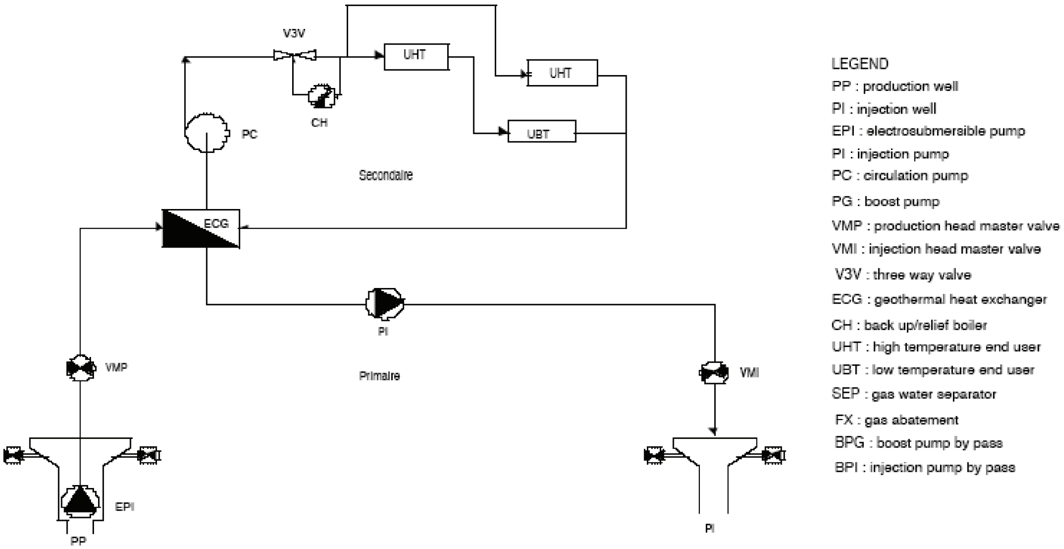
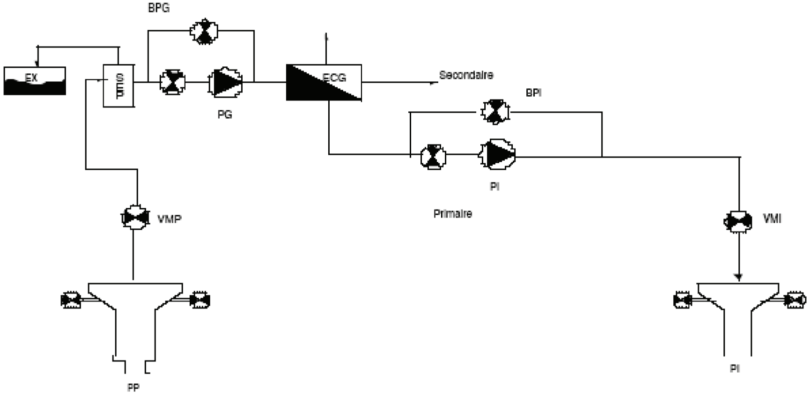


Fig.7.76. Geothermal district heating parameters (Ungemach, 2005)



Artificial lift production (electro-submersible pump)



Boost pump sustained self flowing

Fig.7.77. Geothermal well (sustained and self-flowing) production modes

heat exchangers and a distribution grid to end users.

The standard geothermal district heating system is based on the well doublet concept, as shown in fig. 7.75, and on the surface system and governing parameters sketched figures afterwards. It should be noticed that:

(i) as shown in Fig.7.75, most well (production/injection) trajectories are deviated from a single drilling pad with wellhead and top reservoir spacing of 10 and ca. 1,000 m respectively. They are produced via, variable speed drive, electric submersible pump (ESP) sets;

(ii) the heat is recovered from the geothermal brine by, corrosion resistant, titanium alloyed plate heat exchangers;

(iii) geothermal heat is used as base load and therefore combined with backup/relief, fossil fuel fired, boilers, unless otherwise dictated by combined gas cogeneration/geothermal systems (Fig.7.76);

iv. district heating complies to retrofitting which means that geothermal heat supply has to adjust to existing conventional heating devices, most often not designed for low temperature service. This has obvious implications and well deliverables on rejection (injection) temperatures.

Very interesting technical solutions for connecting different type of users at different points of the distribution system are applied.

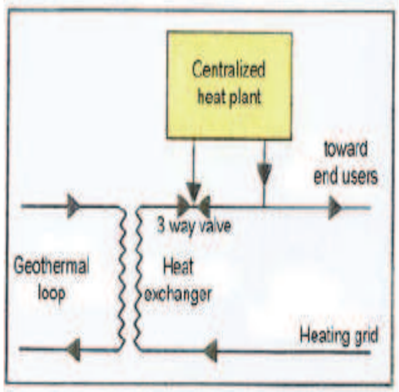


Fig. 7.76. Centralized back-up/relief plant design (Ungemach, 2005)

Table 1: Geothermal district heating analysis.
System components and parameters(after Harrison et al)

GEOTHERMAL POWER	**NETWORK/HEATERS**	**HEAT DEMAND**
$P_g = M_g (q_g - q_r)$ $M_g = r_w g_w q_g / 3.6$	$P_n = M_n (q_a - q_{ref})$ $M_n = NED \times V \times G / (m_{hi} / m_{ho})$ $m_{hi} = (q_{hi} - q_{nh}) / (q_a - q_{ref})$ $m_{ho} = (q_{ho} - q_{nh}) / (q_a - q_{ref})$	$P_d = M_d (q_a - q)$ $M_d = NED \times V \times G /1{,}000$ $W_d = 24 \times NDD \times M_d / 1{,}000$ $NDD = \int_0^{NHD} (\theta a - \theta) dt$

HEAT EXCHANGE	**GEOTHERMAL SUPPLY**
$P_{hx} = h_{hx} P_g = h_{hx} M_g [(q_g - q_{nh}) - M_{ho} (q - q_{ref})]$ $h_{hx} = \{1 - \exp [- N (1 - R)]\} / \{1 - R \exp [- N (1$ $N = UA / M_g$ $R = M_g / M_n$	$W_{hx} = h_{hx} M_g \{(q_g - q_{nh}) - m_{ho} \times 24 \int_0^{NHD} [q(t) - q_{ref}]$ $GCR = W_{hx} / W_d$
REGULATION CRITERIA $q_{no} = q_{ref} + m_{no} (q_a - q)$ $q<q^*$: maximum geothermal flowrate, back $q^*<q<q_{ref}$: total geothermal supply	

NOMENCLATURE

P = power (kW_t)
W = energy (MWh_t /Yr)
M = thermal capacity (kW_t/°C)
NED = number of equivalent dwellings
NDD = number of degree days
NHD = number of heating days
V = equivalent dwelling volume (m^3)
G = average dwelling heat loss ($W/m^{3}{}^\circ C$)
N = number of heat transfer units

U = heat exchanger heat transfer coef. ($W/m^{2}{}^\circ C$)
A = heat exchanger area (m^2)
R = flow ratio
GCR = geothermal coverage ratio
m = heater characteristic (slope)
q = flowrate (m^3/h)
g = specific heat (J/kg°C)
r = volumetric mass (kg/m^3)
q = temperature (outdoor) (°C)

Subscripts

g = geothermal
w = fluid (geothermal)
d = demand
n = network
h = heater
hx = heat exchanger
i = inlet

o = outlet
hi = heater inlet
ho = heater outlet
nh = non heating (lowest heater temperature)
a = ambient (room)
ref = minimum reference outdoor
r = rejection (return)

Typical values (Paris area)

NED = 2,000/4,500
NDD = 2,500
NHD = 240
N = 5
qg = 200/350 m3/h
g = 1.05 W/m3°C

V = 185 m3
q_{ref} = - 7°C
q_r = 40/50°C
q_g = 55/75°C
q_a = 17/18°C
q_{nh} = 20°C

q_{hi}/q_{ho} =
90/70°C cast iron radiators
70/50°C convectors
50/40°C floor slabs

For instance, different evaporators, depending on the temperature of the heating fluid on disposal, can be connected as shown at Fig.7.77 and Fig.7.79. Full use of the temperature difference on disposal is enabled in that way.

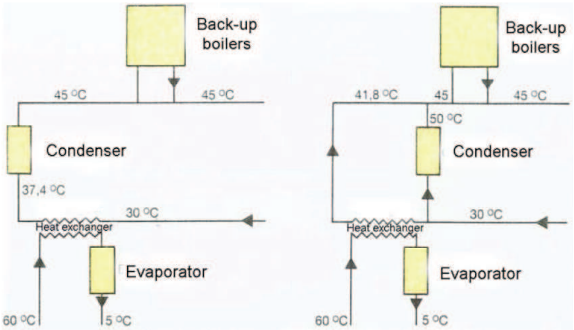


Fig.7.77. Evaporators connected to the geothermal distribution network (Ungemach, 2005)

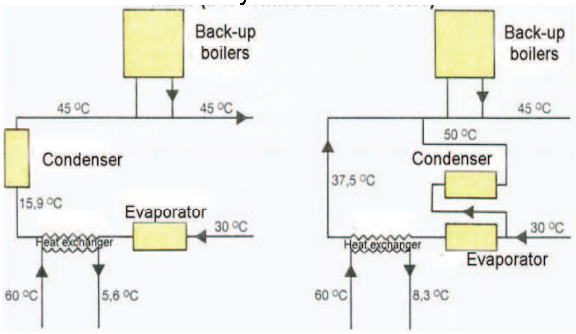


Fig.7.78. Evaporators connected to the grid rejected fluids (i.e. downstream users) (Ungemach, 2005)

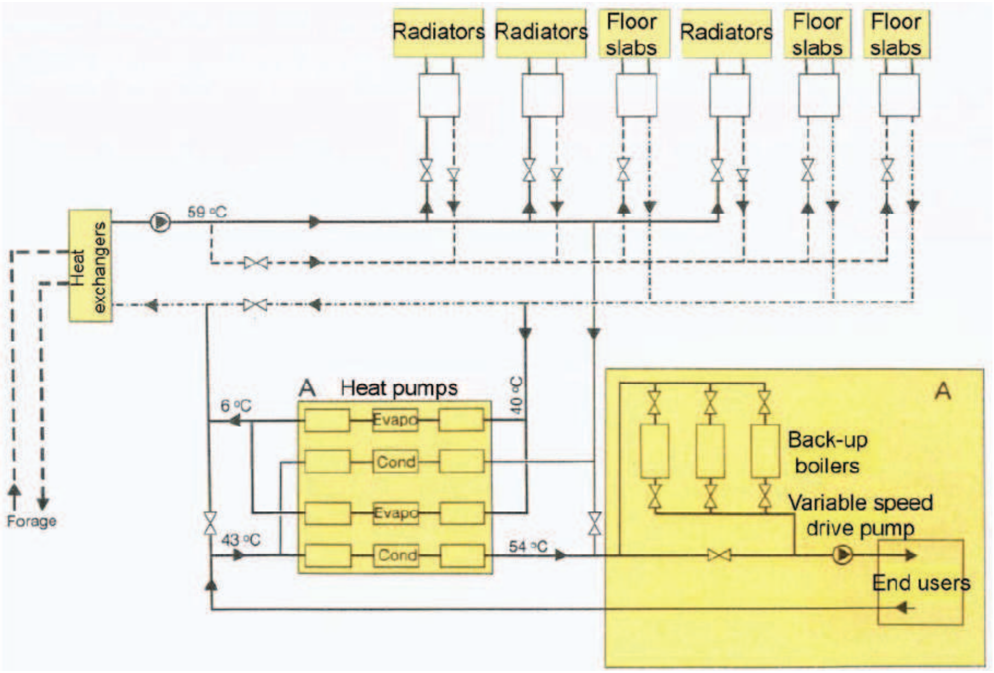


Fig. 7.79. Example of heat pump contribution to geothermal district heating energy balance

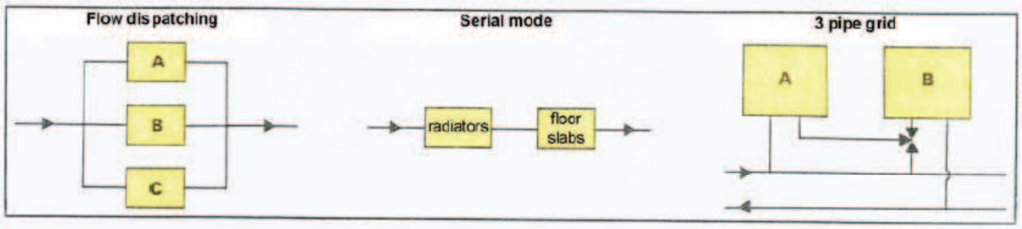


Fig.7.80. Flow dispatching (Ungemach, 2005)

Due to the fact that quite low temperatures of geothermal fluid are on disposal, also geothermal heat pumps are introduced in the district heating scheme composition. Their operating mode (Fig.7.79) is as follows:

1. -7 to 1°C

- No geothermal heat supply to radiators

- Geothermal heat is dispatched to floor slabs and to the cascading heat pump assembly (A)

2. from -1 °C

- Geothermal heat is directed towards radiators which serve, via a rejection cascading sequence, the floor slabs and, ultimately, the heat pump outfit (A)

3. from 7 °C

- Boiler back up supplies are shut down

4. from 12 °C

- Heat pumps are shut down and the whole grid is supplied straightforwardly by geothermal heat

Several types of heating fluid supply can be used (Fig.7.80), i.e.:

- Flow dispatching – This configuration may address a group of users sharing the same behaviour, which is unlikely.
- Serial mode – The outlet temperature of the first user must be compatible with the inlet temperature of the next user.
- Three pipe grid – User B utilizes in priority the fluid depleted by user A.

7.6. REFRIGERATION

Absorption space cooling with geothermal energy has not been popular (and still it is not) because of the high temperature requirements and low efficiency. However, geothermal heat pumps (groundwater and ground coupled) have become popular in Europe and U.S.A. (Fig. 7.81), used for both heating and cooling (see the Chapter for GHP).

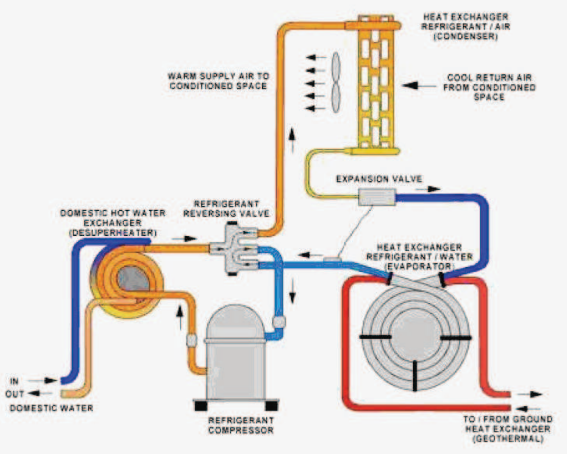


Fig.7.81. Cooling with heat pump

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

For geothermally-driven refrigeration below the freezing point of water, the ammonia absorption system must be considered.

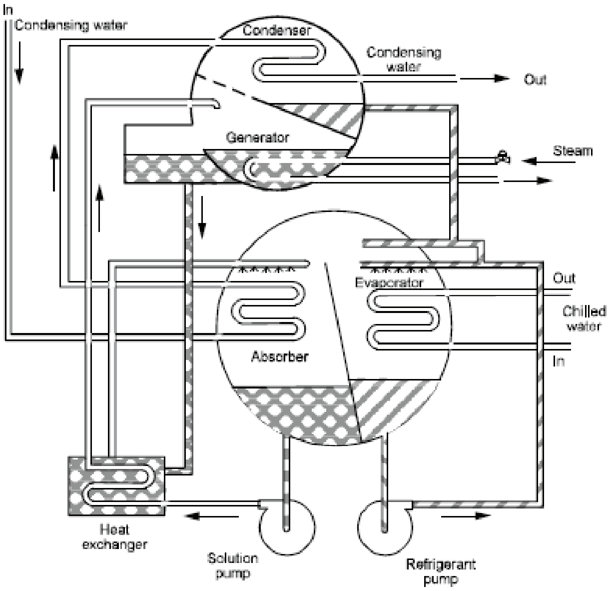


Fig.7.82. Principle of geothermal absorption cooling (Rafferty, 1983)

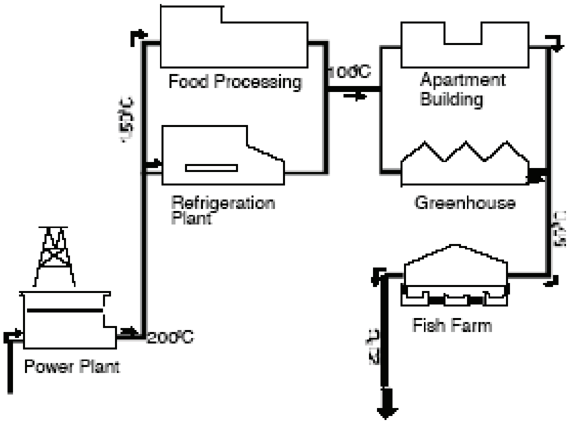


Fig.7.83. Refrigeration as a part of geothermal district heating system (cascade use of heat) (Rybach, 1995)

However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above about 120ºC for a reasonable performance. Fig.7.82 illustrates how the geothermal absorption process works and Fig.7.83, how a refrigeration plant can be incorporated in a district heating system (needing the highest possible temperature of the geothermal fluid).

7.7. EQUIPMENT AND MATERIALS

Up to now, there is no special equipment on disposal, particularly constructed and produced for use in geothermal direct use projects. Standard one is used in most of the projects, provided allowances are made for the nature of geothermal water and steam.

Temperature is an important consideration, so is the water quality. Corrosion and scaling caused by the sometimes unique chemistry of geothermal fluids, may lead to operating problems with equipment components exposed to flowing water and steam. However in many instances, fluid problems can be designed out of the system. One such example concerns dissolved oxygen, which is absent in most geothermal waters, except perhaps the lowest temperature ones. Taking into account that its presence results with corrosion when metallic pipes and equipment is used, care should be taken to prevent atmospheric oxygen from entering heating waters; for example, by proper design of storage tanks and application of proper valves and other joint materials. Very good technical solution is the isolation of geothermal water by installing a heat exchanger which is solving this and similar water quality derived problems. In such a case, a clean secondary fluid is then circulated through the used side of the system (indirect connection, i.e. closed loop system!).

The primary components of most low temperature direct use systems are downhole and circulation pumps, transmission and distribution pipelines, peaking or backup plants, and various forms of heat extraction equipment. Fluid disposal is either surface or subsurface (injection). For most of them information for equipment is given in parallel with the description of their function or work. However, for more precise data and information pay a look to the chapter for geochemistry, scaling and corrosion problems and materials used in geothermal projects in general.

7.8. ECONOMIC CONSIDERATIONS

Low-temperature direct use geothermal projects require a relatively large initial capital investment, with small annual operating costs thereafter.

For instance, a district heating project, including production wells, pipelines, heat exchangers and injection wells, may cost several millions euro. By contrast, the initial investment in a fossil fuel system includes only the cost of a central boiler and distribution lines.

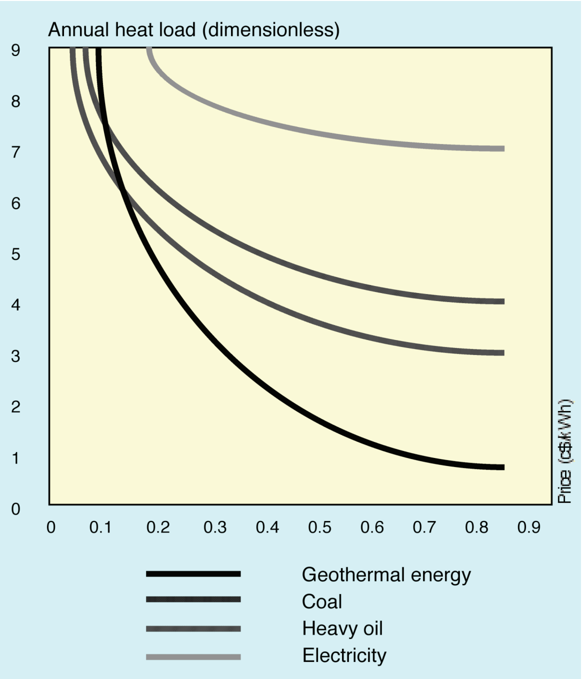


Fig.7.84. Price of used heat of different energy sources versus annual heat loading factor (Popovski, 1996)

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

Geothermal resources fill many needs: power generation, residential heating, greenhouse heating, industrial processing, and bathing - to list a few of them. It is not possible to make a general statement that geothermal energy is or not more economical than the fossil fuels or other renewable energies use. Considered individually, some of the uses may and some may not promise an attractive return on investment because of the high initial capital cost.

However, if reaching enough high annual heat loading factor, the influence of high investment costs is decreased (Fig.7.84) and geothermal energy becomes a competitive and, in some cases, very attractive solution for direct uses. That can be reached either by combination of heat users with different daily or annual changes of heat consumption or by using the geothermal fluid several times before let it back to the reservoir or to the environment in order to maximize benefits of consisted heat in it. This multistage utilization, where lower and lower water temperatures are used in successive steps, is called cascading or waste heat utilization.

Geothermal cascading has been proposed and successfully attempted on a limited scale throughout the world. It is one of the most challenging problems of geothermal energy development now-a-days.

More detailed discussion about the economy of geothermal projects in general is made in the chapter on Economy of geothermal application.

7.9. FUTURE DEVELOPMENTS

There appears to be a large potential for the development of low-to-moderate enthalpy geothermal direct use across the world. However, it is not currently being exploited due to financial constraints and the low price of competing energy sources. According to the reached experience and investigations made, it is possible to state that if given the right environment, and as gas and oil supplies dwindles, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy.

Future development will most likely occur under the following conditions (Lund, 2002):

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

Recent and present increase of the liquid fossil fuels and gas prizes looks as a possibility for opening a new intensive development process, like was the one in 70-ies of last century.

7.10. REFERENCES

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

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

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

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

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

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

Fournadzieva, S., Bojadgieva, K., Fytikas, M. and Popovski, K. A Conception of a Geothermal Application in Common Microalgal Development in Balkan Countries; Proceedings: ISS International Geothermal Days GREECE 2002, K/ Popovski, M. Fytikas – Edirors, Thessaloniki 2002

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

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

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

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

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

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

Lund, J. W. and D. H. Freeston, 2000. Worldwide Direct Uses of Geothermal Energy 2000, *Proceedings of the World*

Geothermal Congress 2000, Japan.

Lund, J. W. Geothermal Direct-Heat Utilization. Short Courses -World Geothermal Congress 2005, Antalya (Turkey)

Lund, J. W. Agri-Business Uses of Geothermal Energy, Short Courses -World Geothermal Congress 2005, Antalya (Turkey)

Lund, J.W. Introduction to Geothermal Aquaculture, Short Courses -World Geothermal Congress 2005, Antalya (Turkey)

Popovski, K., 2003, Geothermal Energy for Agriculture, *International Workshop of Swiss Geothermal Association, Luzern, Switzerland*

Popovski, K. et al.- 1993. Factors influencing the Choice of Low Temperature Heating Systems for the Use of Industrial Thermal Effluents and Geothermal Energy for Protected Crop Cultivation, *ESNA-XXIIrd Annual Meeting, Halle (Salle), Germany*

Popovski, K. – 1993. Heating Greenhouses with Geothermal Energy, *ISS textbook, Pisa (Italy)*

Popovski, K., Popovska, S. – 1993. Recent Developments of Direct Application of Geothermal Energy in Agriculture, *International Course on "Geothermal Energy, Technology, Ecology", Bansko, Bulgaria*

Popovski, K., Popovska-Vasilevska, S. – 1998. Summary of Technical Elements of Geothermal District Heating Scheme, *International Course on "Economy of Integrated Geothermal Projects", Ponta Delgada, Azores, Portugal*

Popovski, K. Heating Greenhouses with Geothermal Energy, Short Courses -World Geothermal Congress 2005, Antalya (Turkey)

Popovski, K. Economic Comparison with Other Energy Sources, Short Courses -World Geothermal Congress 2005, Antalya (Turkey)

Popovska-Vasilevska, S. – 1996. Low-Temperature Technologies for Heating Rooms, *International Course on "Geothermal District Heating Schemes", Cesme, Turkey*

Popovska-Vasilevska, S.- 1996. Low-Temperature Technologies for Cooling, International Course on "Geothermal District Heating Schemes", Cesme, Turkey

Popovska-Vasilevska, S.- 2001. Geothermal Energy Direct Application in Industry in Europe, *European Summer School on Geothermal Energy Applications, Oradea, Romania*

Popovska-Vasilevska, S.- 2002. Food Processing Uses of Geothermal Energy, *International course on District Heating, Agricultural and Agroindustrial Uses of Geothermal Energy, International Summer School on Direct Application of Geothermal Energy, Thessaloniki, Greece*

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

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

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

Sanner, B. Shallow Geothermal Systems, Ground Source Heat Pumps, Short Courses -World Geothermal Congress 2005, Antalya (Turkey)

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

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

Ungemach, P. Environmental Impacts of Low Enthalpy Direct Uses. The Geothermal District Heating Case, Short Courses -World Geothermal Congress 2005, Antalya (Turkey)