### 5.6. Benefit of GSHP systems

Geothermal source heat technology has several benefits, including:

- *Low operating cost* - The efficiency of the heat pumps operating under moderate loop temperatures provides the basis for high efficiency and low operating cost. The cost to move energy around the building is also low, as heat pumps are placed at each space. There is no need to circulate large amounts of air around the building to transport energy, nor is there a need to reheat air to maintain comfort in certain areas of a building.
- *Simplicity* – The distributed nature of the system makes it easy to understand. A heat pump located at each space will provide independent heating and cooling. The operation of one heat pump does not affect any other heat pump. Control simply requires turning the unit on or off in response to the area that needs heating or cooling.
- *Low maintenance* – The heat pump itself is a packaged unit no more complex than typical residential air conditioning equipment. The components are the same as those used for outdoor applications that have much wider operating ranges and exposure to the weather. Diagnosing problems has become easier due to the distributed nature of the system. Any problem is typically closely related to the equipment serving the particular space.
- *No supplemental heat required* – Heat pumps can meet all of the space loads, including ventilation loads. Ventilation air can be tempered by separate heat pumps and/or conditioned with heat recovery equipment.
- *Low cost integrated water heating* – Heat pumps can be dedicated to meet hot water loads. These heat pumps become particularly attractive when there is a large cooling load relative to the heating load. By extracting some of the heat from the ground loop for water heating, the ground heat exchanger size and cost can be reduced.
- *No required exposed outdoor equipment* – The ground heat exchanger is buried and the heat pumps are located inside the building. Vandalism, noise, and visual screen problems are eliminated. Designers do not have to supply space on the roof for equipment, making options such as standing seam metal roofs or large sloped roofs possible.
- *Low environmental impact* – No fossil fuels need to be consumed on site. Pollution can be best mitigated at a central power plant where electricity is produced. As the efficiency of electricity production or renewable power generation increases, so does the environmental efficiency of the heat pump system has low environmental impact.
- *Level seasonal electric demand* – With winter heat pump operation displacing fossil fuel use, and summer heat pump operation occurring at moderate, more efficient loop temperatures, the electric demand is more consistent throughout the year so the average price of electricity is reduced.
- *Longer life expectancy* - Both the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Electric Power Research Institute have concluded, based on independent research studies, that the appropriate service life value for ground source heat pump technology is 20 years or more. This benchmark is the current industry standard.

# 6. DIRECT USE OF GEOTHERMAL ENERGY

## 6.1. Introduction

Geothermal resources through geothermal hot springs have been utilized for centuries through “direct use.” Direct use resources are tapped by drilling wells and bringing hot water to the surface directly for a variety of uses, primarily for space heating, but also for drying farm and timber products, aquaculture and industrial uses.

Though hot springs are still used today, geothermal water can now be used directly (known as “direct use”) for an expanded variety of uses, primarily related to heating and cooling. The main utilization categories are swimming, bathing and balneology; space heating and cooling, including district energy systems; agricultural applications such as greenhouse and soil heating; aquaculture application such as pond and raceway water heating; and industrial applications such as mineral extraction, food and grain drying.

Direct use of geothermal energy relates to the low-temperature (between 21 and 149°C) 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 use" is accepted in order to make difference between the electricity ("indirect application") and other uses of geothermal heat ("direct use"), i.e. the immediate use of the consisted heat rather than to its conversion to some other form of energy.

In modern direct-use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well, and a mechanical system-piping, a heat exchanger, and controls—delivers the heat directly for its intended use.

Direct-use of geothermal resources is primarily for direct heating and cooling. The main utilization categories are:

1. Swimming, bathing and balneology.
2. Domestic hot water systems
3. Space heating and cooling including district energy systems.
4. Agricultural applications such as greenhouse and soil heating.
5. Aquaculture application such as pond and raceway water heating.
6. Industrial applications such as mineral extraction, food and grain drying, and
7. Geothermal (ground-source) heat pumps (GHP), used for both heating and cooling.

The main advantage of using geothermal energy for direct use projects in this low- to intermediate-temperature range is that these resources are more widespread and exists in at least 80 countries at economic drilling depths. In addition, there are no conversion efficiency losses and projects commonly use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the fluid). Most projects can be on line in less than a year.

Care must be taken to prevent oxygen from entering the system (geothermal water normally is oxygen free), and dissolved gases and minerals such a boron, arsenic, and hydrogen sulfide must be removed or isolated as they are harmful to plants and animals. On the other hand, carbon dioxide, which often occurs in geothermal water, can be extracted and used for carbonated beverages or to enhance growth in greenhouses.

The typical equipment for a direct-use system is illustrated in Figure 6.2.1 below, and includes down hole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up generators (usually fossil fuel fired) to reduce the use of geothermal water and reduce the number of wells required, and water disposal systems (injection wells). Geothermal energy can usually meet 95% of the annual heating or cooling demand, yet only be sized for 50% of the peak load. Geothermal heat pumps include both open (using ground-water or lake water) and closed loop (either in horizontal or vertical configuration) systems.

The world direct utilization of geothermal energy is difficult to determine; as, there are many diverse uses of the energy and these are sometimes small and located in remote areas. Finding someone or even a group of people in a country who are knowledgeable on all the direct uses is difficult. In addition, even if the use can be determined, the flow rates and temperatures are usually not known or reported; thus, the capacity and energy use can only be estimated. This is especially true of geothermal waters used for swimming pools, bathing and balneology.

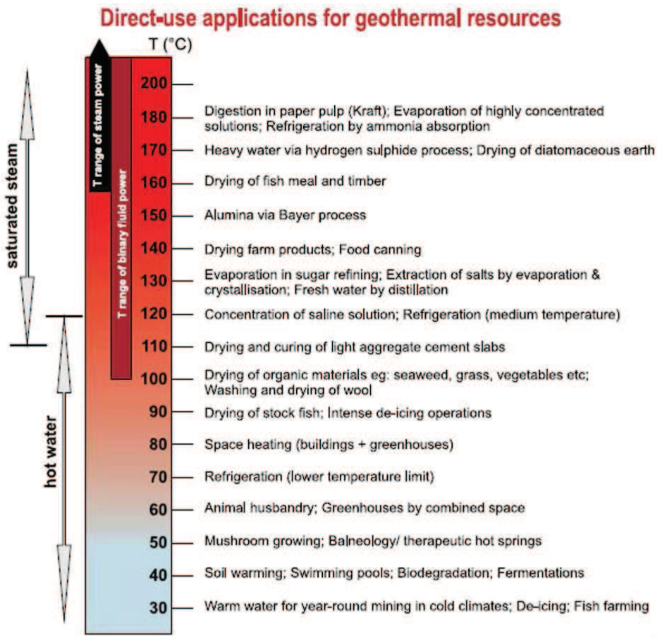

Fig.6.1.1 examples of direct-use applications for geothermal energy (modified from Lindal (1973)) [24]

Direct-use of geothermal energy can involve a wide variety of end users, but for heating applications it is an energy efficient alternative to converting the resource to some other form of energy such as electricity. Figure 6.1.1 show examples of direct-use applications for geothermal energy (modified from Lindal (1973)).

The different applications for direct-use of geothermal energy vary according to temperature, as illustrated by the Lindal diagram (Figure 6.1.1). Direct-use is typically associated with lower-temperature geothermal resources (those with temperatures less than 150°C), though some applications may require higher temperatures. In Australia, geothermal heat could be used in agriculture for greenhouse heating or crop drying as well as in aquaculture and space heating. It could also be used for industrial processes such as concrete curing, milk pasteurization, chemical extraction, refrigeration, drying organic materials (seaweed, grass etc), desalination, and wool processing and pre-heating of water in coal-fired power stations. Cascading use, whereby the same water is used in successive processes at progressively lower temperatures, is possible within a single geothermal operation. This can improve efficiency and economic feasibility.

There are economic, environmental and energy efficiency benefits associated with the direct use of geothermal energy, including:

- Lower heating costs by reducing electricity, oil or gas consumption.
- Reduced emissions of $CO_2$ and oxides of nitrogen and sulfur, by reducing consumption of fossil-fuel-generated electricity.
- Better use of resources, with reduced consumption of a high-grade fuel (such as natural gas) for low-grade heating, and
- Minimal ongoing costs after installation.

In addition, at the lowest end of the temperature spectrum, ground source heat pumps can be used almost anywhere in the world to provide heating and cooling for buildings.

## 6.2. Technologies for direct use of geothermal energy

When direct use 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 u-ser(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.

### *6.2.1. Heat exchangers (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.

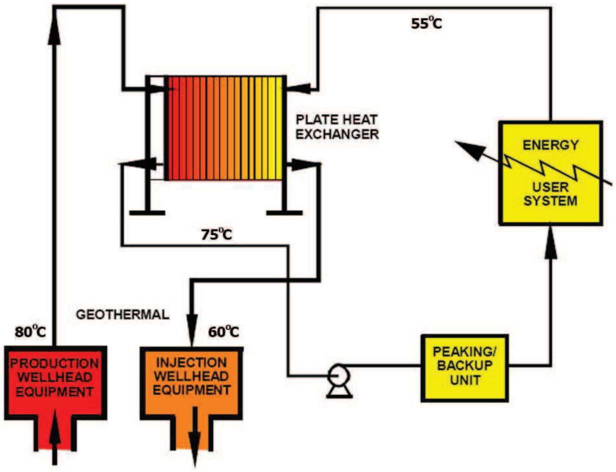

Fig.6.2.1 Typical direct use geothermal heating system configuration [27]

Using 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 corn-position and, in that way, a full protection of the heating system parts, divided from the geothermal water flow by a heat exchanger (Fig.6.2.1).

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

*Gasketed plate heat exchangers.* The plate-and-frame or gasket plate heat exchanger (PHE) consists of a number of thin rectangular metal plates sealed around the edges by gaskets and held together in a frame as shown in Fig. 6.2.2. The frame usually has a fixed end cover (headpiece) fitted with connecting ports and a movable end cover (pressure plate, follower, or tailpiece). In the frame, the plates are suspended from an upper carrying bar and guided by a bottom carrying bar to ensure proper alignment. For this purpose, each plate is notched at the center of its top and bottom edges. The plate pack with fixed and movable end covers is clamped together by long bolts, thus compressing the gaskets and forming a seal. The carrying bars are longer than the compressed stack, so that when the movable end cover is removed, plates may be slid along the support bars for inspection and cleaning.

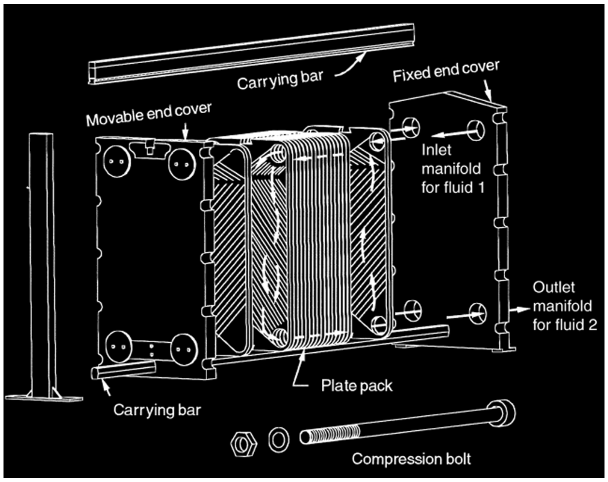

Fig.6.2.2 Gasket plate- and-frame heat exchanger construction

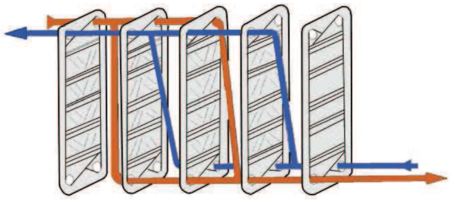

Fig.6.2.3 Flows in plate heat exchanger [55]

Each plate has four corner ports. In pairs, they provide access to the flow passages on either side of the plate. When the plates are assembled, the corner ports line up to form distribution headers for the two fluids. Inlet and outlet nozzles for the fluids, provided in the end covers, line up with the ports in the plates (distribution headers) and are connected to external piping carrying the two fluids. A fluid enters at a corner of one end of the compressed stack of plates through the inlet nozzle.

The countercurrent flow and high turbulence achieved in plate heat exchangers (Fig.6.2.3), 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.

*Shell-and-Tube Exchangers*. This exchanger, shown in Fig. 6.2.4, is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes. The major components of this exchanger are tubes (or tube bundle), shell, frontend head, rear-end head, baffles, and tube sheets.

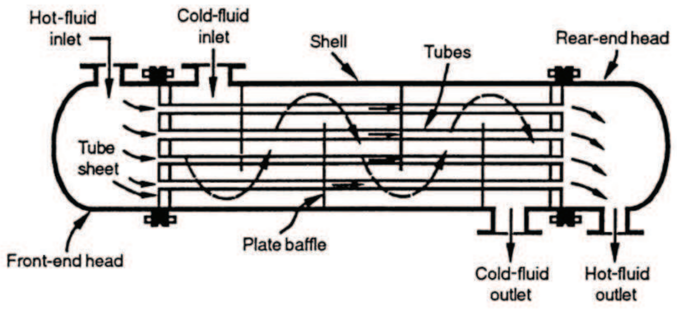

Fig.6.2.4 Shell-and-tube exchanger with one shell pass and one tube pass

A variety of different internal constructions are used in shell-and-tube exchangers, depending on the desired heat transfer and pressure drop performance and the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, to control corrosion, to accommodate highly asymmetric flows, and so on.

The three most common types of shell-and-tube exchangers are (1) fixed tube sheet design, (2) U-tube design, and (3) floating-head type. In all three types, the front-end head is stationary while the rear-end head can be either stationary or floating, depending on the thermal stresses in the shell, tube, or tube sheet, due to temperature differences as a result of heat transfer.

Classical shell-and-tube heat exchangers (Fig.6.2.4) may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (difference between incoming and outgoing fluid temperature), and the larger size.

*Downhole heat exchangers.* The downhole heat exchanger (DHE) eliminates the problem of disposal of geothermal fluid, since only heat is taken from the well. The exchanger consists of a system of pipes or tubes suspended in the well through which “clean” secondary water is pumped or allowed to circulate by natural convection. These systems offer substantial economic savings over surface heat exchangers where a single-well system is adequate (typically less than 0.8 MWth, with well depths up to about 150 m and may be economical under certain conditions at well depths to 450 m.

Several designs have proven successful; but, the most popular are a simple hairpin loop or multiple loops of iron pipe (similar to the tubes in a U-tube and shell exchanger) extending to near the well bottom (Figure 6.2.5). An experimental design consisting of multiple small tubes with “headers” at each end suspended just below the water surface appears to offer economic and heating capacity advantages.

In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and the casing, and perforations above and below the heat exchange surface. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing through the upper perforations. If the design parameters of bore diameter, casing diameter, heat exchanger length, tube diameter, number of loops, flow rate and inlet temperature are carefully selected, the velocity and mass flow of the natural convection in the well may approach those of a conventional shell-and-tube heat exchanger.

Technology of the "down hole" 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 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.

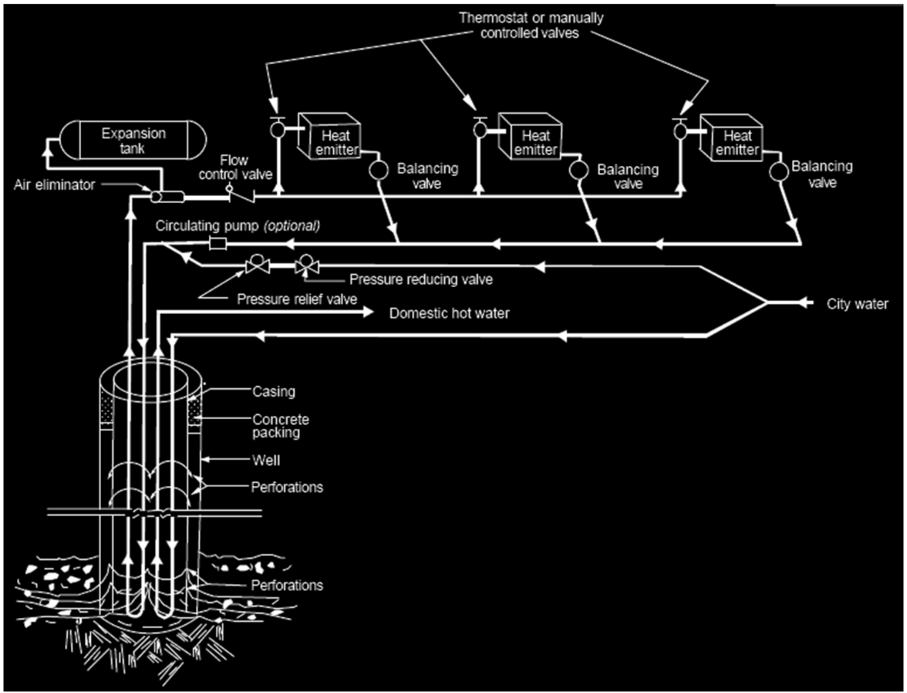

Fig.6.2.5 Typical downhole heat exchanger system (Klamath Falls, OR).

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 characteristically for Europe, where normally there are not very shallow geothermal aquifers on disposal.

### *6.2.2. Heat distribution and piping*

The source of geothermal fluid for a direct use application is often located some distance away from the user. This requires a transmission pipeline to transport the geothermal fluid.

Geothermal fluid for direct use applications is usually transported in the liquid phase -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. Several factors including pipe material, dissolved chemical components, size, installation method, head loss and pumping requirements, temperature, insulation, pipe expansion and service taps should be considered before final specification.

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.

Thermal expansion of pipelines heated rapidly from ambient to geothermal fluid temperatures (which could vary from 50 to 200°C) causes stress that must be accommodated by careful engineering design.

Piping materials for geothermal heating systems have been of numerous types with great variation in cost and durability. Some of the materials which can be used in geothermal applications include: asbestos cement (AC), ductile iron (DI), slip-joint steel (STL-S), welded steel (STLW), gasket polyvinyl chloride (PVC-G), solvent welded PVC (PVC-S), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), cross-linked polyethylene (PEX), mechanical joint fiberglass reinforced plastic (FRP-M), FRP epoxy adhesive joint-military (FRP-EM), FRP epoxy adhesive joint (FRP-E), FRP gasket joint (FRP-S), and threaded joint FRP (FRP-T). The temperature and chemical quality of the geothermal fluids, in addition to cost, usually determines the type of pipeline material used. Generally, the various pipe materials are more expensive the higher the temperature rating.

Both metallic and nonmetallic piping can be considered for geothermal applications. The attractiveness of metallic piping is primarily related to its ability to handle high temperature fluids. In addition, its properties and installation requirements are familiar to most installation crews. The advantage of nonmetallic materials is that they are virtually impervious to most chemicals found in geothermal fluids. However, the installation procedures, particularly for fiberglass and polyethylene are, in many cases, outside the experience of typical laborers and local code officials. This is particularly true in rural areas.

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 1500 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 of last resort. Additionally, buried steel pipe is also subject to external corrosion unless protected with a suitable wrapping or cathode protection.

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 60°C.

Fiberglass piping, commonly referred to as RTRP (reinforced thermosetting resin pipe) or 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 140°C. 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 60°C) 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 100°C. Pressure handling ability at this temperature is very low (as is PVC at its maximum temperature) and support requirements are almost continuous.

Fig.6.2.6 Aboveground geothermal pipes to the Nesjavellir geothermal power plant

Polyethylene (PE) 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°C. Very high molecular weight/high density PE can be employed for low pressure applications up to temperatures as high as 80°C 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 serviceable to 90°C.

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.

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.6.2.7 Buried pre-insulated pipes for geothermal district heating, Xian Yang – China

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.6.2.7). 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-day, a pre-insulated piping system.

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-condensable 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 re-injected 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 re-circulated 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.

## 6.3. Types of direct use of geothermal energy

### *6.3.1. Domestic hot water heating*

Possibly the oldest recorded use of geothermal water was for bathing and health. The history of balneology, using natural mineral waters for the treatment and cure of disease, is thousands of years old. Mineral waters have been used for bathing since the Bronze Age 5000 years ago, according to archeological finds.[25] The word spa derives from a natural hot spring of iron-bearing water in Belgium that was used starting in 1326 to cure ailments. The resort spring, called Espa (fountain, in the Walloon language), became so popular that in English, the word spa became the common term for any similar health resort.

Geothermally heated spas don't really have an alternative energy source. One of the major attractions at a spa is that the water is naturally heated. A spa must be located near the spring or well. The hot water from the earth, containing certain minerals can give the spa meaning from a religious, symbolic, aesthetic, philosophical, or medical context.[25]

The typical temperature for a swimming pool is 81°F (27oC). Thus, in a geothermal heated pool, the hot water must often be cooled by mixing with cooler water, aeration, or in a holding pond. If the geothermal water is used directly in the pool, then a flow-through process is needed to replace the "used" water regularly. In many cases, geothermal water is used to heat water treated with chlorine which is in a closed loop. A heat exchanger is used to transfer heat from the geothermal fluids to the treated water. Geothermally heated swimming pools do have alternative energy sources if the geothermal water is not used directly in the pool. Solar energy or natural gas pool heaters are an alternative to geothermal heaters if the geothermal water does not flow directly into the pool. Comparing the alternatives, the price of natural gas could offset the higher prices for the heat exchanger and piping needed for the geothermal system. A solar heated pool is often less expensive in capital costs and operating costs than a geothermal system. However, a solar system cannot operate during all times (cloudy or at night) when it may need to operate. A geothermal system is available on demand throughout the year.

### *6.3.2. Domestic hot water heating*

District heating and domestic hot water supply using geothermal energy is dominant in many cold European countries. Though most of them use ground source heat pumps, those which have large geothermal resources like Iceland use geothermal energy (Fridleifsson, 2001).

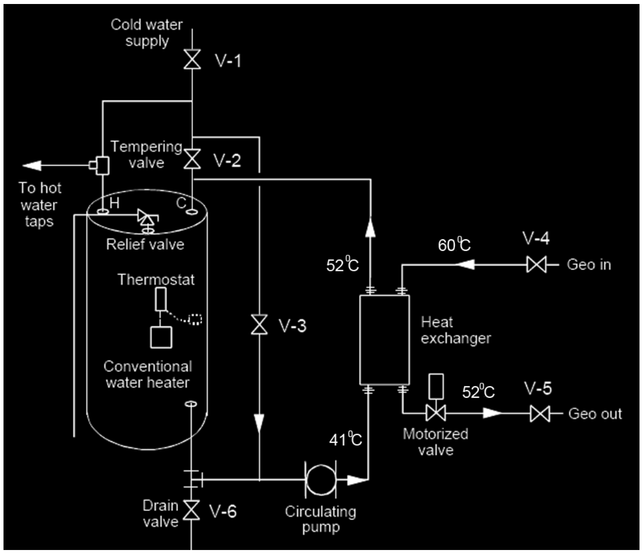

Fig.6.3.1 The storage recharge method for domestic hot water heating [58]

The various uses for domestic hot water include dish washing, laundry, bathing and hand washing. Hot water consumption depends on uses and application temperature (Yao et. al., 2003). According to BRE, 2008, domestic hot water should be supplied at 60$^{o}$C to avoid multiplication of Legionnaire bacteria and to avoid scalding.

Domestic hot water heating often requires higher temperature water than space heating does. This is due to the fact that heat is being transferred to a 49$^{o}$C or greater sink rather than the 21$^{o}$C air in a space heat application. There are several ways to configure a domestic water heating system. The two most common are storage recharge and instantaneous. There is also the possibility of using the geothermal water directly as makeup to the domestic hot water heater if the water chemistry permits.

*Storage Recharge***.** The storage recharge method is illustrated in Figure 6.3.1. A small heat exchanger transfers heat from the geothermal water to the domestic hot water. To accomplish this, water is circulated from the water heater tank to the heat exchanger by a circulating pump. This pump responds to a thermostat positioned to monitor the temperature of the storage tank.

On a call for heat, the thermostat enables both the circulating pump and a motorized valve located on the geothermal water line. Depending upon the temperature of the water, it may be advisable to add a tempering valve at the hot water outlet. This valve assures that water delivered to the home does not exceed a preset value (adjustable). This method can only be used when relatively high temperature water (>60 $^{o}$C) is available. Properly designed, this approach to water heating can provide 100% of the energy requirements.

*Instantaneous Water Heating***.** Instantaneous water heating is a strategy that can be used with any water temperature. When higher water temperature is available, this strategy can meet nearly 100% of the water heating needs (only tank standby losses would be met by the conventional fuel source). At lower water temperatures, this method supplies only a portion of the water heating needs with the conventional water heater supplying the balance. The major difference between this approach and the storage recharge above is that this design is based on providing all the heat to the water before it enters the water heater tank. The heat exchanger must have much greater capacity to accomplish this and as a result it is more expensive than the heat exchanger used in the storage design. The advantage of this design is that it is simpler in terms of the components required and it can make use of lower temperature water for which the storage recharge method is not practical.

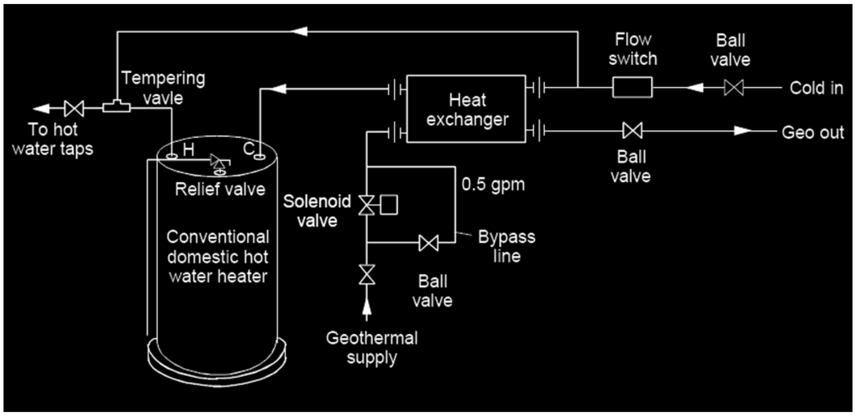

Fig.6.3.2 Instantaneous method for domestic hot water heating [58]

Figure 6.3.2 presents a layout of the instantaneous water heating arrangement. Cold water passes through the heat exchanger on its way to the water heater. When the flow switch senses flow in the line, it signals the hot water control valve to open and supply water to the heat exchanger. A small bypass line is provided to maintain the heat exchanger in a warm condition. Due to the requirement for fast response, the valve used in this application must be a solenoid or other fast opening type design. In addition, the heat exchanger should be sized to minimize pressure drop in the hot water line. These valves can be noisy when switching positions and consideration of this should be reflected in the installation location.

Hot water is usually required to be delivered from the tap at temperatures in the range 35°C to 45°C and for domestic installations; the thermal power output of the heat pump will be inadequate to deliver direct heating of incoming mains water to this level so a storage system is required. Heating is usually carried out via a primary coil or jacket to a storage cylinder. For most domestic heat pumps the maximum output temperature will be 55°C and the maximum water storage temperature achievable will be 50°C. An auxiliary electric immersion heater will be required to provide a 'boost' facility, and also to raise the water temperature so that it can be stored at 60°C in order to reduce the risk of Legionella. Because the efficiency of the heat pump falls as the output temperature rises it may be more economic to use the immersion heater to heat the stored water at temperatures above 45°C.The stored water volume should be sized so that virtually all the energy input could be supplied during the Economy 7 (or other reduced rate) electricity tariff period.

### *6.3.2. Heating of swimming pool*

Direct with geothermal water. In almost all areas where hot springs are found, the geothermal water is used for pools for bathing, mainly because of therapeutic effects but also for relaxation. In present time, there are many swimming pools using geothermal water directly.

The size of a swimming pool is one of the important items for design of the pool; it is a basic factor for determining the pool's service, water value, selection of equipment etc.

Figure 6.3.3 shows a schematic diagram of the swimming pool. The method adopted for distributing the purified water to the pool and the withdrawal of the contaminated water is of the utmost importance in maintaining the whole of the water in the pool at the required standard of purity and temperature if the water is heated. A balancing tank is required to even out variations in the quantity of water leaving and entering the pool.

The oldest and most popular method of filtration is sand. The sand filters use special filter sand, normally 0.45-0.55 mm, which has sharp edges that serve to separate particles, allowing filtration to take place. They operate on the basis of "depth" filtration; dirt is driven through the sand bed and trapped in the minute spaces between the particles of sand. Initially, a clean sand bed will remove larger particles, and then, as the bed starts to load up with dirt, it will remove finer particles. Cleaning of the media, or sand, is accomplished through reversing the flow through the filter, to the "waste" line. This is known as backwashing.

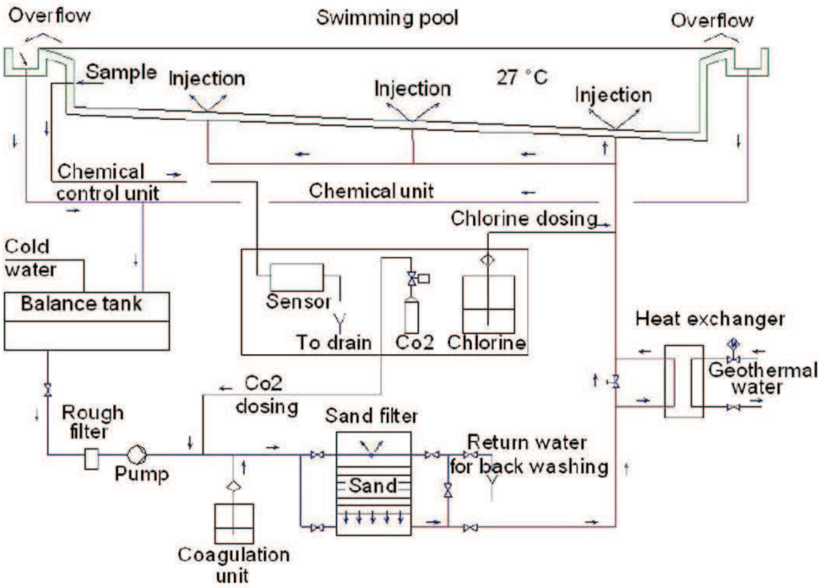

Fig.6.3.3 Swimming pool heating with geothermal water [59]

The rough filter is working as protection equipment for the circulating pump by removing large impurities like sand particles, hairs, etc. It increases the lifetime of the impellers of the pump and decreases the requirement for the back washing process in the filter sand.

A chemical control unit controls the concentration of chemicals in the system. As shown in Figure 6.3.3, samples are taken directly from the pool's water. When there are any changes identified in chemical properties, the sensor will send an electrical signal to improve chemical compounds in the pool's water.

Coagulation and flocculation of microorganisms is of practical importance in waste water treatment because flocculated organisms are relatively easy to collect from the various streams in a wastewater treatment plant. Chemical coagulation of biologically treated wastewaters is usually the initial step in water renovation systems. Coagulants used today generally consist of alum, lime or a synthetic polyelectrolyte. Separation of the flock is accomplished by flotation or sedimentation (Rensselaer, 2004).

Using chlorine is the proven way to destroy bacteria, viruses and alga in the pools. A Clearwater Chlorinator produces its own chlorine when mildly salted water is passed through the Salt Cell (salt is made up of two elements- sodium and chlorine). The chlorine dissolves instantly in the water, going to work immediately to safely sanitize. A Clearwater Chlorinator also produces a small amount of ozone which gives that added sparkle and freshness.

Water conveyance, water treatment, and in fact the entire swimming pool technology requires pipes and piping system components in large numbers. The selection of materials plays an important role for the water quality of the entire operation and its service life. Thermal water has curative properties, but it can also be very aggressive. All pipes made of polypropylene (PP) or polyethylene (PVC) has passed the tests, so the pipe material chosen is PVC and PP which can resist the above conditions. Before concreting of the floor, pipes with large diameter must be put in the bottom. It will provide good facility for the pipes so they can be connected and packed later. Also, if there are problems with the pipes during operation, they can be solved without any destruction of the walls or floor of the pool.

Heat loss from outdoor pools is mainly due to (Svavarsson, 1990):

- Convection
- Evaporation
- Radiation
- Conduction
- Rain

The main heat losses from the swimming pool occur by convection and evaporation. The obtained results from earlier research and analyses show that heat losses due to the other three factors (radiation, conduction, rain) can be estimated to be equal to 10% of total heat loss due to convection and evaporation. Heat loss due to conduction is small, because of good insulation in the pool building materials. Heat loss by means of rain and radiation is also not very big. In the following calculation, 10% of total heat loss by convection and evaporation will be assumed for these three mentioned factors.

*With geothermal heat pump systems*. Heating swimming pool with geothermal pump depends on the climate." The design challenge arises from the fact that GHP systems are exactly that: they are systems. The addition of a swimming pool to a GHP system changes the heat balance of the original system (i.e., without a pool), and the new design depends on the climate.

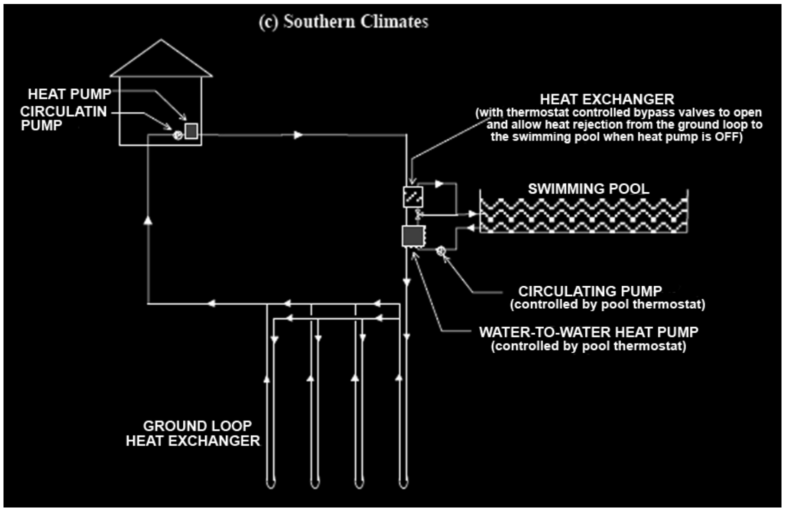

Fig.6.3.4 Swimming pool heating with geothermal heat pump [59]

In northern climates, more heat is generally extracted from the ground than is rejected during the year. Therefore, a water-to-water heat pump and more ground loop would be required to heat a pool in summer months, but the amount of extra ground loop needed would depend on the length of the swimming season and on the heating/cooling loads profile for the home during the remainder of the year. In southern climates, the opposite occurs and more heat is generally rejected to the ground than is extracted during the year. In these cases, heat from the ground loop that would otherwise be rejected to the ground can be used to heat a swimming pool either directly or with a water-water heat pump. The decision to heat a pool with a GHP is an economic one, similar to the decision to heat/cool a home with a GHP. There are tradeoffs between first cost and operating cost savings.

Figure 6.3.4 illustrates the system for Southern climates. The vertical-bore ground loop was used for the combined loads of the house and pool (Figure 6.3.3) and some heat rejection from the ground loop to the pool was accomplished.

### *6.3.3. Space heating and cooling (air conditioning)*

Under the expression "space air 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.

Space conditioning includes both heating and cooling. Absorption space cooling with geothermal energy has not been popular because of the high temperature requirements and low efficiency. However, newer units recently placed on the market report to use temperatures below 100°C efficiently. Geothermal heat pumps (groundwater and ground-coupled) have become popular in the U.S., Canada and Europe, used for both heating and cooling.

District heating involves the distribution of heat (hot water or steam) from a central location, through a network of pipes to individual houses or blocks of buildings. The distinction between a district heating and space heating system is that space heating usually involves one geothermal well per structure. The heat is used for space heating and cooling, domestic water heating and industrial process heat. A geothermal well field is the primary source of heat; however, depending on the temperature, the district may be a hybrid system, which would include fossil fuel and/or heat pump peaking.

An important consideration in district heating projects is the thermal load density, or the heat demand divided by the ground area of the district. A high heat density is recommended. Often fossil fuel peaking is used to meet the coldest period, rather than drilling additional wells or pumping more fluids, as geothermal can usually meet 50% of the load 80 to 90% of the time, thus improving the efficiency and economics of the system.

Geothermal district heating systems are capital intensive. The principal costs are initial investment costs for production and injection wells, down hole and circulation pumps, heat exchangers, pipelines and distribution network, flow meters, valves and control equipment, and building retrofit. The distribution network may be the largest single capital expense, at approximately 35 to 75% of the entire project cost. Operating expenses, however, are in comparison lower and consists of pumping power, system maintenance, control and management. The typical savings to consumers range from approximately 30 to 50% per year of the cost of natural gas.

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 healing.

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 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.

*Main characteristics of space heating*

- Preferred water temperatures in the range 60-90°C. Common return water temperature is 25-40°C
- Chemical composition of the water is important
- Radiators or floor heating systems are commonly used. Air heating systems are also possible.
- Geothermal heat pump can be used if the temperature of the resource is too low for direct application

The supply temperatures required for a range of domestic heating distribution systems.

| Distribution system | Delivery temperature °C |
|---|---|
| Under floor heating | 30-45 |
| Low temperature radiators | 45-55 |
| Conventional radiators | 60-90 |
| Air | 30-50 |

GSHP systems may not be suitable for direct replacement of conventional water-based central heating systems because of the high distribution temperatures unless extensive measures are taken to improve the thermal insulation of the building. A wet radiator system usually operates at 60°C to 80°C and a drop in circulating temperature by 20°C would require an increase in emitter surface of 30% to 40% to maintain the same heat output. For an air system reducing the delivery temperature to 35°C would require increasing the air change rate by up to three times to maintain the same output.

For new housing where high insulation levels result in low heating demand, low temperature air distribution systems, low temperature water-based systems or under floor heating are all possible options.

The most efficient type of space heating to use with a GSHP system is under floor heating. Ideally the system should be designed to give floor surface temperatures no higher than 26°C and should be sized using a water temperature difference of about 5°C.

Because of the higher output temperature, the seasonal performance of a low temperature radiator system will not be as high as that for an under floor design. Fan convectors can be used but flow temperatures of around 50°C may be necessary to ensure high enough air temperatures which will also reduce the system efficiency.

### *6.3.3.1 Heating elements*

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

*Natural air convection systems.* The air flow through the heating element as a result of difference density (temperature) between hot and cold air.

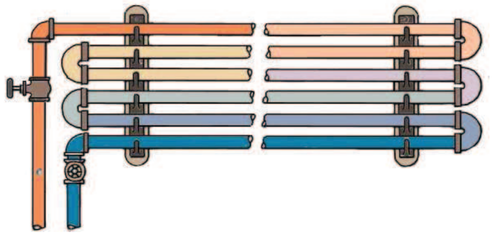

Fig.6.3.5 Pipes heating element

*Pipes*. The simplest 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.6.3.5) and transferring the heat from the water streaming in them to the surrounding air. It's a cheap but aesthetically rather poor technical solution.

*Convectors*. Much better is the use of convectors, made of finned pipes (Fig.6.3.6b). 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.

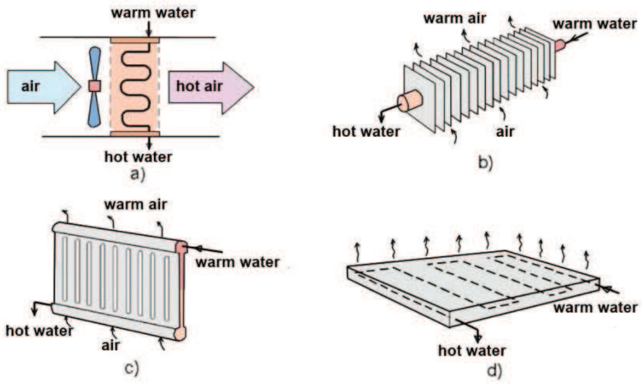

Fig.6.3.6 Different types of heating elements [59]
**a**-fan coil; **b**-convector; **c**-radiator; **d**-floor heating

Finned tube/convector systems (skirting board convector), as illustrated in Fig.6.3.6b, 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.

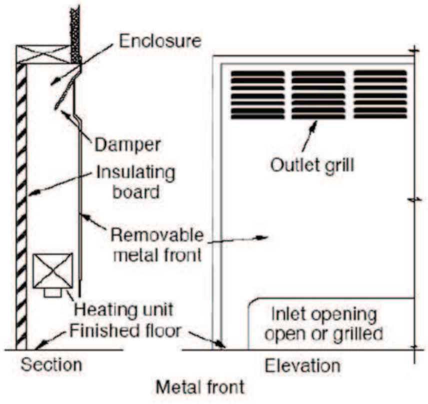

Fig.6.3.7 Convector in the wall construction with the masks on the front side

Heat is given off primarily by natural convection. Hot water is pumped through copper tube in the skirting board convector and nature does the rest. Cooler air enters through the bottom of the "Thermal board" as the air flows passes the finned copper tube it is heated and escapes through the top. Warm air is gently circulated throughout the room without draughts or noise maintaining an even temperature from floor to ceiling.

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 specifically designed metallic masks, enabling creation of a controlled vertical air flow (Fig.6.3.7). Eventual use of 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.6.3.8. Cast iron radiator

*Radiators.* The most spread solution in use is the so called radiators. They can be made in different forms and from different materials. Most known are radiators made of steel plates (Fig.6.3.6c), cast iron radiators (Fig.6.3.8) and aluminum radiators.

Radiators are 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 40$^o$C), and people is used to see them as a part of the room interior.

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, argue high ceiling manufacturing structures, hospitals and schools.

Radiant panel systems, as indicated in Fig.6.3.9, involve the circulation of warm water (35-45°C) 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 now-a-days.

*Radiant floor heating*. Radiant floor heating has also been popular for a long time. Typically, however, radiant floor systems have utilized fossil fuel (natural gas, fuel oil or propane) boilers as a source for heated water. Combining a water-to-water geothermal heat pump with a radiant floor installation provides unmatched comfort and efficiency.

Fig.6.3.9  Radiant floor heating system

The combination of geothermal and radiant floor heating results in a system which not only has the benefits of both technologies independently, but also has some distinct advantages as a result of the combination.

Floor heating systems have several benefits in residential, commercial and industrial heating applications. In a building with a radiant floor heating system, the entire floor acts as a heat source for the room.

Air temperatures in a room with floor heating tend to be warmer at the floor than the ceiling, helping keep heat where it is needed, at the occupant level. The combination of geothermal systems and radiant floor heating provides the ultimate in home comfort with the added benefit of even lower operating costs than geothermal forced air systems.

Radiant floor heating operates very effectively in the temperature range of 30-45$^{o}$C, and therefore is the most effective means of supplying heat to a dwelling from a water output heat pump. In new build housing this is straightforward to install. However, it is expensive and disruptive to install in an existing property unless the floor needs to be replaced anyway.

*Forced air convection 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.

Fig.6.3.10 Fan coil unit

*Fan coil units*. The fan coil units themselves are comprised of a finned-tube coil, an insulated drain pan under the coil to collect condensate, a fan to move air through the coil, filters, control valve, and a cabinet to house these components. Typically fan coils are either located above ceilings or ducted to ceiling diffusers, or under windows using console units. Console units are sometimes ducted through the wall for ventilation air. Fan coil units are used for attaining a desired temperature in a small area e.g. a small room.

A two-pipe fan coil system consists of fan coil units with single coils, which are connected to two pipes (one supply pipe and one return pipe) that either provide hot water or chilled water throughout the building. A building with a two -pipe system is either entirely in a heating mode or entirely in a cooling mode. It is not possible to cool some rooms while heating others. A two-pipe system is usually operated in the heating mode in the winter and the cooling mode in the summer.

The desired temperature in the serving area is achieved by the simultaneous control of the control valve and the fan. The control valve regulates the flow of water inside the coil. The fan blows the supplied air through the coil further changing its temperature before it comes to the serving area. When further heating or cooling is not required the control valve is closed preventing the water from flowing through the coil. The fan is often designed in such a way that it operates in more than one speed.

The temperature of the serving area is controlled according to a set point and a temperature measurement. The controller regulates both the fan speed and the control valve according to the deviation of the current room temperature and the set point. The fan can be operated either with manually or automatically. In manual mode the fan speed can be set to operate always in one of the three speeds. In automatic mode the fan speed is determined by the valve position.

*Fan heaters*. Fan heaters are normally used for permanent heating of warehouses, industrial premises, workshops, sports halls, shops and the like. Fan heaters can be supplemented with a mixing section that supplies fresh air, and can then also be used as supply air unit.

The fan heater consists of an axial fan with integrated motor and water coil, mounted in a corrosion-proof hot-dip galvanized sheet steel casing. The fan heater has individually adjustable linear grilles to lead the air flow in the desired direction.

The fan heater can be mounted on the wall or the ceiling and the water connection can be on either the left or the right hand side. The air stream can be regulated in multiple steps.

Fig.6.3.11 FHW fan heater with water coil

Fan heaters can achieve high heat output and quick response for a low cost. Compared with other methods of heating, fan heaters have the lowest price per installed kW and are therefore well suited for applications with not permanent operation. Stationary fan heaters are often installed in industrial premises and warehouses. They can also be installed to supplement other methods of heating for particularly cold days. The large portable models are popular for construction sites and for drying applications.

*Air handling units*. When heating more rooms in a building and in industry, where air conditioning is needed, centralized air conditioning unit for supply of more rooms is necessary.

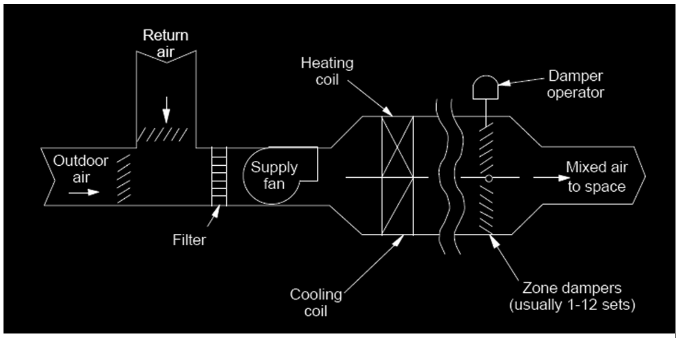

Fig.6.3.12 Central air handling unit for a building with more rooms (Bloomquist, 1977)

“Air conditioning” is defined as the conditioning of indoor air in order to maintain its temperature, humidity, cleanliness and air movement at levels suited to human health and comfort or the industrial processes conducted. The supply air temperature should be kept constant to allow the adjustment of temperature in each room with separate thermostats or dampers. The supply air humidity must not exceed a certain level. Also the circulation of air should always be sufficient.

Air conditioning is done for *comfort* or *industrial purposes*. “Comfort air conditioning” is the conditioning of air to achieve such an environment. People living in environments with proper comfort air conditioning get tired less, get sick less, and work with higher efficiency.

Air handling units condition indoor air with their heating, cooling, humidification and de-humidification functions. Furthermore, air handling units supply the fresh air requirement of the environment with filtered air.

Main advantages 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.

Many combinations of such centralized air conditioning (Fig.6.3.12) are possible, depending on particular requests of heat sours.

### *6.3.3.2 District heating systems*

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.

After heat extraction, the geothermal water is thrown on the surface of the Earth if it allows its quality; otherwise it goes back to the Earth through a reinjection well. If the water source is high quality, it can be entered directly in the central heating system (open system). Geothermal waters which in themselves have dissolved salts, in order to avoid the occurrence of corrosion and sedimentation, are entered directly into the central heating system, but with the help of heat exchanger which give heat to the secondary fluid-chemical prepared water (closed system (Fig.6.3.13).

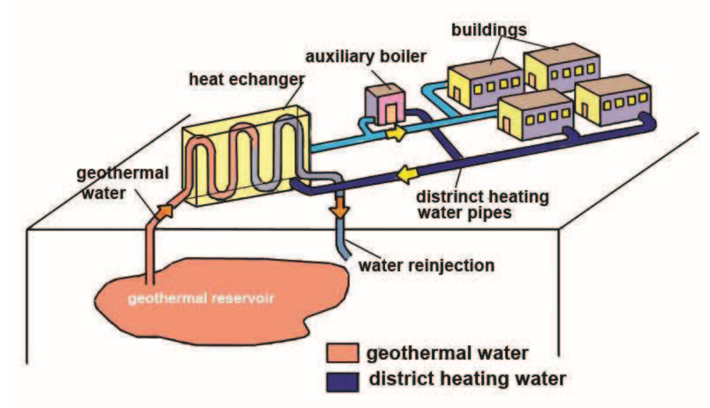

Fig.6.3.13 Closed loop double pipe geothermal district heating system [43]

Heat required for heating a building depends on several factors such as: purpose, climatic conditions, the quality of the thermal isolation and the participation of windows in the total wall and roof area, isolation of the foundations of the building, the location of the building, if there is a terrace or roof construction etc. In an apartment, the air in certain rooms (living room, bathroom) is heated higher, and in some (bedroom, hallways, kitchen, etc.) at lower temperature.

Because the temperature of the geothermal water is relatively low, and the fact that these systems are not designed to cover the entire heat consumption, but part of it, in case of low outside temperatures, an additional heat source is needed. In those cases it can be applied to an auxiliary boiler that runs on conventional fossil fuel or heat pump (fig.6.3.13).

Central district heating with geothermal energy can be applied in buildings that previously had central heating fitted or new ones. In the first case it is necessary to make some modification and adaptation of the old system to function effectively. In new buildings, the system is projected to be optimal to the temperature of the geothermal fluid.

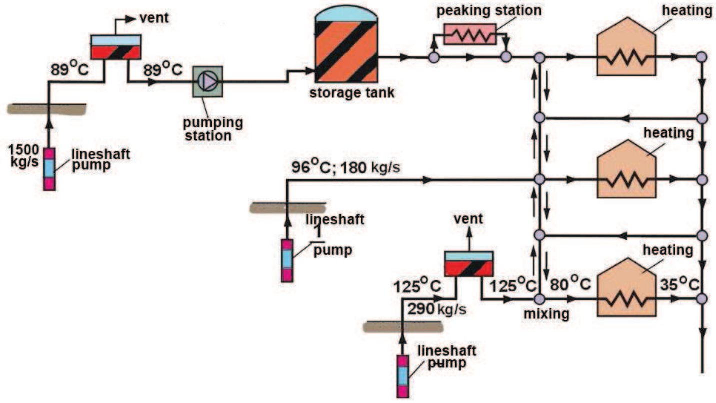

Fig.6.3.14 Reykjavik district heating system (prior to the Nesjavellir connection)

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 (Figure 6.3.14) is probably the most famous (Frimannsson 1991 and Lund, 2005c). This system supplies heat for a population of around 190,000 people. The installed capacity of 830 MWt is designed to meet the heating load to about -10$^{o}$C; however, during colder periods, the increased load is met by large storage tanks and an oil-fired booster station (Ragnarsson, 2005).

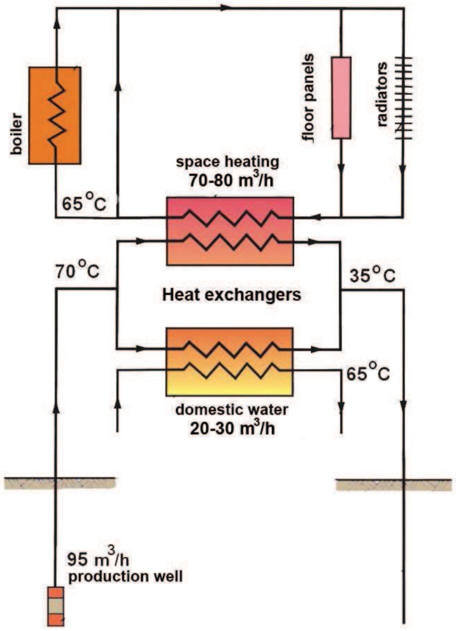

Fig.6.3.15 Melun l'Almont (Paris) doublet heating system [22]

In France, production wells in sedimentary basins provide direct heat to more than 500,000 people in 170,000 dwellings from 34 projects with an installed capacity of 243 MWt and annual energy use of 4,030 TJ/yr (Laplaige *et al.,* 2005). These wells provide from 40 to 100$^{o}$C water from depths of 1,500 to 2,000 m.

A doublet system (one production and one injection well) provides 70$^{o}$C water, with the peak load met by heat pumps and conventional fossil fuel burners (Figure 6.3.15). The geothermal water is removed from production well. After cooling in heat exchangers for space heating and domestic water heating, the water with a temperature of 35$^{o}$C, is injected through reinjection well.

Due to dissolved salts in the geothermal water in this plant are using two heat exchangers. Heat exchanger for space heating is preparing soft water intended for district heating, and the second heat exchanger is prepare domestic hot water in amount of (20 ÷ 30) m$^3$/h. Extreme loads of the plant are covered with heat pump and auxiliary boiler, in which fossil fuel is burning.

Space conditioning includes both heating and cooling. Space heating with geothermal energy has widespread application, especially on an individual basis. Buildings heated from individual wells are popular in Klamath Falls, Oregon; Reno, Nevada, USA, and Taupo and Rotorua, New Zealand. Absorption space cooling with geothermal energy has not been popular because of the high temperature requirements and low efficiency. However, newer units recently placed on the market report to use temperatures below 100$^{o}$C efficiently.

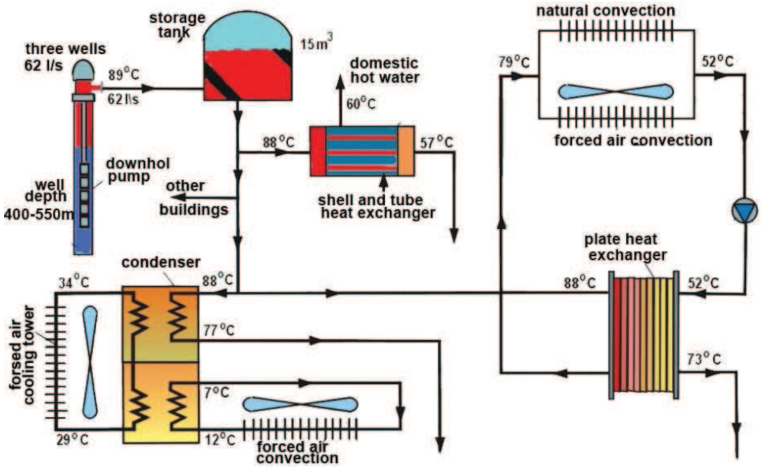

Fig.6.3.16 Oregon Institute of Technology heating and cooling system

An example of space heating and cooling with low-to-moderate temperature geothermal ener-gy is the Oregon Institute of Technology in Klamath Falls, Oregon (Fig.6.3.16). Here, eleven buildings (approximately 62,000 m$^2$ of floor space) are heated with water from three wells at 89$^{o}$C. Up to 62 l/s of fluid can be provided to the campus, with the average heat utilization rate over 0.53 MWt and the peak at 5.6 MWt. In addition, a 541 kW (154 tons) chiller requiring up to 38 l/s of geothermal fluid produces 23 l/s of chilled fluid at 7°C to meet the campus cooling base load (recently decommissioned) (Boyd, 1999).

Geothermal district heating systems are capital intensive. The main costs are initial investment costs, for production and injection wells, down-hole and transmission pumps, pipelines and distribution networks, monitoring and control equipment, peaking stations and storage tanks. Operating expenses, however, are comparatively lower than in conventional systems, and consist of pumping power, system maintenance, control and management. A crucial factor in estimating the initial cost of the system is the thermal load density, or the heat demand divided by the ground area of the district. A high heat density determines the economic feasibility of a district heating project, since the distribution network is expensive. Some economic benefit can be achieved by combining heating and cooling in areas where the climate permits. The load factor in a system with combined heating and cooling would be higher than the factor for heating alone, and the unit energy price would consequently improve (Gudmundsson, 1988).

In indirect central heating systems, geothermal water at the exit of flat plate heat exchanger may have a temperature between (40÷45) °C. Waste geothermal water at this temperature can be used for heating of domestic hot water (Fig.6.3.17), or as a heat source for geothermal heat pump (Fig.6.3.18) which heats the hot water for central heating.

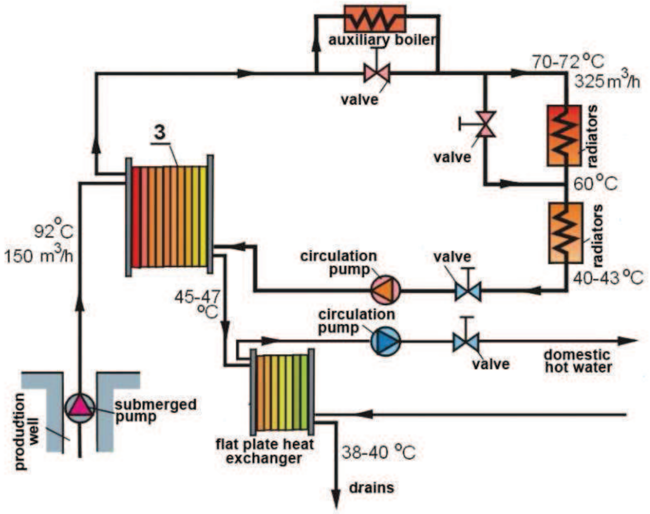

Fig.6.3.17 District heating and domestic hot water preparation in the city Zijinxinli in the province Tianjun in China

Figure 6.3.17 shows the schematic diagram of central geothermal heating plant for Zijinxinli city with 200,000 inhabitants, province Tianjun in China. Geothermal water from the production well, using a submerged pump is transported to the main flat plat heat exchanger, where it deliver the heat to the water that goes into heating units. The water through the central heating system is moving with a circulating pump.

Geothermal water, which leaves the flat plat exchanger with temperature (45÷47)°C, goes to another flat plate heat exchanger, where further, is cooled to a temperature of (38÷40)°C. In the flat plate heat exchanger the water is heated to a temperature about 30°C, which is used for sanitary purposes.

Figure 6.3.18 shows the schematic diagram of central geothermal heating plant, in which the return water from the heating elements, with a temperature of about 45°C is used as a heat source for a geothermal heat pump. Using a heat pump the water temperature is rising to about 60°C, which can be used for heating.

Geothermal water from the well using a submerged pump is brings to the one flat plate heat exchanger, where he deliver the heat to the circulating water through fan coil units as a heaters. From the flat plate heat exchanger geothermal water, with a temperature of (30 ÷ 32)°C using a circulating pump is re-injected in the second well. From fan coil units, the water with temperature of 45°C enters to the evaporator of the geothermal heat pump, which evaporates the refrigerant working fluid.

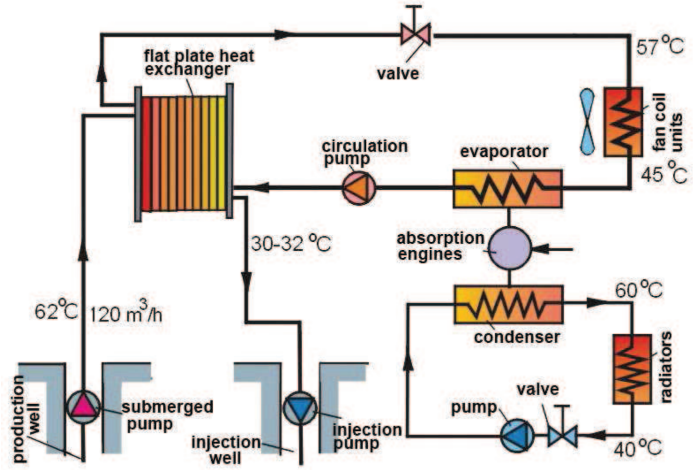

Fig.6.3.18 District heating with geothermal water and geothermal heat pump

Refrigerant working fluid condenses in the condenser, which receives heat sufficient and heat water to a temperature of 60°C designed for central heating radiator in the second circulation cycle.

*Space cooling* is a feasible option where absorption machines can be adapted to geothermal use. The technology of these machines is well known, and they are readily available on the market. The absorption cycle is a process that utilizes heat instead of electricity as the energy source.

The refrigeration effect is obtained by utilizing two fluids: a refrigerant, which circulates, evaporates and condenses, and a secondary fluid or absorbent. For applications above 0°C (primarily in space and process conditioning), the cycle uses lithium bromide as the absorbent and water as the refrigerant. For applications below 0°C an ammonia/water cycle is adopted, with ammonia as the refrigerant and water as the absorbent. Geothermal fluids provide the thermal energy to drive these machines, although their efficiency decreases with temperatures lower than 105°C.

Geothermal *space conditioning* (heating and cooling) has expanded considerably since the 1980s, following on the introduction and widespread use of *heat pumps*. The various systems of heat pumps available permit us to economically extract and utilize the heat content of low-temperature bodies, such as the ground and shallow aquifers, ponds, etc. (Sanner, 2001).

### *6.3.3.3 Refrigeration*

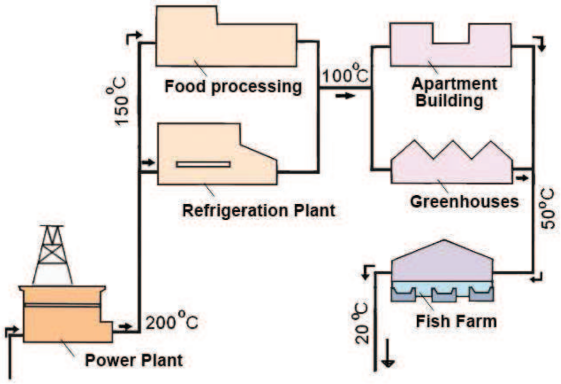

Fig.6.3.19 Refrigeration as a part of geothermal district heating system (cascade use of heat) (Rybach, 1995

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems (Rafferty, 1983; Lund et al., 1998, chapter 13). 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 160°C); but, they also have high efficiency. The single-stage units can be driven with hot water at temperatures as low as 77 °C. The lower the temperature of the geothermal water, the higher the flow rate required and the lower the efficiency. Generally, a condensing (cooling) tower is required, which will add to the cost and space requirements.

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

Geothermal resources fill many needs: power generation, space heating, greenhouse heating, industrial processing, and bathing to name a few. Considered individually, however, some of the uses may not promise an attractive return on investment because of the high initial capital cost. Thus, we may have to consider using a geothermal fluid several times to maximize benefits. This multistage utilization, where lower and lower water temperatures are used in successive steps, is called cascading or waste heat utilization. A simple form of cascading employs waste heat from a power plant for direct use projects referred to as a combined heat and power application.(Figure 6.3.19).

### *6.3.4. Agribusiness applications*

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

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

The *agricultural applications* of geothermal fluids consist of open-field agriculture and greenhouse heating. Thermal water can be used in open-field agriculture to irrigate and/or heat the soil. The greatest drawback in irrigating with warm waters is that, to obtain any worthwhile variation in soil temperature, such large quantities of water are required at temperatures low enough to prevent damage to the plants that the fields would be flooded. One possible solution to this problem is to adopt a subsurface irrigation system coupled to a buried-pipeline soil-heating device. Heating the soil in buried pipelines without the irrigation system could decrease the heat conductivity of the soil, because of the drop in humidity around the pipes, and consequent thermal insulation. The best solution seems to be that of combining soil heating and irrigation. The chemical composition of the geothermal waters used in irrigation must be monitored carefully to avoid adverse effects on the plants.

#### *6.3.4.1 Heating greenhouses with geothermal energy*

The most common application of geothermal energy in agriculture is, however, in *greenhouse heating*, which has been developed on a large scale in many countries. The cultivation of vegetables and flowers out-of-season, or in an unnatural climate, can now draw on a widely experimented technology.

Greenhouse heating is one of the most common uses of geothermal resources. Because of the significant heating requirements of greenhouses and their ability to use very low- temperature fluids, they are a natural application. The evaluation of a particular greenhouse project involves consideration of the structure heating requirements, and the system to meet those requirements.

In general, construction may be considered to fall into one of the following four categories:

1. Glass
2. Plastic film
3. Fiberglass or similar rigid plastics
4. Combination of two and three.

All of the above are generally constructed of steel or aluminum frames.

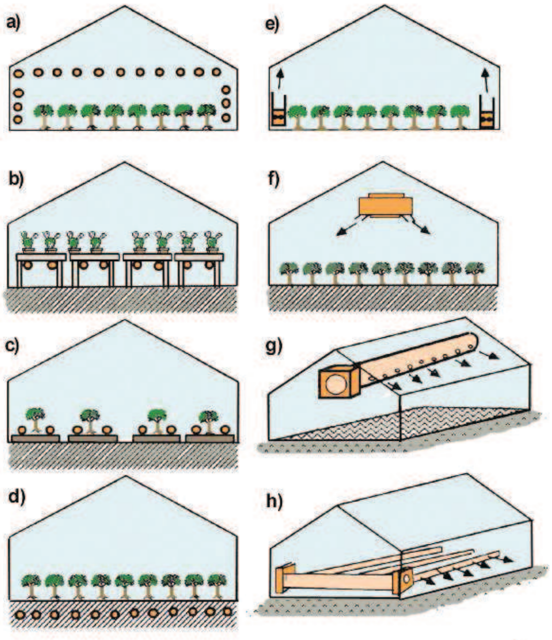

Fig.6.3.20 Heating systems in geothermal greenhouses.

*Heating installations with natural air movement (natural convection):*

**a**- aerial pipe heating; **b**- bench heating; **c**- low position heating pipes for aerial heating; **d**- Soil heating.

*Heating installations with forced air movement (forced convection):*

**e**- lateral position; **f**- aerial fan; **g**- high position ducts; **h**- low-position ducts (From von Zabeltitz, 1986.)

Glass greenhouses are the most expensive to construct because of both the cost of the glazing material and the requirement for a stronger framework to support the glass. In many cases, fiberglass panels are employed on the side and end walls of the structure. The building profile is generally of peaked design, with 11 and 12,82 m widths, and lengths in 6 m increments most common. This type of greenhouse is preferred by growers whose plants require superior light transmission qualities.

Plastic film greenhouses are the newest variation in greenhouse construction techniques. This type of structure is almost always of the arched roof or "quonset hut" design. The roof can come all the way down to the ground or can be fitted with side walls. The side walls, if employed, and end walls are generally of fiberglass construction. Maintenance requirements for the plastic film are high in that it generally requires replacement on 3-year intervals or less, depending on the quality of the material.

Fiberglass greenhouses are similar in construction to the glass houses described above. They are generally of peaked roof design, but require less structural support as a result of the lower weight of the fiber glass. Heat loss of the fiberglass house is about the same as the glass house.

Although the fiberglass material has a lower conductivity than glass, when considered in the overall building heat loss, this has little effect.

*Heating requirements*. In order to select a heating system for a greenhouse, the first step is to determine the peak heating requirement for the structure. Heat loss for a greenhouse is composed of two components: (a) transmission loss through the walls and roof, and (b) infiltration and ventilation losses caused by the heating of cold outside air.

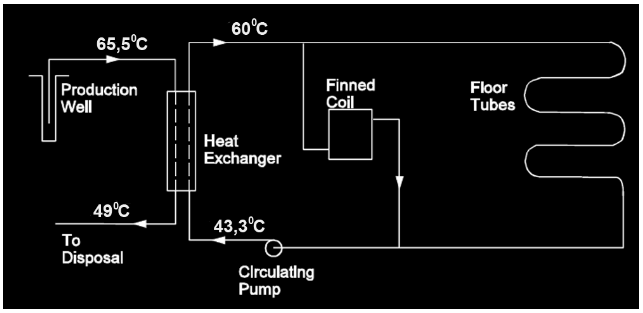

Fig.6.3.21 Heat exchanger schematic.

*Heat Exchangers***.** In most geothermal applications, a heat exchanger is required to separate actual heating equipment from the geothermal fluid. This is because of the scaling and corrosion associated with most geothermal fluids. Generally, the heat exchanger is placed between two circulating loops, the geothermal loop and the clean loop, as shown in Figure 6.3.21.

*Greenhouse heating units*. There are basically six different geothermal heating units (fig.6.3.20) which are applied to greenhouses: *finned pipe; standard unit heaters; low-temperature unit heaters; fan coil units; soil heating* and *bare tube*.

Heating of commercial greenhouses is accomplished with a variety of different systems, the choice of which is usually made by the grower based on the type of plants being grown. For a small “backyard” type greenhouse, among the simplest heating systems is the hot water unit heater. This device consists of a hot water coil with a propeller fan attached. Air distribution is normally through a “poly tube”, a thin clear plastic tube perforated with holes. The tube is normally hung from the ceiling but can also be installed on the floor. Unit heaters are a practical method of greenhouse heating at supply water temperatures down to approximately $60^{o}$C to $65^{o}$C. Below this range, heat output is reduced by more than 50% and the cost of larger equipment becomes an obstacle.

*Heating systems***.** The heating systems can be classified according to the position of the heating installation. The categories are the following:

1. Heating systems in the soil;
2. Heating systems lay on the soil surface or on the benches;
3. Aerial heating systems;
4. Cascading;
5. Combinations of the above.

*Aerial beating systems.* The dominant aerial systems are pipe heater units and fan coil units. The pipes can be smooth or finned steel pipes or smooth plastic pipes which are placed along the length of plant rows, along the side walls under the roof or below the cultivation benches. In Figure 6.3.19a the pipes are placed along the walls and hung from the roof. The position of the system depends on the cultivation, the plant requirements, the greenhouse construction, farmer preference, the climate and the cultivation technology. This heating system is the oldest known system. It is convenient in any climate and usable in big greenhouses. It is not economically feasible in small and inexpensive greenhouses. The system is also convenient for combination with other heating systems.

The aerial pipes (fig.6.3.22) benefit several cultivations but there are differences in the yield and quality of the products depending on the location of the pipes. The temperature of the geothermal water should be above 60°C for the same reason as the above systems.

Fig.6.3.22 Aerial pipe heating system

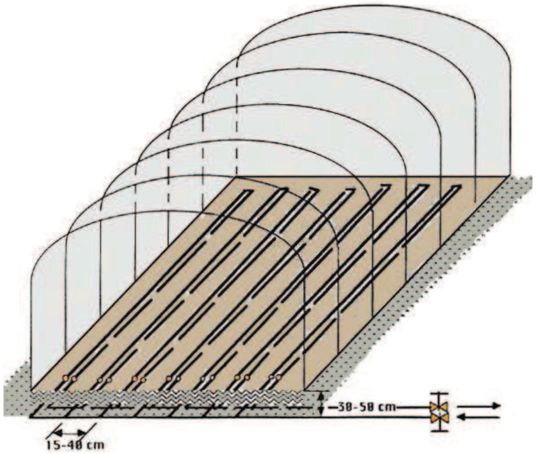

Fig.6.3.23 Soil heating system (pipes are buried in the soil)

*Soil heating.* In this system the soil is used as a large radiator. An example is demonstrated in Figure 6.3.23. The tubes are buried in the soil and the determination of their size and spacing is a function of heat output required, mean-water temperature, soil conductivity and burial depth. The warm water is circulated through the tubes and the produced heat is transferred to the soil and eventually to the air of the greenhouse.

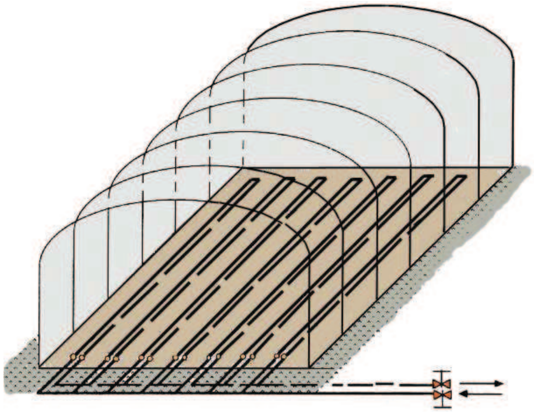

Fig.6.3.24 Soil heating system (pipes are buried in the soil)

In the past, tube materials were generally copper or steel. Because of corrosion and expansion problems with these materials, nonmetallic materials have seen increasing application in recent years. The most popular of these is polybutylene. This material is able to withstand relatively high temperatures (up to – 82$^{o}$C) and is available in roll form for easy installation. PVC piping is only available in rigid form and is limited with respect to temperature. Polyethylene and similar materials are available in flexible roll form, but are (as PVC) generally limited in terms of temperature handling ability. The polybutylene is the most resistant of these in the high temperature range and the most expensive.

A soil heating system is preferred by many operators because it results in very even temperature distribution from floor to ceiling and does not obstruct floor space or cause shadows. Furthermore it is proven that the use of soil heating is very positive for a list of vegetables and bulbous flower cultivations providing earlier harvesting, improved yield and quality of products. Also, it is convenient for root temperature control and for covering minimal heat requirements. However, its ability to supply 100% of the heating requirements of a greenhouse necessitates a rather mild climate and a low inside design temperature. This is caused by the nature of heat transfer in the system.

*Heating systems lay on soil surface or on the benches*. This category includes thin pipes, polyethylene sleeves or / plastic pipes located on the ground as is shown in Figure 6.3.24. The thin pipe system is widely used and the others are installed only in small or inexpensive small greenhouses. The pipes are made of steel or poly material. The location of the pipes can be between the plant rows or directly in the plant rows. The system can be arranged in unit loops or in a loop with a parallel system of two or three pipes.

A disadvantage of this system is that after the end of the production season the plastic pipes must be collected and the steel ones lifted for soli cultivation. Moreover, when the pipes are made by polyethylene they periodically need rearrangement because of the uncontrolled temperature dilations and they do not allow temperatures above 60°C. When the temperature is below 60°C, the heating system will consist of a great number of pipelines. Such a system might not be feasible because of high investment cost and the shading of the pipelines. Another disadvantage is the unprotected top leaves of the plants against the cold sky radiation and condition. For this reason in cold climates it is used in combination with another heating system. This system has a small but significant influence on the soil temperature and as in the soil heating system, provides earlier harvesting, improved yield and good quality of the products in most of the known cultivations.

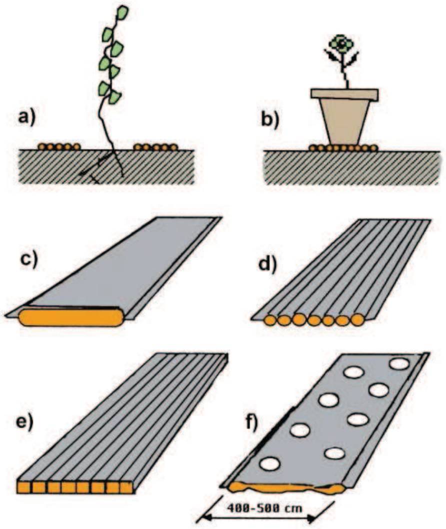

Fig.6.3.25 Type of heating elements of the vegetative heating system

a-parallel pipes positioned along the plants rows; b-pipes positioned bellow the growing pots row; c-soft plastic tubes positioned in parallel with the plant rows; d-the same but with prefabricated connected poly-pipe lines; e-rigid plastic plates with channels for allocation of plants

Fig.6.3.26 Soft plastic bags with holes for allocation of plants

As heating units at the soil heating systems, beside the single smooth or corrugated plastic pipes (Fig.6.3.25a) and b), it is possible to follow the use of special soft plastic tube (nags), polytubes made of prefabricated system of connected pipes (d), rigid plastic plates (e) and specially prepared plastic tube 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.

*Forced air heaters*. The forced air heated units (Figure 6.3.20f) are usually aerial systems, placed along the greenhouse side walls, between the plant rows or hung from the roof (Figure 6.3.27). The two main categories are the unit heaters and the fan coil units. The difference is primarily in the coil itself. The unit heaters usually have one or two row coils. The coil in the fan systems is much thicker and has closer fin spacing than in unit heaters. It has six or eight rows creating more surface area. The additional area gives more effective heat transfer, resulting in the ability to extract more heat from the water. The fan and the units systems usually need high geothermal fluid temperature because with low temperatures the efficiency of the system is lower and some adjustment of unit capacity is necessary. The geothermal fluid must be clean enough because the most common construction material of the units is copper and it is very sensitive to corrosion. In addition, the long path through which the water flows can result in scaling, thus makes a heat exchanger necessary.

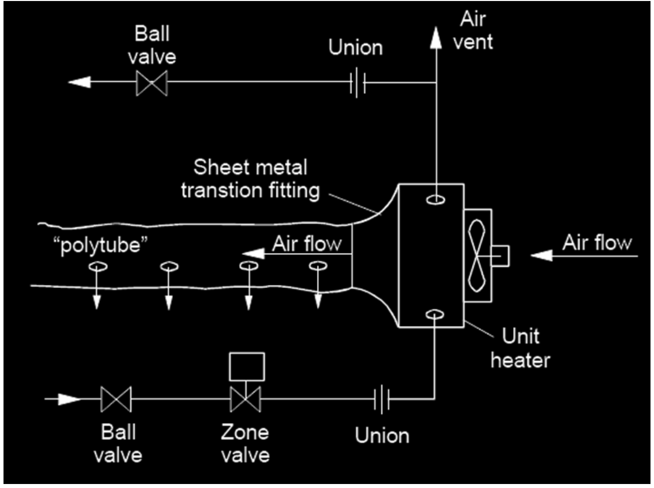

Fig.6.3.27 Typical unit heaters installation [58]

The standard installation of unit heaters consists of hanging the unit at one end of the structure and discharging the supply air toward the opposite end. In longer houses (>38 m), it is advisable to install units at both ends to assure even heat distribution. For the example house, the two units could be installed at one end. Figure 6.3.27 provides a diagram of a typical installation.

*Cascading.* This heating system is applied only in double layered constructions and is common in cheap plastic green houses. A water pipeline is installed into the space between the two layers (Fig 6.3.28) and warm water is sprayed in this space. As a heating method, it is effective but it has a lot of disadvantages and is not widely applicable. The water must be extremely clean and without inclination of deposition. The problems of the depositions are not resolved, though many trials with chemical additives have been performed. After some months of exploitation, the plastic permits less light quantities. Also, the installation of roof windows is not possible. Additionally, the down positioned layer must be absolutely tight because infiltration of geothermal water can harm the plants.

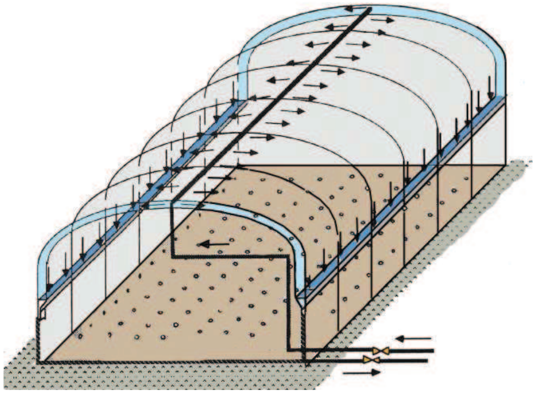

Fig.6.3.28 Cascading greenhouse heating

*Combination.* A combination of different heating systems is necessary in cold climates. The forced aerial systems are usually applied together with so all heating systems (in or on the soil) providing even temperature distribution in the greenhouse. Common combined ions of aerial heating systems are for example systems with pipes placed along the walls and under the roof (Figure 6.3.20a), or hung from the roof and beside the plants, or on the roof, on the wall and beside the plants. When the pipes are placed only on the roof and the walls, the plants have pathogenic problems (fungus). This happens because the moisture remains on the plant leaf surface but when the thermal pipes are placed beside the rows of cultivation, a significant amount of moisture disappears.

For small greenhouses, equipment selection is simply a matter of determining whether the heating requirement of the structure can be met by a single unit or whether more than one will be necessary.

Various solutions are available for achieving optimum growth conditions, based on the optimum growth temperature of each plant (Figure 6.3.29), and on the quantity of light, on the $CO_2$ concentration in the greenhouse environment, on the humidity of the soil and air, and on air movement.

The walls of the greenhouse can be made of glass, fiberglass, rigid plastic panels or plastic film. Glass panels are more transparent than plastic and will let in far more light, but will provide less thermal insulation, are less resistant to shocks, and are heavier and more expensive than the plastic panels. The simplest greenhouses are made of single plastic films, but recently some greenhouses have been constructed with a double layer of film separated by an air space. This system reduces the heat loss through the walls by 30 - 40%, and thus greatly enhances the overall efficiency of the greenhouse. Greenhouse heating can be accomplished by forced circulation of air in heat exchangers, hot-water circulating pipes or ducts located in or on the floor, finned units located along the walls and under benches, or a combination of these methods (Figure 6.3.20).

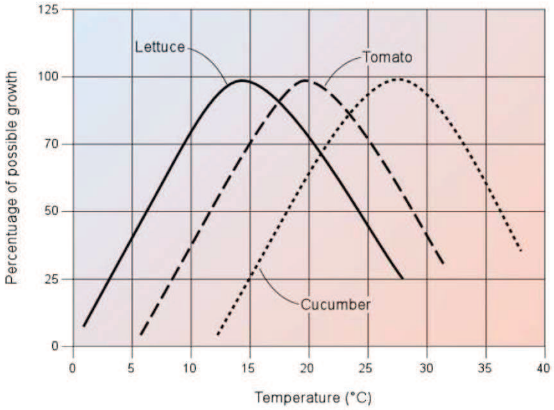

Fig.6.3.29 Growth curves for some crops. (From Beall and Samuels, 1971)

Exploitation of geothermal heat in greenhouse heating can considerably reduce their operating costs, which in some cases account for 35% of the product costs (vegetables, flowers, house-plants and tree seedlings).

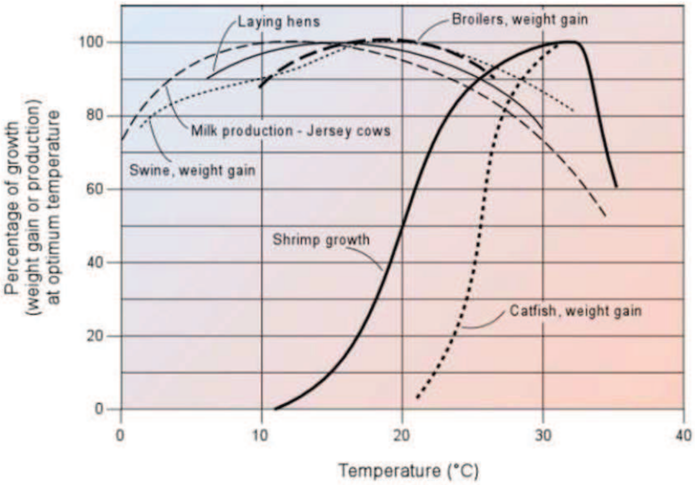

Fig.6.3.30 Effect of temperature on growth or production of food animals. (From Beall and Samuels, 1971).

### *6.3.4.2 Farm animals*

Industrial farm animal production encompasses all aspects of breeding, feeding, raising, and processing animals or their products for human consumption. Producers rely on high-throughput production to grow thousands of animals of one species (often only a few breeds of that species and only one genotype within the breed) and for one purpose (such as pigs, layer hens, broiler chickens, turkeys, beef, or dairy cattle).

The goal of agriculture then, as now, was to meet human demand for food, and as the population grew, early agriculturalists found new ways to increase yield, decrease costs of production, and sustain productivity.

Farm animals and aquatic species, as well as vegetables and plants, can benefit in quality and quantity from optimum conditioning of their environmental temperature (Figure 6.3.30). In many cases geothermal waters could be used profitably in a combination of *animal husbandry* and geothermal greenhouses. The energy required to heat a breeding installation is about 50% of that required for a greenhouse of the same surface area, so cascade utilization could be adopted. Breeding in a temperature-controlled environment improves animal health, and the hot fluids can also be utilized to clean, sanitize and dry the animal shelters and waste products (Barbier and Fanelli, 1977).

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

### *6.3.4.3 Aquaculture*

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species that are typically raised in geothermal waters are catfish, tilapia, bass, trout, sturgeon, giant fresh water prawns, and tropical fish. The application temperature (table 6.3.1) in fish farming depends on the species involved.

Table 6.3.1. Temperature of water determines which species can be raised

| Species | Tolerable Extremes (°C) | Optimum Growth | Growth period to market size (months) |
|---|---|---|---|
| Lobsters | 0-31 | 22-24 | 24 |
| Salmon (Pacific) | 4,5-25 | 15 | 6-12 |
| Catfish | 1,7-35 | 28-30,6 | 6-24 |
| Tilapia | 8,4-41 | 22,2-30 | 12 |
| Trout | 0-31,7 | 17,3 | 6-8 |
| Shrimp | 4,5-40 | 23,9-30,6 | 6-8 |

The temperatures required for aquatic species are generally in the 20 - 30 °C range. Typically, catfish grow in 4 to 6 months at 18 to 24°C, trout in 4 to 6 months at 13 to 18°C and prawns in 6 to 9 months at 27 to 30°C. The benefit of a controlled rearing temperature in aquaculture operations can increase growth rates by 50 to 100% and thus increase the number of harvest per year. Growth rate is reduced when the temperature is above or below the optimum point. Mortality of the fish can occur at extreme temperature conditions. Water quality and disease control are very important in fish farming.

Control of the breeding temperatures for aquatic species is of much greater importance than for land species, as can be seen in Figure 6.3.30, which shows that the growth curve trend of aquatic species is very different from that of land species. By maintaining an optimum temperature artificially we can breed more exotic species, improve production and even, in some cases, double the reproductive cycle (Barbier and Fanelli, 1977). The species that are typically raised are carp, catfish, bass, tilapia, mullet, eels, salmon, sturgeon, shrimp, lobster, crayfish, crabs, oysters, clams, scallops, mussels and abalone.

Aquaculture also includes alligator and crocodile breeding, as tourist attractions and for their skins, which could prove a lucrative activity. The experience has shown that, by maintaining its growth temperature at about 30 °C, an alligator can be grown to a length of about 2 m in 3 years, whereas alligators bred under natural conditions will reach a length of only 1.2 m over the same period.

Geothermal fluids can be used to control the temperature of the fish culture facilities to produce larger and faster growing fish and also allow fish production in the winter when it would otherwise not be possible. Usually the geothermal heated water can be used directly in the ponds. This eliminates the need for heat exchange equipment. Pumps are required to produce the water. Most large growers have two to three wells for their operations. For an aquaculture farm, water quality and water temperature are important. The size of the installation will depend on the temperature of the geothermal source, the temperature required in the fish ponds and the heat losses from the latter.

There are many possible ways to classify and describe the very diverse freshwater aquaculture production types. But from a sustainability point of view, the production methods can be the most reasonable basis for a classification system. Whilst, there are many overlaps and transitions amongst freshwater fish production systems, the following basic methods can be distinguished:

- Pond fish farming
- Flow-through systems
- Recirculation Aquaculture Systems
- Cage cultures

Fig.6.3.31 Geothermal heated pond for fish farming on Lower Klamath Lake Road.

Most fish and crustacean aquaculture is undertaken in earthen ponds or large tanks with flowing water. Pond culture requires large areas of flat land and significant quantities of clean groundwater. Flow-through tank aquaculture requires less land but needs more water per pound of fish produced to maintain good growing conditions within the tank.

Some of the water quality factors that can affect growth of an aquaculture species are: temperature, dissolved oxygen, nitrogenous wastes, pH, alkalinity, hardness, carbon dioxide, salinity, chlorine and hydrogen sulfide. Careful measurement and management of some/all of these factors is important for fish survival.

Temperature has an influence on all biological and chemical process in an aquaculture operation. Each species has its own optimum temperature where it grows best. Growth rate is reduced when the temperature is above or below the optimum point and mortality can occur at extreme conditions.

Aquaculture using geothermal resources really has no economically competitive energy alternatives. If a farm wants to grow a certain species in a certain climate, only a geothermal heated farm can provide low-cost, dependable hot water that increases the fish's growing rate and can keep them alive during the winter.

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 immersed in sea water above the horizontal heat exchanger, made of snakelike system of plastic pipes where geothermal water flows. Warm water above the exchanger flows up through the cages and creates a convenient environment for the fishes.

Fig.6.3.32 Geothermal heated pond for alligator farming in Colorado.

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. Microalgae 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.

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.

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

- Use of geothermal $CO_2$ and energy for optimizing photosynthesis.
- Use of geothermal water for nutrition algal media preparation.
- 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.6.3.33 Open air algae cultivation in Israel.

The cultivation of *Spirulina* can also be considered a form of aquaculture. This single-celled, spiral-shaped, blue-green micro-alga is frequently called ‘super-food’ because of its nutrient density; it has also been proposed to solve the problem of famine in the poorest countries of the world, although at the moment it is being marketed as a nutritional food supplement. Spirulina is now being farmed in a number of tropical and sub-tropical countries, in lakes or artificial basins, where conditions are ideal for its fast and widespread growth (a hot, alkaline environment rich in $CO_2$). Geothermal energy has already been used successfully to provide the heat needed to grow Spirulina throughout the year in temperate countries.

### *6.3.5. Industrial applications*

The entire temperature range of geothermal fluids, whether steam or water, can be exploited in *industrial applications*, as shown in the Lindal diagram (Figure 6.1.1). The different possible forms of utilization include:

- Drying- the most common operation
- Process heating–preheating of boiler water etc.
- Evaporation–extraction of salt
- Distillation–liquor and hydrocarbon industry
- Washing–food industry
- Chemical extraction–gold separation from ores
- Pasteurization of milk
- de-icing
- Refrigeration–absorption freezing (lithium-bromide and ammonia).

Industrial process heat has applications in 19 countries (Lund and Freeston, 2001), where the installations tend to be large and energy consumption high. Examples also include concrete curing, bottling of water and carbonated drinks, paper and vehicle parts production, oil recovery, milk pasteurization, leather industry, chemical extraction, $CO_2$ extraction, laundry use, diatomaceous earth drying, pulp and paper processing, and borate and boric acid production. There are also plans to utilize low-temperature geothermal fluids to deice runaways and disperse fog in some airports. A cottage industry has developed in Japan that utilizes the bleaching properties of the $H_2S$ in geothermal waters to produce innovative and much admired textiles for ladies' clothing. In Japan, also experiments have been performed on a technique for manufacturing a lightweight “geothermal wood” that is particularly suited to certain types of constructions. During treatment in the hot spring water the polysaccharides in the original wood hydrolyze, rendering the material more porous and thus lighter.

Several reports have been written in the past to identify sectors where geothermal heat could play a role. Such studies have been made by Lindal (1993), Reistad (1975), Howard (1975 and Lienau (1991).

| | |
|---|---|
| 180°C | Evaporation of highly concentrated solutions, Refrigeration by ammonia absorption Digestion in paper pulp (Kraft) |
| 170°C | Heavy water via hydrogen sulfide process. Drying of diatomaceous earth. |
| 160°C | Drying of fish meal. Drying of timber. |
| 150°C | Alumina via Bayer's process. |
| 140°C | Drying farm products at high rates. Food canning. |
| 130°C | Evaporation in sugar refining. Extraction of salts by evaporation and crystallization. Fresh water by distillation. |
| 120°C | Most multi-effect evaporation. Concentration of saline solution. |
| 110°C | Drying and curing of light aggregate cement slabs. |
| 100°C | Drying of organic materials. Seaweed, grass, vegetables etc.Washing and drying of wool. |
| 90°C | Drying of stock fish. Intense de-icing operations. |
| 80°C | Space-heating (buildings and greenhouses). |
| 70°C | Refrigeration(lower temperature limit) |
| 60°C | Animal husbandry. Greenhouses by combined space and hotbed heating |
| 50°C | Mushroom growing. Balneology. |
| 40°C | Soil warming Swimming pools, biodegradation. Fermentations. |
| 30°C | Warm water for year-round mining in cold climates. De-icing. Fish hatching. |
| 20°C | Fish farming. |

### *6.3.5.1. Industrial drying and dehydration*

The reason is that the cost of oil or electricity for heating of the drying air during the drying process is considerably higher than the cost of hot water or geothermal steam. It is, therefore, more cost-efficient to locate the processing near inexpensive hot water and steam sources and collect the raw material and transfer it to the processing plant.

- Agricultural crops
  - Vegetables, fruits, grain, coffee, tea leaves, onion and garlic
- Pulp, paper and wood processing plant in New Zealand
- A diatomite plant in Iceland
- Fish products
- Drying of wood

*Batch – tunnel dryer***.** Vegetable and fruit dehydration involves the use of a tunnel dryer, or a continuous conveyor dryer using fairly low temperature hot air from 38 to 105°C, the cabinets most frequently consisting of two tunnels with a pyramid in the center. The pyramid can be moved in such a way that if the cabinet is only half fulls all the airflow is directed through one tunnel. Air-valves are inserted in the inlets and recycling outlets, but the regulation of the valves is controlled by the air humidity, measured at the opening of the cabinet. A regulating valve on the hot water inlet, connected to a thermometer, which is located at the same place as the humidity sensor, controls the temperature in the drying cabinet (Figure 6.3.34).

A tunnel dryer is an enclosed, insulated housing in which the products to be dried are placed upon tiers of trays or stacked in piles in the case of large objects. Heat transfer may be direct from gases to products by circulation of large volumes of gas, or indirect by use of heated shelves or radiator coils.

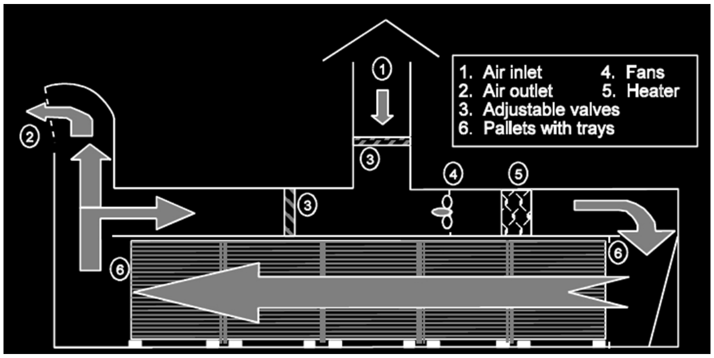

Fig.6.3.34 The construction of the rack drying cabinet

Because of the high labor requirements usually associated with loading or unloading the compartments, they are rarely used except in the following cases:

1. A long heating cycle is necessary because of the size of the solid objects or permissible heating temperature requires a long hold-up for internal diffusion of heat or moisture.
2. The quantity of material to be processed does not justify investment in more expensive, continuous equipment. This would be the situation for a pilot plant.

In addition to the heating requirements, electrical energy is needed for the draft and recirculation fans and small amounts for controls and driving the bed motors.

Using a 7°C minimum approach temperature between the geothermal fluid and process air, a well with 110°C fluid is required. The first-stage air temperature can be as low as 82°C; however, temperatures >93°C are desirable.

*Continuous - Conveyor Belt Dryer*. Drying and dehydration are important moderate-temperature uses of geothermal energy. Various vegetable and fruit products are feasible with continuous belt conveyors or batch (truck) dryers with air temperatures from 40° to 100°C (Lund and Rangel 1995). Geothermal drying alfalfa, onions, garlic, pears, apples and seaweed are examples of this type of direct use.

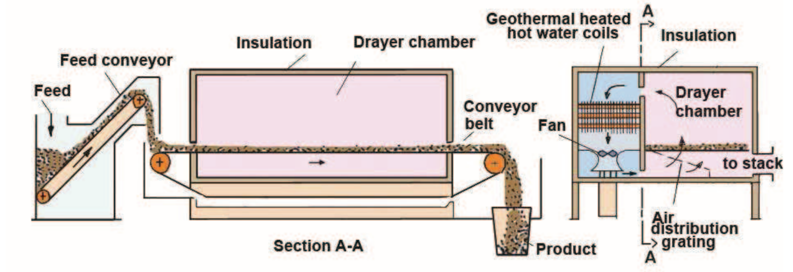

Fig.6.3.35 Continuous belt dehydration plant, schematic

Three conveyor-belt dryers are in use in Iceland. They are located with the company Saesteinn and Thorungavinnslan. One of the conveyor belt dryers is used for primary drying of cod-heads and small fish, such as capelin and blue whiting, and the other one is used to dry seaweed and kelp. Initially, the wet raw material is placed on the top belt and then the belt is left idle for about 3 hours. After that, the product is moved down to the next belt and at the same time the first belt is refilled, etc. The two lowest belts are driven at half the speed of the three top ones so that the product stays for six hours on each belt. The raw material is therefore 20-24 hours in the cabinet and has then been reduced to about 60% of its original weight. The temperature in the cabinet is about 25$^{o}$C and the air velocity is about 2 m/s.

An example of a small-scale food dehydrator is one located in northeastern Greece where four tones of tomatoes are dried annually, using 59$^{o}$C geothermal water to dry 14 kg/hour on racks placed in a long tunnel drier.

At the other end of the spectrum is the large scale onion and garlic drying facilities located in western Nevada, USA employing 75 workers (Lund and Lienau, 1994). These continuous belt drier are fed 3,000 to 4,300 kg/hr of onions at a moisture content of around 85% and after 24 hours produce 500 to 700 kg/hr of dried onions at moisture contents around 4%. These large belt driers are approximately 3.8 m wide and 60 m long. Figure 8 is a simplified sketch of a continuous belt dryer.

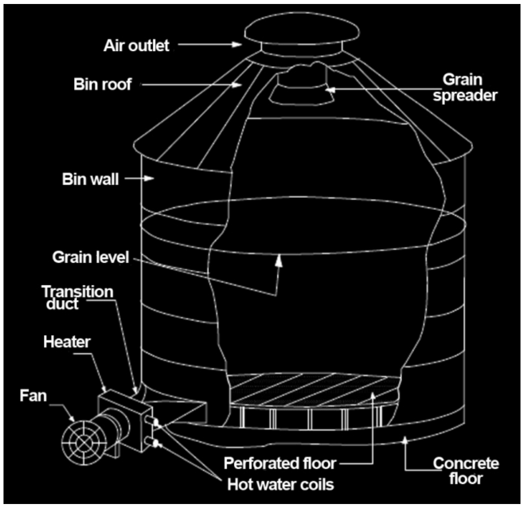

Fig.6.3.36 Perforated false floor system for bin drying of grain [32]

*Grain drying*. Significant amounts of energy are consumed annually for grain drying and barley malting. These processes can be easily adapted to geothermal energy in the temperature range of 38 to 82$^{o}$C. Most farm crops must be dried to, and maintained at, a moisture content of 12 to 13% wet basis, depending on the specific crop, storage temperature, and length of storage. Mold growth and spoilage are functions of elapsed storage time, temperature, and moisture content above the critical value. Grain to be sold through commercial markets is priced according to specified moisture content, with discounts for moisture levels above a specified value.

The grain dryer is typically a deep bed dryer, as shown in Figure 6.3.36. Most crop-drying equipment consists of: fan to move the air through the product, controlled heater to increase the ambient air temperature to the desired level, and a container to distribute the drying air uniformly through the product. The exhaust air is vented to the atmosphere.

Several operating methods for drying grain in storage bins are in use. They may be classified as full-bin drying, layer drying, and batch drying. The deep bed dryer can be installed in any structure that will hold grain. Most grain storage structures can be designed or adapted for drying by providing a means of distributing the drying air uniformly through the grain. This is most commonly done by either a perforated false floor or duct systems placed on the floor of the bin.

Full-bin drying is generally done with unheated air or air heated 10 to 20°C above ambient. A humidistat is frequently used to sense the humidity of the drying air and turn off the heater if the weather conditions are such that heated air would cause over drying.

The depth of grain (distance of air travel) is limited only by the cost of the fan, motor, air distribution system, and power required. The maximum practical depth appears to be 6 m for corn and beans, and 4 m for wheat. Grain stirring devices are used with full-bin systems. These devices typically consist of one or more open, 5 cm diameter, standard pitch augers suspended from the bin roof and side wall and extending to near the bin floor.

Conversion of the deep bed dryer to geothermal energy is accomplished by simply installing a hot water coil in the inlet duct using geothermal fluid in the 38 to 49°C temperature range.

Traditionally, grains and beans drying have been done by heating the products under sunshine (solar drying). The products will be influenced by seasonal and weather changes, thus making the drying process un-continuous. This will result in cracking, fracturing, and imperfect drying products.

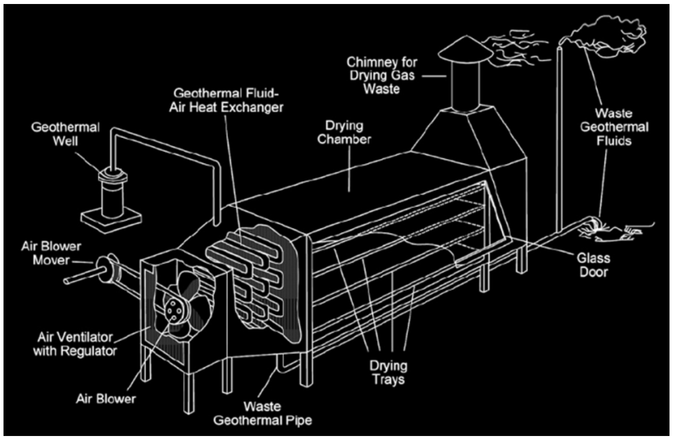

Fig.6.3.37 *3D* view design of the geothermal batch dryer for drying grains and beams

To improve the process, drying has to be done continuously, requiring continuous heat supply. This can be reached by using continuous energy resource supply such as geothermal fluid flows.

*Equipment Design.* The dryer used in this research will be made of a fluid-air heat exchanger to produce hot air that will be blown into a drying room filled with trays of grains or beans. Figures 6.3.37 show the design of the equipment. The waste geothermal fluid is flowed into a bank of steel pipes, and air is blown outside the pipes to extract heat from geothermal fluids inside the tubes for the drying process.

The equipment does not use a drying belt to save energy for moving the belt. Instead, the beans and grains are placed on trays in the drying room. The only moving part is an air blower that can be designed to move by geothermal energy (pressure), while its heat content is used for the heat exchanger. The air blower is placed on one side of the heat exchanger while the drying room is on the other side.

The drying duration depends on the original humidity of the products. By doing several drying experiments, an ideal drying time can be found for which the product is perfectly dried. The dryer is designed as simple to assist the technical feasibility of geothermal energy direct utilization. If the drying is proven to be feasible, then the technology and design can be improved while the scale can be increased to meet a commercial project.

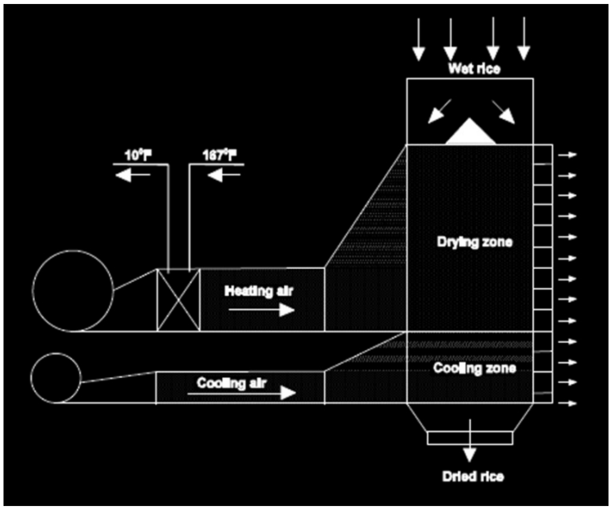

Fig.6.3.38 A schematic flow diagram of the geothermal rice drying plant in Kotchany, Macedonia (Popovski et al., 1992)

Of all grains, rice is probably the most difficult to process without quality loss. Rice containing more than 13.5% moisture cannot be safely stored for long periods. When harvested at a moisture content of 20 to 26%, drying must be started promptly to prevent the rice from souring. Deep-bed or columnar dryers could be used; a columnar dryer will be considered.

The two important variables in the drying operation are the air-mass flow rate and the temperature at the inlet to the dryer. Hot air is blown from the bottom and a static pressure is maintained between columns. Air temperature is controlled by regulating the burner output from several thermocouples installed inside the column to monitor the air and kernel temperature.

Rice is loaded in the dryer at approximately 21 to 22% moisture content and the drying cycle is normally completed after three to four passes. The final moisture content should be below 15% before it can be safely stored in the warehouse. After each pass, partially dried rice is stored in tempering bins for at least 12 h before another pass takes place. The rice is tempered to equalize internal moisture content, thus minimizing thermal stresses and avoiding breakage of kernels. Kernel temperature is normally maintained at 38°C when the moisture content is approximately 21% and at lower moisture content, <17%, temperature is limited to 35°C. At a constant grain temperature of 37,8°C, air is heated to 82 to 93,3°C during cold weather and approximately 60 to 82°C during the warm season.

Converting the columnar dryer to geothermal fluids involves the installation of a hot water coil upstream of the blower fan to obtain uniform temperature inside the plenum chamber. The air flow pattern and there is no air recirculation because of the presence of dust on the downstream side.

Air flow could be maintained at a constant rate; then the only variable would be the flow rate of the grain.

A rice drying facility has been installed at Kotchany in Macedonia using 78°C geothermal water at 1.3 gpm (Figure 6.3.38). The Unit has a capacity of 8 tons/hr (Popovski, et al., 1992).

*Drying Lumber.* A process flow diagram for a typical lumber mill is shown in Figure 6.3.39. In small lumber mills where drying kilns are heated by steam from conventional oil fired boilers, substitution of geothermal energy for the heating energy source can achieve substantial energy cost savings. In larger, well integrated mills, all energy from operations can be provided by burning sawdust and other wood waste products.

The sap sets at 57 to 60°C. Warping is prevented by establishing uniform moisture content throughout the thickness. Lumber left to dry under ambient conditions loses its moisture from exposed surfaces at a faster rate than internally. This differential drying rate sets up stresses that cause the warping. Moisture occurs in wood in cell cavities and in the cell walls. The majority of the moisture is first lost from the cavities. This loss is not accompanied by changes in the size of the cell or in war page. When water is lost from the cell walls, however, shrinkage of the wall fibers takes place setting up the stresses that cause warping.

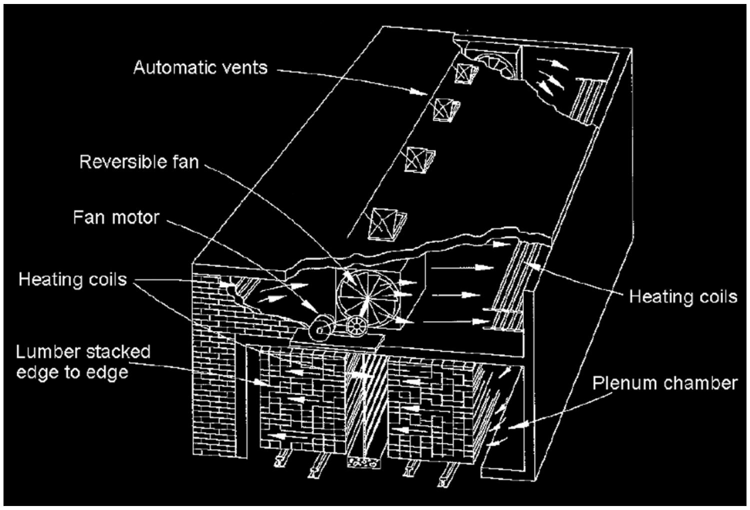

Fig.6.3.39 Long shaft double-track compartment kiln with alternately opposing internal fans [32]

In the kiln drying process, the evaporation rate must be carefully controlled to prevent these stresses. The allowable drying rates vary from species to species and decrease with thicker cut sizes. Kiln drying is usually carried out as a batch process. The kiln is a box-shaped room with loading doors at one end. It has insulated walls and ceiling and has fans to re-circulate the air at high velocity through the lumber. The sawed lumber is spaced and stacked to assist the free air movement and is loaded by large forklifts or other specialized lumber handling trucks into the kiln. When fully loaded, the doors are closed and the heating cycle is started. Make up air, preheated to a temperature consistent with the drying schedule, enters the kiln where it recalculates through the stacked lumber and picks up moisture. Exhaust fans draw the moist air from the kiln and discharge it to the atmosphere. The exhaust is primarily air and water. The rates of flow and temperature are adjusted so that the temperature and the humidity in the kiln will retard the drying rate sufficiently to prevent warping. During the drying cycle, the lumber loses a large portion of its weight from evaporation of water, 50 to 60% for many species.

Figure 6.3.39 shows a typical lumber drying kiln. The vents are over the fan shaft between the fans. The vent on the high pressure side of the fan becomes a fresh air inlet when the direction of circulation is reversed.

Drying schedules are specific for each species of lumber and for size. The larger the size the more tightly the moisture is held in the wood fiber, and slower the schedule. Drying schedules range from less than 24 h to several weeks per batch.

Geothermal energy could be adapted to kiln drying by passing air over finned heat exchanger tubes carrying hot water. The finned tube heat exchanger could be placed inside existing kilns so that the air recirculation route would include a pass over the heat exchangers. The water temperature must be at least 7 to 14$^{o}$C above the ambient operating temperature in the kiln. This would mean a geothermal supply temperature of 93 to 115$^{o}$C would be required. Where geothermal fluid of insufficient temperature is available (<82$^{o}$C for most uses), energy supplies could be supplemented by conventional heating systems during the final high temperature portions of the drying schedules.

### *6.3.5.2. Dairy processing*

Milk starts to go bad within hours once expressed from the cow. It is, therefore, important to begin processing it as soon as possible in order to preserve it longer. Processed milk can be preserved for days or even months depending on the kind of treatment it has been subjected to. The major methods of treatment are chilling, heat treatment and evaporation (Bylund, 1995). It is clear that these are all thermal processes that entail the removal or addition of heat.

*Chilling.*Chilling is the initial treatment of milk prior to further processing. The temperature of milk is reduced to 2-4°C so as to slow down the action of microorganisms and enzymes which are responsible for spoilage. In addition, after processing the milk should be cooled again before packaging to secure a longer shelf life. Ice water is used to provide cooling in storage silos and in the cooling section of the pasteurizer.

*Thermal treatment.* Thermal treatment involves heating every particle of milk or a milk product to a specific temperature for a specific period of time without allowing recontamination during the heat treatment process. This thermal treatment of milk is done for two major reasons. Firstly, it should achieve total destruction of all pathogenic microorganisms which could cause diseases in people. Secondly, a significant reduction in the quantity of spoilage enzymes and microorganisms in the milk should be achieved in order to improve the shelf life of the milk from a day or two up to about two weeks (DST, 1999).

In order to meet its objectives without destroying the natural chemical and physical properties of milk as well as the nutrients, a suitable time-temperature combination for heat treatment should be determined. The combination is determined by the concentration of microorganisms to be destroyed, the acceptable concentration of microorganisms that can remain behind after thermal treatment and the thermal resistance of the target microorganisms. This combination is based on the thermal death time of *Coxelliae burnettii*, which is the most heat resistant pathogen found in milk (Bylund, 1995).

Some of the most common thermal treatment techniques are shown in Table 6.3.2 together with their required time-temperature combinations. Pasteurization is the most common of these techniques and can either be low temperature long time (LTLT) or high temperature short time (HTST).

TABLE 6.3.2: The main categories of heat treatment in dairy processing (Bylund, 1995)

| Process | Tempera-ture (°C) | Time (s) |
|---|---|---|
| Thermisation | 63-65 | 15 |
| LTLT pasteurisation of milk | 63 | 1800 |
| HTST pasteurisation of milk | 72-75 | 15-20 |
| HTST pasteurisation of cream | >80 | 1-5 |
| Ultra pasteurisation | 125-138 | 2-4 |
| UHT (flow sterilisation) | 135-140 | 1-3 |
| Sterilisation in container | 115-120 | 1200-1800 |

*Energy demands.* The growth of industries the world over has relied heavily on the availability of energy to drive the mechanical, electrical and thermal processes. The energy demand varies from one industry to another with the smelting industries leading with the highest demand.

The energy demand in dairy processing is mainly for heating water which is used in the pasteurization and cleaning of equipment. Other operations that require energy are running the machinery, refrigeration of the milk before and after processing to control spoilage, and evaporation in order to obtain milk powder. Table 6.3.2 shows the energy consumption in a typical modern dairy.

### *6.3.5.3. 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 decrease 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.

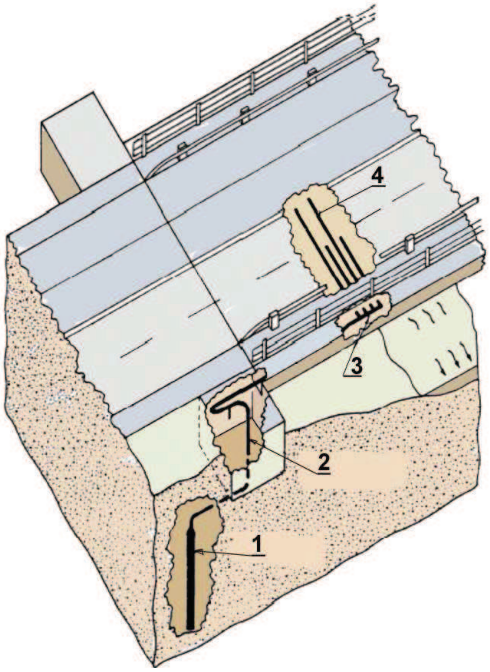

Fig.6.3.40 Geothermal heating of roads and pavements (Lund, 1986)

Fig.6.3.41 A pavement in Klamath Fall with snow melting installation

Most commonly, it is done with a glycol solution, hot water or steam being circulated in pipes within or below the pavement (Fig. 6.3.40), 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.6.3.41) are that they eliminate the need for snow removal, provide greater safety for pedestrians and vehicles, and reduce the labor of slush removal.

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.6.3.40 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 cathode protection. The use of salts for deicing and the elevated temperature accelerate corrosion of these materials. The corrosion rate approximately doubles for each 10°C 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 135°C 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 0°C;
- Deck surface sensor indicates wet deck and surface temperature is below 0°C.

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 5°C.

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.