IV

DEVELOPMENT OF DIRECT-USE PROJECTS

John W. Lund[6]

INTRODUCTION

A geothermal direct use project utilizes a natural resource – a flow of geothermal fluid at elevated temperatures, which is capable of providing heat and/or cooling to buildings, greenhouses, aquaculture ponds and industrial process (Lienau, 1998). Geothermal utilization requires a unique blending of skills to located and access a resource, and to concurrently match the varied needs of the user in order to develop a successful project. Each resource development projects is unique, and the flow chart (Figure 1.) of typical activities can serve as a guideline of logical steps to implement a project. The development of a project should be approached in phases so as to minimize risk and costs. The size of the project determines the amount of exploration and development of the resource that can be economically justified. For heating a single home the risk is high, as outside of gathering data on adjacent hot springs, wells and use, the well becomes the exploration tool and hopefully provides the necessary energy to the project. Larger projects, such as district heating and industrial applications can justified more investigation to better characterize the resource and thus reduce the risk.

The first phase generally involves securing rights to the resource. This includes information on ownership, leasing, agencies involved, water rights, injection requirements, competition with adjacent geothermal users, and any potential royalty payments. The second phase involves interdisciplinary activities of geology, geochemistry, geophysics, drilling and reservoir engineering. These exploration activities are usually expensive and often the economics of a direct-use activity will not support an extensive program. However, a minimum exploration and resource characteristics that are necessary would include depth to the resource, temperature, flow-rate, drawdown and chemistry of the fluid to provide information to determine if a project is feasible and will meet the needs of the proposed activity.

The preliminary and conceptual design of a direct-use project could start during the reservoir testing and evaluation, however, depending on the risk and financing issues, the phase may have to wait until the reservoir characteristics are confirmed. During the design phase special consideration must be given to the design and selection of equipment such as well pumps, piping, heat exchangers and space heating equipment. The cost of all these pieces of equipment must be considered, along with potential corrosion and scaling problem, to make the project viable.

1. SELECTING THE POTENTIAL USE OF THE RESOURCE

One of the frequently asked questions that we at the Geo-Heat Center get is "I have this resource, what can I do with it." The answer has many parts to it: (1) what is the estimated (or known) temperature and flow rate of the resource, (2) what is the chemistry of the resource, (3) what potential markets do you have for the energy, and what would be the expected income, (4) do you have the experience, or are you willing to hire experienced people to run the project, (5) do you have financing and is the estimated net income enough to justify the investment, and (6) do you own or can you lease the property and the resource, and are there limitation on its use.

[6] Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon, USA 97601

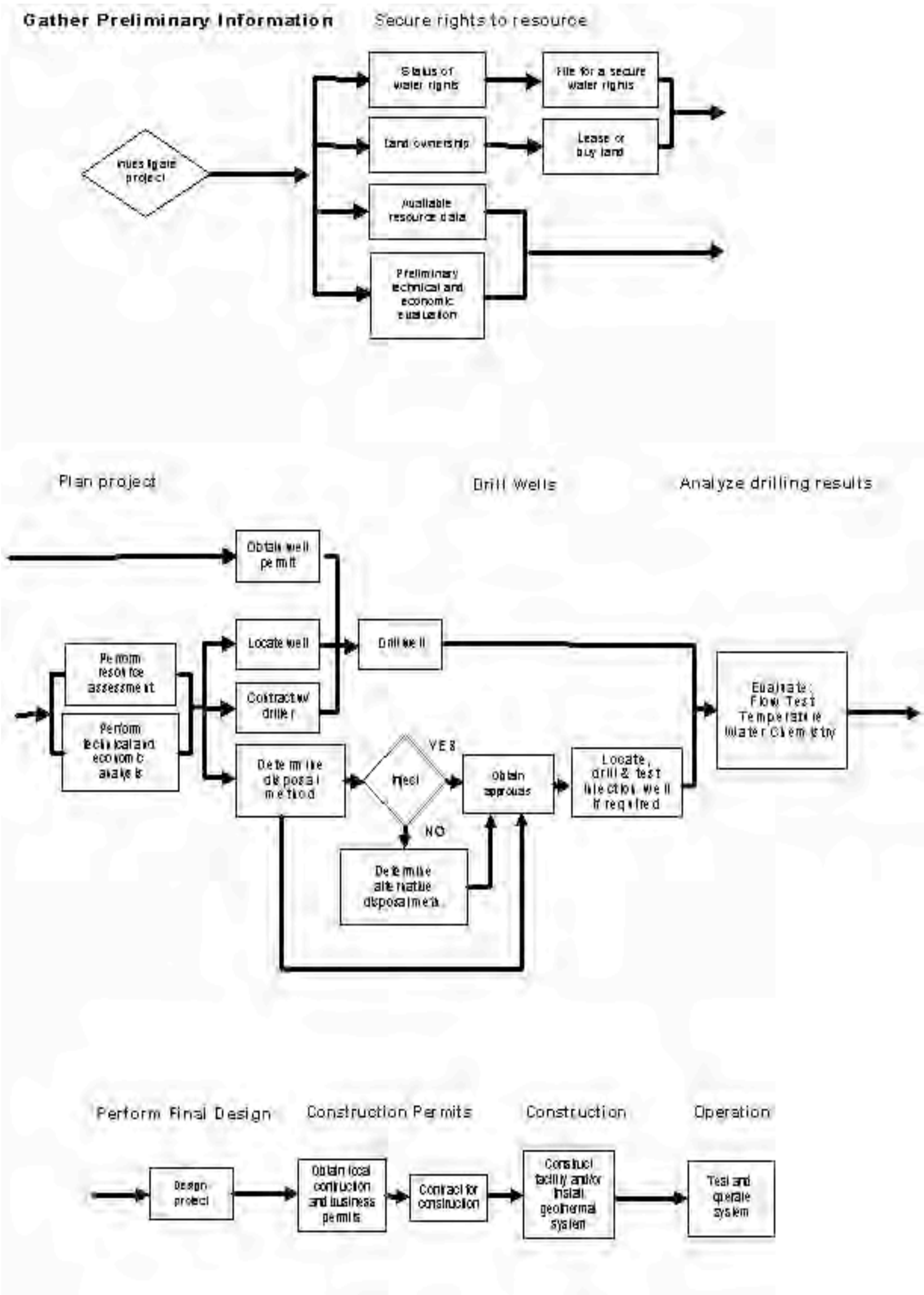


Figure 1. Direct-use development flow chart

Figures 2 and 3. are examples of charts that can be used to match resource temperature with potential uses, and can be used to narrow the choices. A brief discussion of some of the more common uses is presented below.

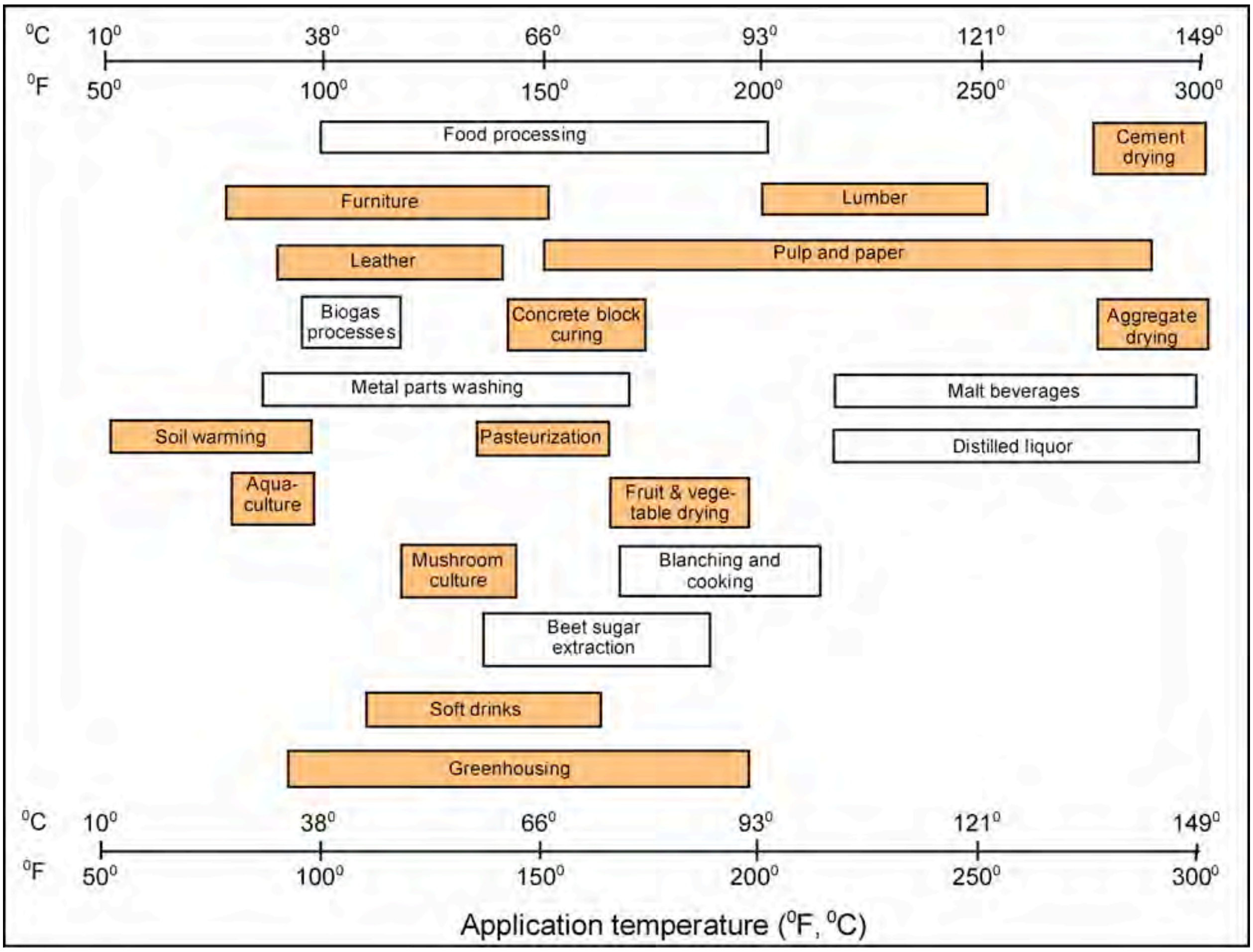


Figure 2. Examples of industrial applications of geothermal energy, with the colored bars indicating those currently using geothermal energy in the world.

1.1. Spas and Pools

People have used geothermal water and mineral waters for bathing and their health for many thousand of years. Balneology, the practice of using natural mineral water for the treatment and cure of disease, also has a long history. A spa originates at a location mainly due to the water from a spring or well. The water, with certain mineral constituents and often warm, give the spa certain unique characteristics that will attract customers. Associated with most spas is the use of muds (peoloids) which either is found at the site or is imported from special locations. Drinking and bathing in the water, and using the muds are thought to give certain health benefits to the user. Swimming pools have desirable temperature at 27°C, however, this will vary from culture to culture by as much as 5°C. If the geothermal water is higher in temperature, then some sort of mixing or cooling by aeration or in a holding pond is required to lower the temperature, or it can first be used for space heating, and then cascaded into the pool. If the geothermal water is used directly in the pool, then a flow through process is necessary to replace the "used" water on a regular basis. In many cases, the pool water must be treated with chlorine, thus, it is more economical to use a closed loop for the treated water and have the geothermal water provide heat through a heat exchanger (Lund, 2000).

1.2. Space and District Heating

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 district heating and space heating systems, is that space heating usually involves one geothermal well per structure. 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, generally above 1.2 GJ/hr/ha or a favorability ratio of 2.5 GJ/ha/yr 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 (Bloomquist, et al. 1987). Geothermal district heating systems are capital intensive, The principal costs are initial investment costs for production and injection wells, downhole

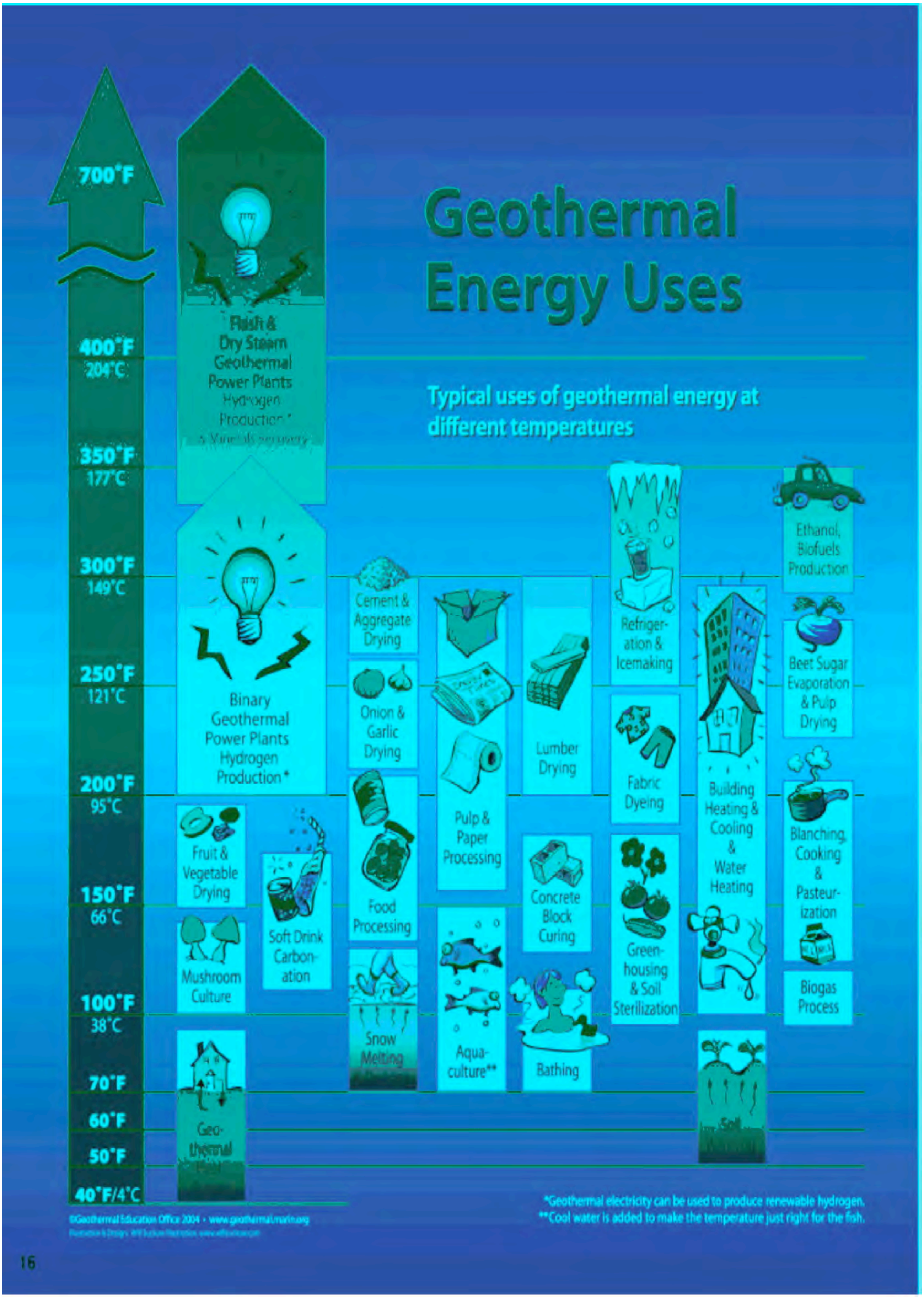


Figure 3. Various geothermal uses, including power generation and direct-use related to their appropriate temperature range (courtesy of Geothermal Education Office).

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 (Lienau, 1998).

1.3. Greenhouses

A number of commercial crops can be raised in greenhouses, making geothermal resources in cold climates particularly attractive. Crops include vegetables, flowers (potted and cut), house plants, and tree seedlings. Greenhouse heating can be accomplished be several methods: finned pipe, unit heater and fan coil units delivering heat though plastic tubes in the ceiling or under benches, radiant floor systems, bare tubing, and a combination of these methods. The use of geothermal energy for heating can reduce operating costs and allow operation in colder climates where commercial greenhouses would not normally be economical. Economics of a geothermal greenhouse operation depends on many variables, such as type of crop, climate, resource temperature, type of structure, market, etc. Peak heating requirements in temperate climate zone are around 1.0 MJ/sq. m, and a 2.0 ha facility would require 10 GJ/yr (2.8 MWt) of installed capacity). With a load factor of 0.50, the annual energy consumption would be around 88 TJ/yr (25 kWh/yr).

1.4. Aquaculture

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species raised are aquatic animals such as catfish, bass, tilapia, sturgeon, shrimp, and tropical fish. The application temperature in fish farming depends on the species involved, ranging from 13 to 30°C, and the geothermal water can be used in raceways, ponds and tanks. The benefit of a controlled rearing temperature in aquaculture operations can increase growth rated by 50 to 100%, and thus, increasing the number of harvest per year. A typical outdoor pond in a temperature climate zone would require 2.5 MJ/hr/sq. m, and a 2.0 ha facility would require an installed capacity of 50 GJ/yr (14 MWt). With a load factor of 0.60, the annual heating requirement would be 260 TJ/yr (73 million kWh/yr). Water quality and disease control are important in fish farming and thus, need to be considered when using geothermal fluids directly in the ponds.

1.5. Industrial

Industrial applications mostly need the higher temperature as compared to space heating, greenhouses and aquaculture projects. Examples of industrial operations that use geothermal energy are: heap leaching operations to extract precious metals in the USA (110°C), dehydration of vegetables in the USA (130°C), diatomaceous earth drying in Iceland (180°C), and pulp and paper processing in New Zealand (205°C). Drying and dehydration may be the two most important process uses of geothermal energy. A variety of vegetable and fruit products can be considered for dehydration at geothermal temperatures, such as onions, garlic, carrots, pears, apples and dates. Industrial processes also make more efficient use of the geothermal resources as they tend to have high load factors in the range of 0.4 to 0.7. High load factors reduce the cost per unit of energy used as indicated in Figure 4.

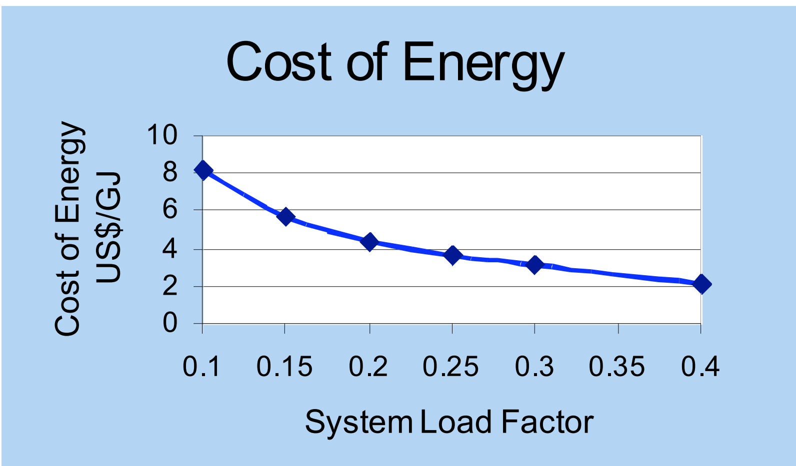


Figure 4. Load factor vs. cost of energy (Rafferty, 2003).

2. SELECTING THE EQUIPMENT

It is often necessary to isolate the geothermal fluid from the user side to prevent corrosion and scaling. 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 5, and includes, downhole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up plants (usually fossil fuel fired) to reduce the use of geothermal fluids and reduce the number of wells required, and fluid disposal systems (injection wells). Geothermal energy can usually meet 80 to 90% of the annual heating or cooling demand, yet only sized for 50% of the peak load.

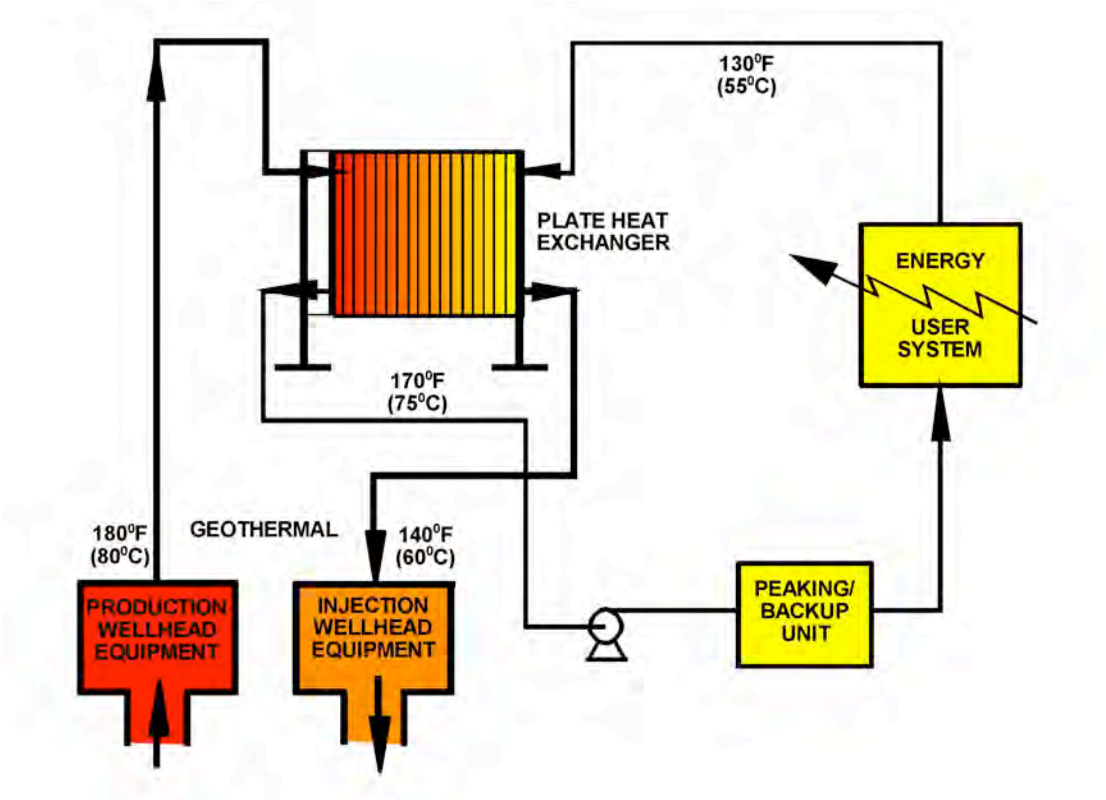


Figure 5. Typical direct use geothermal heating system configuration.

2.1. Downhole Pumps

Unless the well is artesian, downhole pumps are needed, especially in large-scale direct utilization system. Downhole pumps may be installed not only to lift fluid to the surface, but also to prevent the release of gas and the resultant scale formation. The two most common types are: line shaft pump systems and submersible pump systems. The line shaft pump system consists of a multi-stage downhole centrifugal pump, a surface mounted motor and a long driveshaft assembly extending from the motor to the pump bowls. Most are enclosed, with the shaft rotating within a lubrication column which is centered in the production tubing. This assembly allows the bearings to be lubricated by oil, as hot water may not provide adequate lubrication. A variable-speed (frequency) drive set just below the motor on the surface, can be used to regulate flow instead of just turning the pump on and off. The electric submersible pump system consists of a multi-stage downhole centrifugal pump, a downhole motor, a seal section (also called a protector) between the pump and motor, and electric cable extending from the motor to the surface electricity supply. Both types of downhole pumps have been used for many years for cold water pumping and more recently in geothermal wells (line shafts have been used on the Oregon Institute of

Technology campus in 89°C water for 55 years). If a line shaft pump is used, special allowances must be made for the thermal expansion of various components and for oil lubrication of the bearings. The line shaft pumps are preferred over the submersible pump in conventional geothermal applications for two main reasons: the line shaft pump cost less, and it has a proven track record. However, for setting depths exceeding about 250 m, a submersible pump is required.

2.2. Piping

The fluid state in transmission lines of direct-use projects can be liquid water, steam vapor or a two-phase mixture. These pipelines carry fluids from the wellhead to either a site of application, or a steam-water separator. Thermal expansion of metallic pipelines heated rapidly from ambient to geothermal fluid temperatures (which could vary from 50 to 200^{o}C) causes stress that must be accommodated by careful engineering design. The cost of transmission lines and the distribution networks in direct-use projects is significant. This is especially true when the geothermal resource is located at great distance from the main load center; however, transmission distances of up to 60 km have proven economical for hot water (i.e., the Akranes project in Iceland–Ragnarsson and Hrolfsson, 1998), where asbestos cement covered with earth has been successful. Carbon steel is now the most widely used material for geothermal transmission lines and distribution networks; especially if the fluid temperature is over 100^{o}C. Other common types of piping material are fiberglass reinforced plastic (FRP) and asbestos cement (AC). The latter material, used widely in the past, cannot be used in many systems today due to environmental concerns; thus, it is no longer available in many locations. Polyvinyl chloride (PVC) piping is often used for the distribution network, and for uninsulated waste disposal lines where temperatures are well below 100^{o}C. Cross-linked polyethylene pipe (PEX) have become popular in recent years as they can tolerate temperatures up to 100^{o}C and still take pressures up to 550 kPa. However, PEX pipe is currently only available in sizes less than 5 cm in diameter. Conventional steel piping requires expansion provisions, either bellows arrangements or by loops. A typical piping installation would have fixed points and expansion points about every 100 m. In addition, the piping would have to be placed on rollers or slip plates between points. When hot water metallic pipelines are buried, they can be subjected to external corrosion from groundwater and electrolysis. They must be protected by coatings and wrappings. Concrete tunnels or trenches have been used to protect steel pipes in many geothermal district heating systems. Although expensive (generally over U.S.$300 per meter of length), tunnels and trenches have the advantage of easing future expansion, providing access for maintenance and a corridor for other utilities such as domestic water, waste water, electrical cables, phone lines, etc.

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

The quantity of thermal insulation of transmission lines and distribution networks will depend on many factors. In addition to minimize the heat loss of the fluid, the insulation must be waterproof and water tight. Moisture can destroy the value of any thermal insulation, and cause rapid external corrosion. Aboveground and overhead pipeline installations can be considered in special cases. Considerable insulation is achieved by burying hot water pipelines. For example, burying bare steel pipe results in a reduction in heat loss of about one-third as compared to above ground in still air. If the soil around the buried pipe can be kept dry, then the insulation value can be retained. Carbon steel piping can be insulated with polyurethane foam, rock wool or fiberglass. Below ground, such pipes should be protected with polyvinyl chloride (PVC) jacket; aboveground, aluminum can be used. Generally, 2.5 to 10 cm of insulation is adequate. In two-pipe systems, the supply and return lines are usually insulated; whereas, in single-pipe systems, only the supply line is insulated. At flowing conditions, the temperature loss in insulated pipelines is in the range of 0.1 to 1.0^{o}C/km, and in uninsulated lines, the loss is 2 to 5^{o}C/km (in the approximate range of 5 to 15 L/s flow for 15-cm diameter pipe) (Ryan 1981). It is less for larger diameter pipes. For example, less than 2^{o}C loss is experienced in the new aboveground 29 km long and 80 and 90 cm diameter line (with 10 cm of rock wool insulation) from Nesjavellir to Reykjavik in Iceland. The flow rate is around 560 L/s and takes seven hours to cover the distance. Uninsulated pipe costs about half of insulated pipe, and thus, is used where temperature loss is not critical. Pipe material does not have a significant effect on heat loss; however, the flow rate does. At low flow rates (off peak), the heat loss is higher than as greater flows. Figure 6 shows fluid temperatures, as a function of distance, in a 45-cm diameter pipeline, insulated with 50 cm of urethane foam.

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

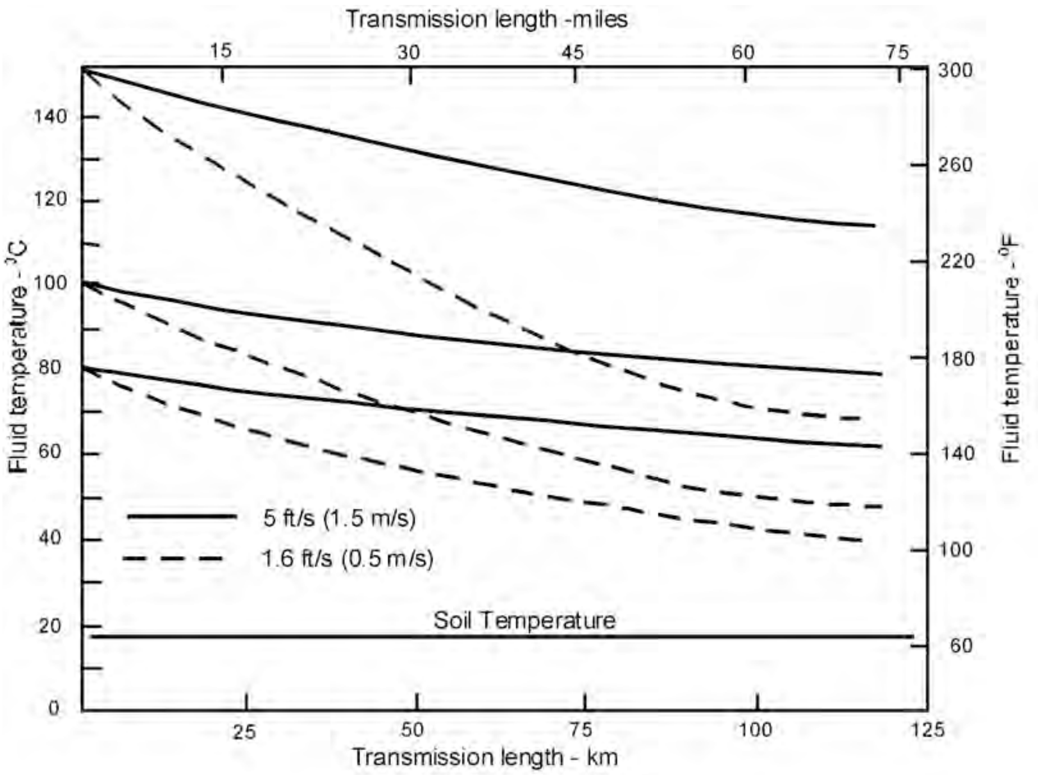


Figure 6. Temperature drop in hot water transmission line.

2.3. Heat Exchangers

The principal heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods. The counter-current flow and high turbulence achieved in plate heat exchangers, provide for efficient thermal exchange in a small volume. In addition, they have the advantage when compared to shell-and-tube exchangers, of occupying less space, can easily be expanded when addition load is added, and cost 40% less. The plates are usually made of stainless steel; although, titanium is used when the fluids are especially corrosive. Plate heat exchangers are commonly used in geothermal heating situations worldwide. Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (difference between incoming and outgoing fluid temperature), and the larger size. Downhole heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads such as the heating of individual homes, a small apartment house or business. The exchanger consists of a system of pipes or tubes suspended in the well through which secondary water is pumped or allowed to circulate by natural convection. In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and casing, and perforations above and below the heat exchanger surface. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing through the upper perforations (Culver and Lund, 1999). The use of a separate pipe or promoter, has proven successful in older wells in New Zealand to increase the vertical circulation (Dunstall and Freeston 1990).

2.4. Convectors

Heating of individual rooms and buildings is achieved by passing geothermal water (or a heated secondary fluid) through heat convectors (or emitters) located in each room. The method is similar to that used in conventional space heating systems. Three major types of heat convectors are used for space heating: 1) forced air, 2) natural air flow using hot water or finned tube radiators, and 3) radiant panels. All these can be adapted directly to geothermal energy or converted by retrofitting existing systems

3. DIRECT-USE TEMPERATURE REQUIREMENTS

The design of mechanical systems involving heat transfer, such as direct-use geothermal systems, is heavily influenced by temperature. Temperature difference (delta T or ΔT) is particularly important as it frequently governs feasibility, equipment selection and flow requirements for the system. Rafferty (2004) addresses these issues with several "rules of thumb" that are described below. He introduces the material with the following discussion:

Two primary temperature differences govern feasibility, flow requirements and design of direct-use equipment. These are illustrated in a simplified way in Figure 7. The first is the difference between the geothermal temperature entering the system (Tge) and the process temperature (Tp). This difference determines whether of not the application will be feasible. For a direct-use project, the temperature of the geothermal entering the system must be above the temperature of the process in order to transfer heat out of the geothermal water and into the process (aquaculture pond, building, greenhouse, etc). Beyond that, it must be sufficiently above the process to allow the system to be constructed with reasonably sized heat transfer equipment. The greater the temperature difference between the geothermal resource and the process, the lower the cost of heat exchange equipment. The key question is how much above the process temperature does the geothermal need to be for a given application.

The second temperature difference is the one between the geothermal entering the system and leaving the system (Tgo in Figure 7). This determines the geothermal flow rate necessary to meet the heat input requirement of the application. The greater the temperature difference between the entering and leaving temperatures, the lower the geothermal flow required. Obviously, the resource temperature is fixed. The process temperature plays a role as well since the leaving geothermal temperature cannot be lower than the process temperature to which it is providing heat. In addition, the specifics of the application and the heat transfer equipment associated with it also influence the temperature required. There are two broad groups of applications with similar characteristics in terms of heat transfer–aquaculture and pools, greenhouses and building space heating.

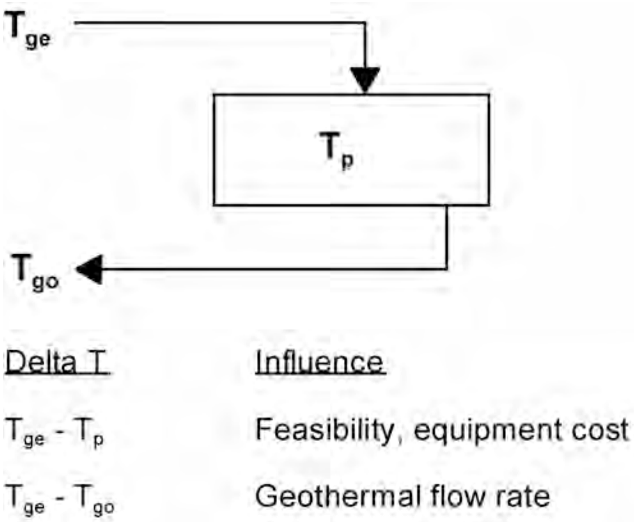
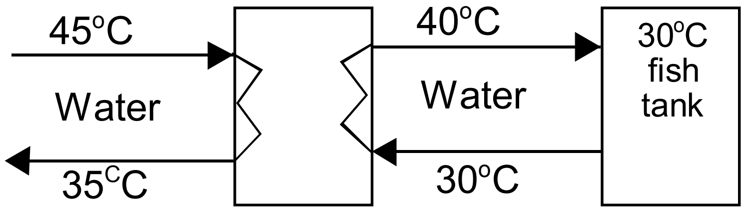


Figure 7. Fundamental direct-use temperature differences (Rafferty, 2004).

3.1. Pool and Aquaculture Pond Heating

Pond and pool heating is one of the simplest geothermal applications, as it usually uses the geothermal water directly in the pond/pool to provide the required heat demand. This is illustrated in Figure 8 (Rafferty, 2004), where 50^{o}C geothermal water is supplied to heat the pool water to 30^{o}. Thus, the ΔT is 20^{o}C, and using a flow rate of 10 L/s, the energy supplied would be 837 kW (3.0 GJ/hr) (kW = L/s x ΔT x 4,184). If the supply temperature were instead 40^{o}C the flow rate would have to be doubled to provide the same amount of energy, and four times at 35^{o}C, and eight times at 30^{o}C.

If the geothermal water cannot be used directly, due to health restrictions, then a heat exchanger is necessary to heat treated water for the pond or pool. Following the "rule of thumb" that the heated water to the pool should be 10^{o}C above the pool temperature, then according to the previous example 40^{o}C secondary water would have to be provided to the pool. Using a heat exchanger between the geothermal water and the secondary water an additional ΔT of 5^{o}C is required to accommodate the heat transfer between the geothermal water and the secondary water. Thus 45^{o}C geothermal water would be required, and on the return side of the heat exchanger the geothermal reject fluid should be 5^{o}C above the return temperature of the secondary water. Thus, the rule of thumb is "10-5-5" as listed below in Figure 8.

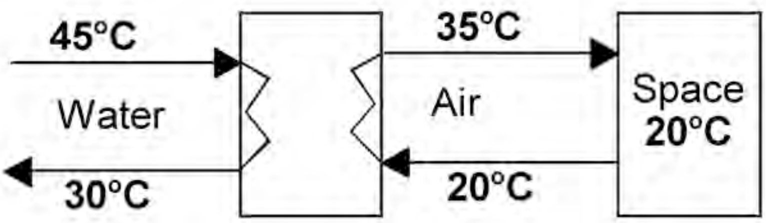


Minimum acceptable supply water temperature = process temp + 10°C
Maximum available supply water temperature = resource temp - 5°C
Minimum achievable geo leaving temp = process temp + 5°C

Figure 8. Pond/pool heating with heat exchanger (modified from Rafferty, 2004).

3.2. Greenhouse and Building Space Heating

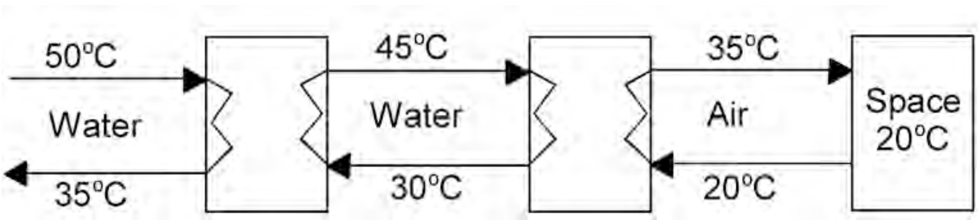
Heating of greenhouses and building often involves the transfer of heat to the air in the structure using a water-to-air heat exchanger called a coil, usually consisting of finned copper tubes (Rafferty, 2004). The simplest version of this application is shown in Figure 10. In order to heat the space, heated air should be delivered at least 15°C above the space temperature, 20°C shown in this example. Thus the air should be delivered at 35°C or above from the water to the coil. The reason for the large difference, 15°C, is to limit the required quantity of air circulated to meet the heating requirements at reasonable levels. Also, as the difference becomes less, the fan and duct sizes become large and the fan power consumption can be excessive. In addition, occupant comfort is important, as when the air supply drops below the 15°C difference, the temperature of the air approaches human skin temperature, which results in a “drafty” sensation to the occupants, even at the desired air temperature. In addition, the geothermal water delivered to the water-to-air heat exchangers should be at least 10°C above the require air temperature to limited the size and cost of this heat exchanger – usually a coil type. The same □T is required between the leaving geothermal water and the return air temperature. Thus, to supply 20°C heat to the room, a geothermal resource temperature would have to be at least 45°C. The “rule of thumb” for this condition is then 15/10/10 as shown in Figure 9.



Minimum acceptable supply water temperature = space temp. + 15°C
Maximum available supply water temperature = geo. water temp. - 10°C
Minimum achievable geo. leaving temperature = return air temp. + 10°C

Figure 9. Space heating without isolation heat exchanger (modified from Rafferty, 2004).

The example above assumes that the geothermal water is suitable to flow directly through the water-to-air heat exchanger (coil); however, if hydrogen sulfide is present, then this gas will attack copper and solder in the coil and cause leakage and failure to the unit. Thus, in the case where the geothermal must be isolated from the heating system equipment, a plate heat exchanger is normally placed between the two circuits to protect the heating equipment (Rafferty, 2004). A plate heat exchanger is then added to the left side of the equipment shown in Figure 10 and resulting in the configuration shown in Figure 11. All the temperatures shown in Figure 10 are still valid, the difference is that the plate heat exchangers will require additional temperature input to maintain the space (home) temperature of 20°C. As in the previous example a ΔT of 5°C is required between the geothermal supply and the output from the secondary water. Thus, the new geothermal temperature required to meet the needs of the system is 50°C. The return geothermal water can only be cooled to 35°C as a result of the intermediate water loop return temperature of 30°C and the required 5°C ΔT. This then provides of “rule of thumb: of 15/10/5 as described below Figure 10.



Su

Supply air to space air = 15°C
Water/air heat exchanger = supply water to supply air of 10°C
Water/water heat exchanger = supply water to supply water of 5°C

Figure 10. Space heating 15/10/5 rule with geothermal isolation plate heat exchanger (modified from Rafferty, 2004)

In summary, the following is provided by Rafferty (2004):

"All of the rules of thumb discussed here are exactly that. It is possible in all cases to "bend the rules," and design systems and equipment for temperatures closer than the guidelines provided above. The values provided here are intended for initial evaluation of applications by those not in the practice of designing heating systems on a regular basis. The guidelines cited apply to new systems using commercially manufactured equipment. Homemade heat exchangers or existing equipment selected for water temperatures well above available geothermal temperature would require additional analysis"

4. CONCLUSIONS

There are many possible uses of geothermal fluids for direct-use; however a number of parameters can limit the choices and need to be determined in advance. First, what are the characteristics of the resource, i.e. temperature, flow rate, chemistry and land availability? Second, what markets are available and do you have the expertise to provide the product, whether it be heat energy, a crop of plants or fish, drying a product (lumber or food), or extracting a mineral from the fluid, and can you get the product to the user economically. Finally what are the capital investments, annual income, and rate of return on investment and/or payback period, and can you raise the funds or find investors.

Another alternative which can be considered to help improve the economics of a projects and better utilize the resource, is to consider a combined heat and power project. Either project alone may not be feasible, however, together they may, even if the resource has low temperature. See Geo-Heat Center Bulletin, Vol. 26, No. 2, (June) 2005 for more details and examples on combined heat and power plants. All GHC Bulletins can be accessed from the website: http://geoheat.oit.edu.

REFERENCES

Bloomquist, R. G., Nimmons, J. T., and K. Rafferty, 1987. District Heating Development Guide, Vol. 1, Washington State Energy Office, Olympia.

Culver, G. G., and J. W. Lund, 1999. "Downhole Heat Exchangers", Geo-Heat Center Quarterly Bulletin, Vol. 20, No. 3 (September), Klamath Falls, OR

Dunstall, M. G., and D. H. Freeston, 1990. "U-Tube Downhole Heat Exchanger Performance in a 4-inch Well, Rotorua, New Zealand", Proceedings of the 12th New Zealand Geothermal Workshop, Geothermal Institute, Auckland, New Zealand.

Gudmundsson, J.S. and J. W. Lund, 1985. "Direct Uses of Earth Heat", International Journal of Energy Research, Vol. 9, No. 3 (July-September), John Wiley& Sons, New York.

Lienau, P. J., 1998. Introduction (Chapter 1)., in Geothermal Direct-Use Engineering and Design Guidebook, (John W. Lund, Editor), Geo-Heat Center, Klamath Falls, OR

Lund, J. W., 2000. "Balneological Use of Thermal Waters", Geo-Heat Center Quarterly Bulletin, Vol. 21, No. 3 (September), Klamath Falls, OR.

Rafferty, K., 2003. "Industrial Process and the Potential for Geothermal Applications", Geo-Heat Center Quarterly Bulletin, Vol. 24, No. 3 (September), Klamath Falls, OR.

Rafferty, K., 2004. "Direct-Use Temperature Requirements: A Few Rules of Thumb", Geo-Heat Center Quarterly Bulletin, Vol. 25, No. 2 (June), Klamath Falls, OR.

Ragnarsson, A., and I. Hrolfsson, 1998. "Akranes and Borgarfjordur District Heating System", Geo-Heat Center Quarterly Bulletin, Vol. 19. No. 4 (December), Klamath Falls, OR.
Ryan, G., 1981. "Equipment Used in Direct Heat Projects", Geothermal Resources Council Transactions, Vol. 5, Davis, CA

Dr. **John Lund** is the current Director of the Geo-Heat Center at the Oregon Institute of Technology (OIT) and has worked in the direct utilization of geothermal energy for over 30 years. He has a PhD from the University of Colorado in Civil Engineering. He is an emeritus Professor of Civil Engineering at OIT where he taught for 32 years. Mr Lund has been a member of the Advisory Committee on Geothermal Energy for the United Stated Department of Energy, and a past president of the Geothermal Resources Council (GRC) (2001-2002). He received the Geothermal Pioneer Award for "Outstanding Achievement in the Development of Geothermal Resources from GRC in 1997. He has also been a lecturer at the geothermal schools in New Zealand and Iceland. He is the Past President of the International Geothermal Association for the period 2004-2007. In 2002 he received the Medal of Honor from the International Summer School, and in 2005 an award from the Italian Geothermal Union for "...pioneering heat uses and fostering geothermal development world wide."