Project co-financed by the European Regional Development Fund

MED Greenhouses
“Green Growth through the capitalization of innovative Greenhouses”

Training course material for stakeholders/actors on geothermal greenhouse installations

University of Thessaly (PP1)

Project Details:

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1. Introduction

During recent years as demand of energy is increased, researchers attracts towards energy production, consumptions, storage, management and saving (Carlini et al.,2010; Rasheed et al., 2015). Access to renewable supplies of energy is one of the main preconditions for the development of agrifood industries and is a key determinant of their competitiveness.

In practice, geothermal resource is a reservoir inside the earth that hold heat (Figure 1), in which through geothermal pump system, that stored energy is transferred to cover energy demands, such as heating and cooling among others. Generally, several different geothermal energy systems according to their outlet temperature supply are able to be performed: high (>150 °C), medium (90-150 °C), low (30-90 °C), and shallow (less than 30 °C) temperature of geothermal source. The choice of the geothermal energy application, therefore, is dictated by the operator's needs and the engineering considerations to use the maximum geothermal resource availability. The sources of high and medium temperature, for instance, are used mostly for direct or indirect, respectively, production of electricity. The low and shallow sources, on the other hand, are usedfor heating or cooling, in direct disposal or through heating pumps. Direct use geothermal energy systems, therefore, are probably the most effective option at the moment, at least in terms of carbon footprint and economics. Figure 2 presents different uses of geothermal energy according to geothermal source temperature.

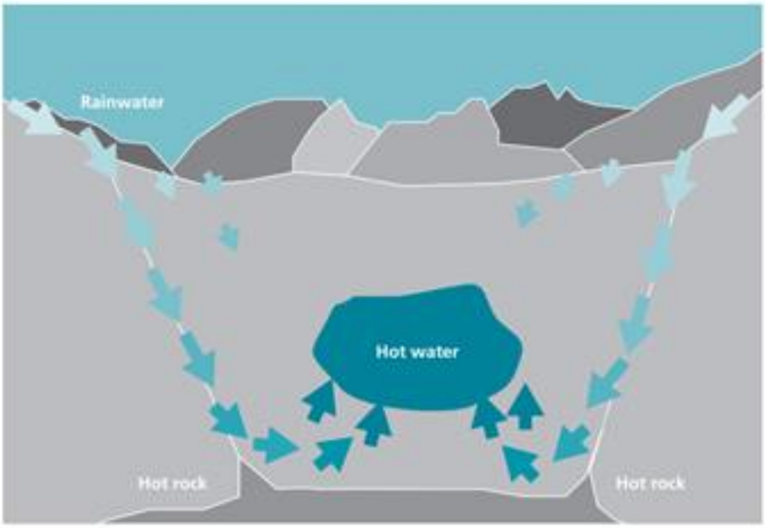


Figure 1. Formation of production well. Source by Van Nguyen (2015)

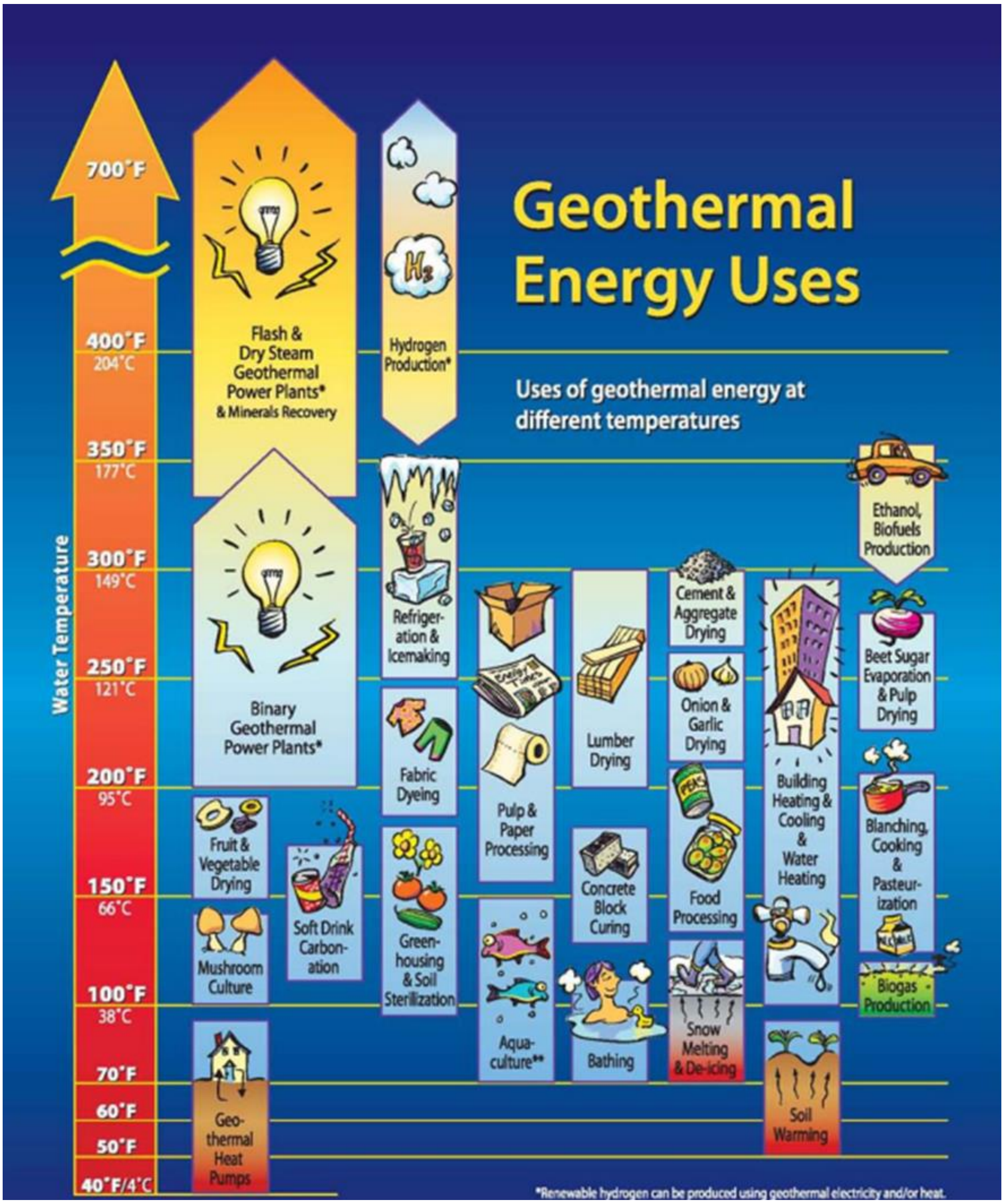


Figure 2. Geothermal energy uses. Source by Geothermal Education Office (2005).

Low temperature geothermal resources are effusive and their application is considerable increased throughout the world (Figure 3). From 2000 until 2005, the group of countries performing geothermal resources and especially of low temperature raised to 72 (from 58), by achieving an installed capacity approximately to 27,825 MWt (Thein et al., 2006). The 63% of the global capacity is mostly consuming by the United States of America (USA), China, Sweden, Germany and Japan. By 2010, the worldwide installed capacity of geothermal energy achieved at 423,830 TJ/year, mostly for direct *activities (Figure 4) such as heatpumps, space heating, greenhouse heating, aquaculture heating, crop drying, industrial applications, cooling, swimming pools and spas (Lund, 2010; Palermo, 2014). The most common direct applications, however, performed in the global market is the use of geothermal heat pumps with 200,149 TJ/year (47.2%), the process of space heating with 63,025 TJ/year (14.9%) and using geothermal system in greenhouse heating operation with 23,264 TJ/year (5.5%)(Lund, 2010).*

In Greece, geothermal energy of high-enthalpy was used for first time in the early 1970s in Milos and Nisyros Islands. Later in the same decade, several low-enthalpy fields in Northern Greece and on some Aegean Islands were deliberated. The climatic variation performed in Northern Greece compared to Central and southern part (Figure 5), allows the easily generation of many low enthalpy geothermal sources and exploited at a very reasonable cost.

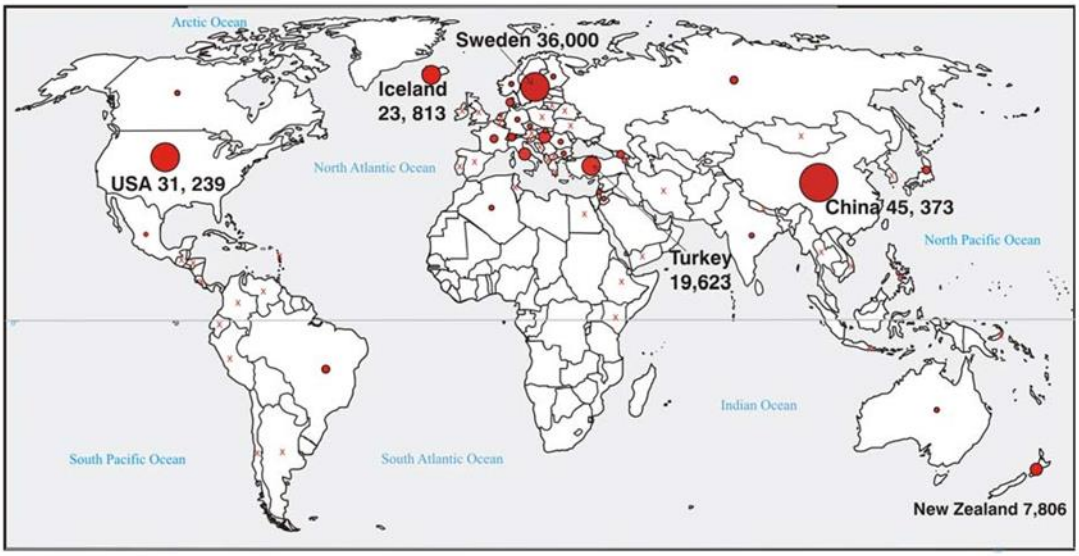


Figure 3. Regions of performing low temperature geothermal systems. Source by Thain et al. (2006).

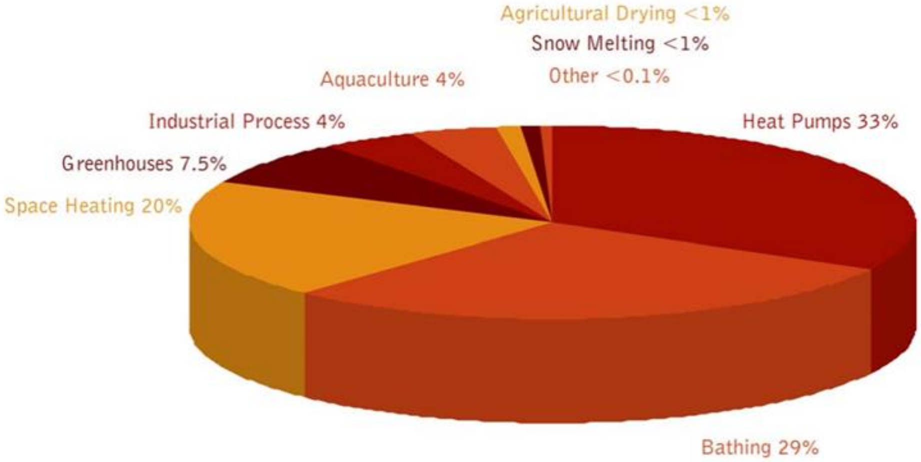


Figure 4. Global uses of low temperature of geothermal resources. Source by Thain et al. (2006).

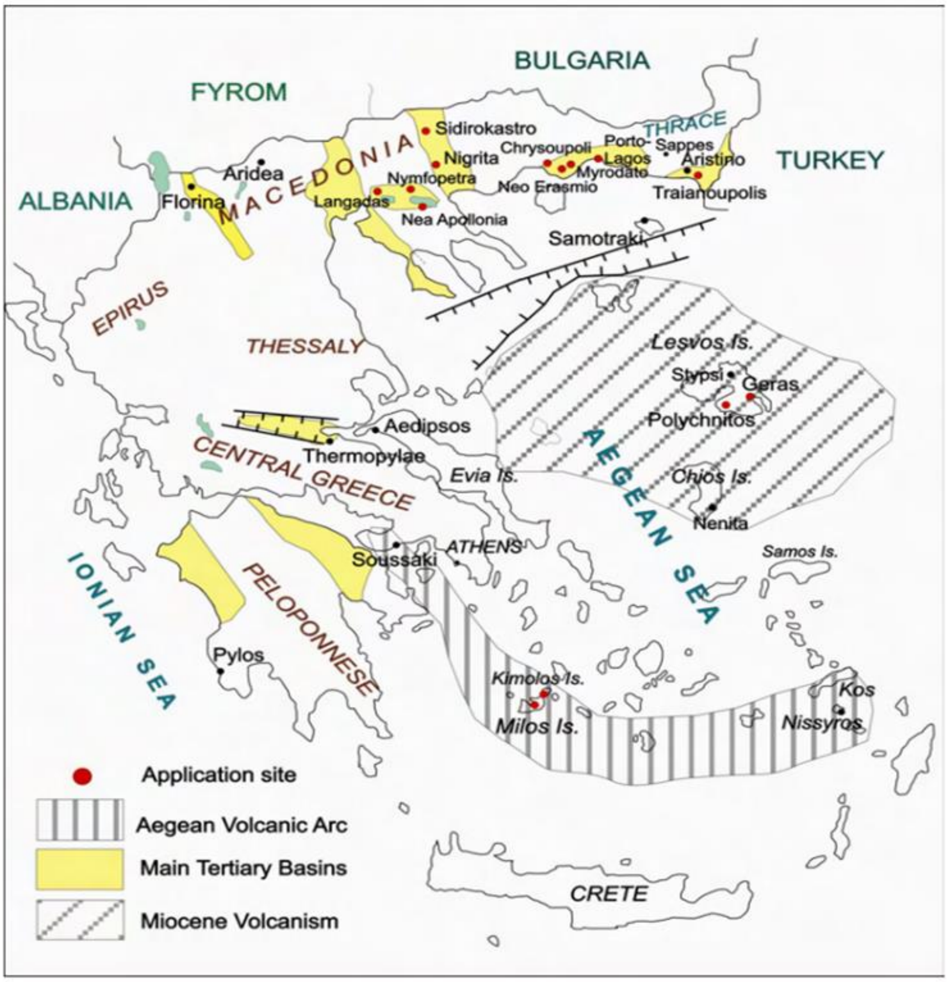


Figure 5. Greece map with geothermal sites performed for direct usage (the balneology sites are not included). Source by Andritsos et al. (2007).

This relatively considerable development observed over the last year is a result of the strong governments support and the specific policies they followed (Directive 2009/28/EC of the European Parliament and of the Council on 23 April 2009) to support that type of investments. In general, the high manufacturing costs and the generic maturity constraints are required make geothermal systems hard to be implemented in large scale. Since 2009, however, due to that government support, more than 100.000 systems each year according to European Geothermal Energy Council, have been installed for heating and cooling uses (Figure 6).Up to now, almost 24 countries apply geothermal energy for generating electric power. Universally, an assessed 67 000 gigawatt hours (GWh) of electricity is produced from a total installed geothermal power capacity of about 10,700 MW.

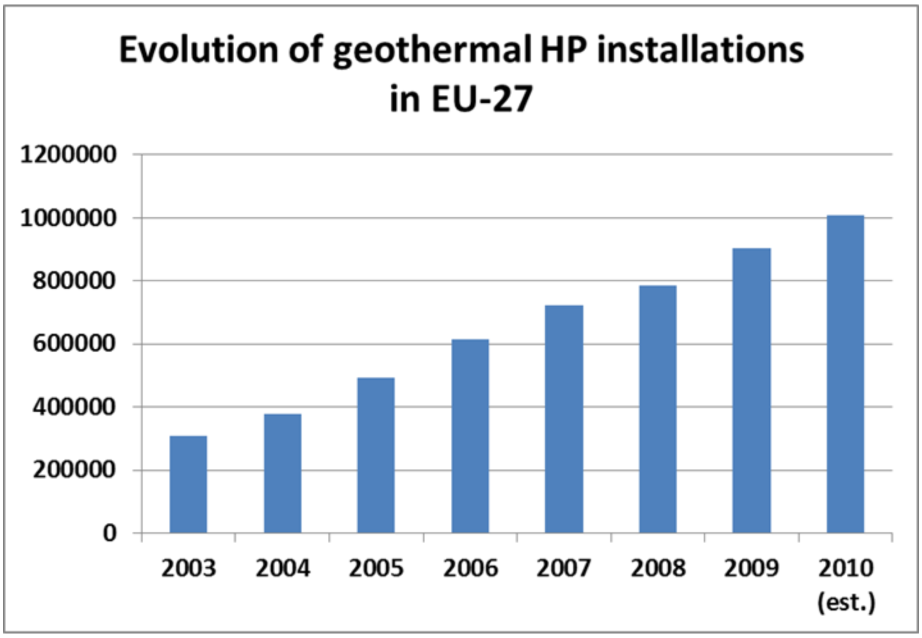


Figure 6. Annual amount of geothermal heat pump installations in the European Union.

The concept of geothermal energy, in which the naturally occurring steam and hot water are being used to produce power, is feed a wide range of energy conversion technologies applied in greenhouses as well. According to Duffield and Sass (2003), Van Nguyen et al. (2015) and Battocletti et al. (2003), the choice of geothermal energy as alternative method instead of traditional energy decreases fuel costs approximately at 80% and total functional costs by 5–8%, since 7,5% of the greenhouse heating, covers the total use of geothermal energy (Bošnjaković et al. 2013).

In this geothermal greenhouse sense, the current training material was designed by the institutional partners of the MED Greenhouses project in order to inform and facilitate the stakeholders/actors of the greenhouse industry regarding the installation, the *operation and the replication procedures of the prototype geothermal greenhouse as well as to inform them about the advantages compared to the conventional greenhouses.*

Accordingly, this overview examines the main technological patterns of the geothermal technology workable in greenhouses, some simplified design tools and criteria for their selection. It also report a resume of adapted practices in this field. The goal is to provide a better familiarity of the technologies that promote the development of projects where provide the establishment of geothermal energy in greenhouses.

2. Brief intro of the Geothermal Greenhouses

The geothermal greenhouses in general, adapted technologies based on low temperature sources. It is the most profit sound choice, since it provides a discrete payback in short-term, according to the system construction and the cost of fossil fuel substitute. The use of low geothermal energy in greenhouses permits cultivation all year round from warmer zones in colder zones, increases the production, improves protection against plant diseases and considerably improves yield values.

In 2010, greenhouse heating had an installed capability equal to1,544 MW and represented a use of 23,264 TJ/yr with Russia (3,279TJ/yr), Hungary (2,388 TJ/yr), China (1,687.9 TJ/yr) and Italy (1,329 TJ/yr) as the top five countries (Lund et al., 2010). In other countries, geothermal heated greenhouse' research has involved design, feasibility analysis and experimental studies using ground source heat pumps and heatexchangers for hot water extracted from geothermal heated aquifers. In Turkey for instance, a geothermal system with output temperature around 54 °C was adapted based on two geothermal heating systems to cover heating requirements of a 30 acre greenhouse cultivation (CampuzanoPáez, 2014). In Argentina, a geothermal greenhouse prototype (105 m^2) was designed and established to cultivate tomato crop with heating pipes and with thermal curtains(Adaro et al., 1999; CampuzanoPáez, 2014).

The geothermal technology in greenhouses was applied in Greece for first time, in the early 1980s (Bakos et al., 1999). By the end of 2008, almost 13.1 ha and 5.1 ha of glass and plastic covered greenhouses were heated with geothermal hot water (Andritsos et al., 2009). In 2012, there was a call for guiding investments in more renewable proposals, while for period 2013-2020 a budget of 70 million € were given in geothermal field (Andritso et al. 2007; 2013). In 2013, one of the most innovative geothermal field technologies ever using (certainly in Greece but in Europe as well) was performed in Thrace greenhouses (14 ha) located in Neo Erasmio (Xanthi). The investment of that effort has gone over than €5.000.000. By the spring of 2016, the overall installed capacity was increased to 231.76 MWt, reporting an increase of 22% (Papachristou et al., 2016).

This Greek effort, in general, contributed greatly to paving the way in developing many other geothermal greenhouses. Since 2014, around 25 greenhouses perform geothermal energy (among others, Selecta, Agritex, Drama, Wonderplant, Agris greenhouses), with total installed capacity equal to 24 MWt in order to produce yearly 246 TJ (Andritsos et al., 2013). By 2030, more geothermal units are expected to be established, since the price trend of conventional fuels is keep increasing with constant rate.

2.1 How it works

Geothermal source can be used to heat or irrigate or, more commonly, to set up an appropriate microclimate within the greenhouse for the cultivation. To achieve this, the geothermal warm water drilled from the earth is the most common tool to transport temperature from one mean to another for covering all the operation needed in a greenhouse structure (Thain et al., 2006).

In practice, greenhouse geothermal heating and cooling system baseline is simple. In heating process, warm water come from a production well and are distributed above or below the canopy through plastic or iron pipes network in a closed or open loop buried underground .In cooling process followed during summer, the cool temperatures of the earth condense the moisture in the air within the greenhouse.

The path the geothermal water will follow to reach the proper temperature is defined by the loop style. In an open-loop system, two wells are typically used in which water is circulated within (Figure 7). In this sense, the water is circulated from the production well directly to the reinjection one. To make this system workable, however, a distance between the production and rejection well is necessary. In this way the impact of the return water in the indoor temperature is avoided. The open-loop systems may be operated except of groundwater, with brackish water and sea water and it offers a low-cost method to heat the space within the greenhouse. In a closed-loop the heat is gathered (or dissoluted) by water or antifreeze circulated through the tubing by a small electric pump, while no liquid imports to the unit from the earth. Usually, the closed-loop system passes the water from a heat exchanger and pump to extract and amplify the heat is absorbed from the ground.

Considerably, there are three types of closed loop systems: horizontal, vertical and pond-lake closed-loop system (Figure 7). In horizontally loops, pipes are located in trenches in lengths to 400'. Usually, to generate the amount of heat needed to heat the greenhouse, multiple loops are performed. In vertically loops, pipes of small diameter filled with a grout material are placed at 75'-500' depth. To achieve excavation at that depth well drilling equipment is needed, while the grout helps to easier transfer the soil heat to the pipes. Standing column wells are, also, used to draw groundwater, but apply on smaller amounts within a very deep well to exchange heat with the surrounding bedrock. The way loops may be placed (horizontally or vertically), is depending on space availability. Closed loops in ponds or lakes is similar to the other closed-loop styles, with only difference being that the warm water is drawn directly from the pond or the lake instead of the ground. This system is the cheapest option of the three closed-loops systems, but it requires the existence of a lake near the greenhouse which will be very difficult actually to meet.

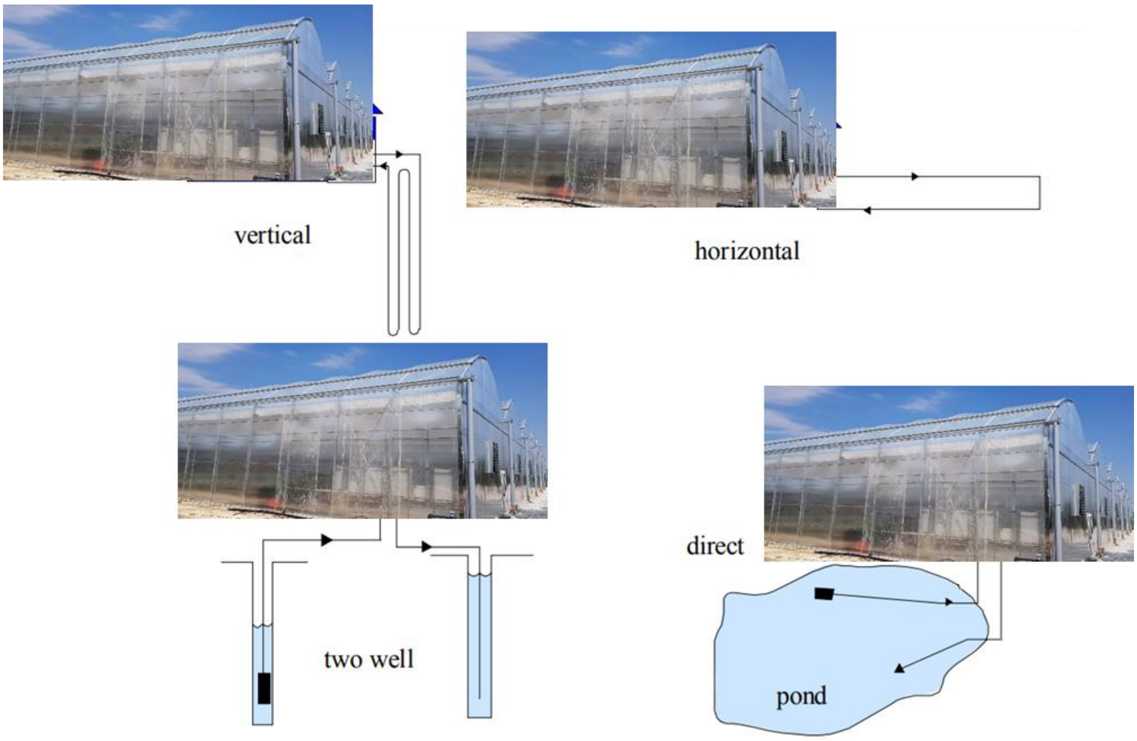


Figure 7. Closed and on open-loop style.

In geothermal units, the process is starting by pumping the fluids from the production well, and most of them integrate heat exchanger system to amplify the ground water temperature. Then, the fluids are entering in the greenhouse with temperature equal to that performed in the production well, in the range of approximately 30 to 60°C. A possible temperature variation depends on the external climate characteristics and the heating period. In case of open-loop system, the reinjection temperature should not exceed 28-30°C in order to avoid even just the potential risks of overheating the crops.

The whole geothermal installation should be close to the geothermal well/tank (20-200 m) to ensure optimum operation with low functional costs, while the transmission pipelines should not exceed 1km.

On this point, it is worth understanding how the geotheremal system of Thrace greenhouses, which is one of the most innovative geothermal unit systems ever using is operated. A simple chart flow of the current system is presented in Figure 8.The production well of the current system is located at a distance of 4.5 km. This distance is considered up to now, as the longest geothermal pipeline system buried. Poly-propylene pipes with an outside diameter of 28 mm material were buried on the ground to forward the circulation process. Due to their long pipeline system, about half (48%) of the total pipeline length is insulated.

In order to cover the installed heating capacity (13,81 MWt per year) of the total production unit of Thrace greenhouses, the geothermal fluids with an average temperature of 60°C are supplied in 250 m^3/h rate (Andritsos et al., 2010; 2013; 2015). Thrace greenhouses require in total energy more than 296.78TJ per year. In practice, the current system can adjust the soil temperature by 4-10ºC. The effectiveness of the system is depending among others on the ambient conditions (temperature, moisture, winds, precipitation), the water flow rate and temperature, the presence of the foil coverage etc. Thrace greenhouses, therefore, take advantage of the dynamic capacity of the heating system to cultivate out-of season vegetables during winter. The aim of Thrace Company is to extend their geothermal greenhouses in 20 ha by the end of 2020.

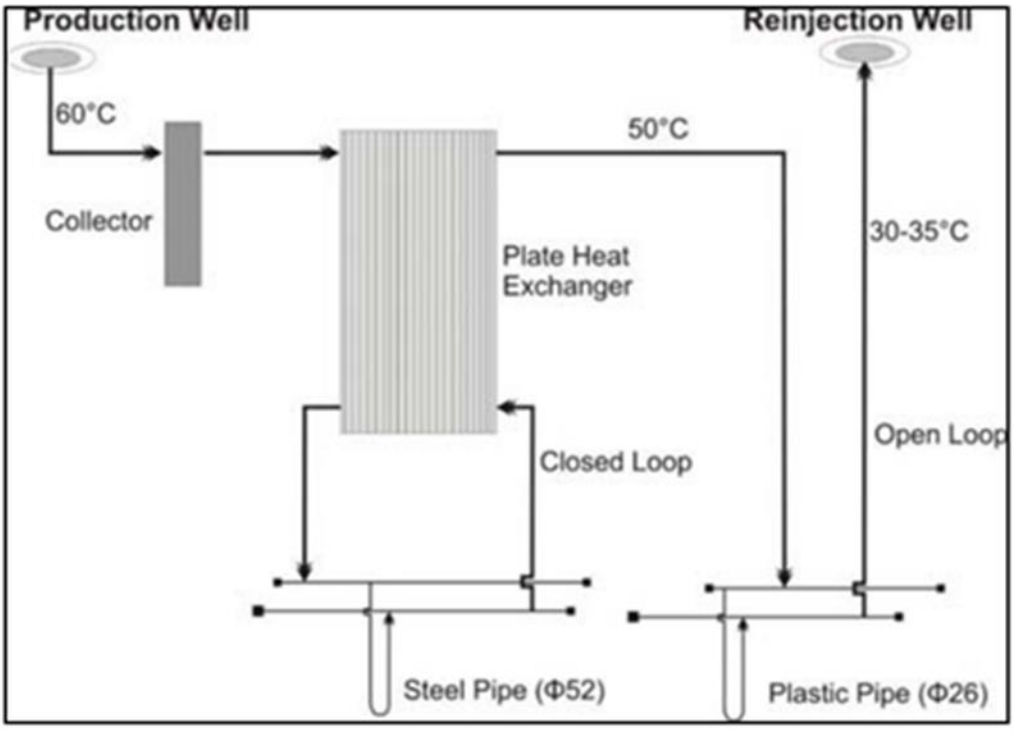


Figure 8. Heating system of the Thrace greenhouses in Neo Erasmio (Xanthi, Northern Greece). Source by Papachristou et al. (2016).

The geothermal system can also use air instead of water to warm or cool the greenhouse. In this case, the air temperature is adjusted to the ground temperature and the environment conditions. Particularly, in winter the cold air is heated by the warm soil and then is circulated via wiggly plastic tubes into the place to be heated. On the other hand, during summer the warm air is circulated from the indoor greenhouse space to the soil and back again. The heat is sucked up by the cooler earth. To ensure optimum operation of the system the tubes should be buried 6' to 12' adown the soil surface. In the system an air to air heat pump could be also adjusted to amplify the air temperature. This technology is adapted by several countries to produce dry agri-food such as garlic, onion, chilli, rice, wheat, fruit, alfalfa, seaweed, and coconut (Thain et al., 2006).

Based on the above technology, novel application of drying vegetable is in operation in Thrace greenhouses. The unit utilize the geothermal fluids of 60°C to produce hot air through a water-air heat exchanger. Two fan units then forced the hot air to the dehydrated tunnels with flow rate equal 25m^3/h. The air flows inside each tunnel at a rate of 14.000m^3/h. The dehydration plant has produced, so far, more than 150tn of excellent quality dried tomatoes (Papachristou et al., 2016).

2.2 Equipment &Infrastructures required

Geothermal systems applied in greenhouse cultivations consist of several parts: the production and reinjection well and the head well pump, the ground heat exchanger, the heating system, and the delivery system (pipe network).Some of the existing systems, use also an artificial tank to collect the geothermal fluids for short period before supplying the greenhouse heating system.The geothermal system, its components and the parts controlled are described in details below.

Geothermal well-Head equipment:

*Production Well properties:*The drilling well is considerable meaningful in achieving success for a geothermal project and are categorized in four phases: exploration/discovery, appraisal, production and work-over. In exploration/discovery phase, geological data or previous drilling records are analyzed, while in appraisal phase, the reservoir’s boundaries are delineated and the drilled process begins. In production phase, the known productive portion of the reservoir is drawn. In the last phase, the system is rephrased by re-entering in the already drilled wells deeper.

The planning procedure for exploration method last quite long and requires more effort than appraisal wells and production drilling, most because the new wells are drilled in unknown territory with high probability of making an error (Ngugi, 2008).Drilling procedure is, also, an important aspect in the running geothermal projects. The main objective of planning a well is to drill safely, minimize costs and drill usable well.

Generally, drilling of new geothermal well is very risky due to high costs of drilling. In order to avoid the mistakes, the greenhouse construction projects must be planned in the areas with existing sources of geothermal energy. There is a role to play, therefore, by the oldest wells, since their properties are fully documented and already known (Thain et al., 2006). In this way, the process is facilitated, thereby saving time and resources. The most common capacity, however met to the low-temperature wells is 15 l/s for 7" casing, 45 l/s for 9-5/8" casing and 100 l/s for 13-3/8" casing.

Well diameter and depth depend on pumping flow rates and hydrology. The depth of the wells used currently range from simple wells of 10 m to deeper wells of 450 m. Usually, have to drill deep to find the right sources. The average depth of the 30 geothermal productive wells is 140 m (Andritsos et al., 2007).

Well-head pump: The production well is equipped with circulating pump to bring the water to the surface and then to flow it either straight to the heating system or to transport it via a heat exchanger. With well-head pump, the flow requirements of the plant are matched by controlling the flow circulation.

The pumps are categorized in lines haft turbine pumps, submergible pumps and centrifugal pumps (Figure 9). The most common lines haft style adjusts motor on surface and is mainly used for deep depth (<250m). That pump includes enclosed line shaft and is less expensive than other types. In submersible pump, the motor is placed in the water level. The centrifugal pumps are either placed directly on the head of the well or next to a holding tank, where the water is directed from the artesian well (Andritsos et al., 2007). In issues with low loop pressures, a booster pump may also be used: when for instance wellhead pressure is around 20 psi.

The choice of the pump category is in general imposed by the flow and pressure needs of the system, the availability of spare parts and maintenance personnel the cost and among others, the water level and temperature. The most heat is extracted from each litter of water pumped, the less pumping requirements are needed. In this sense, more greenhouse space is heated with the less resources (Rafferty & Boyd, 2008).

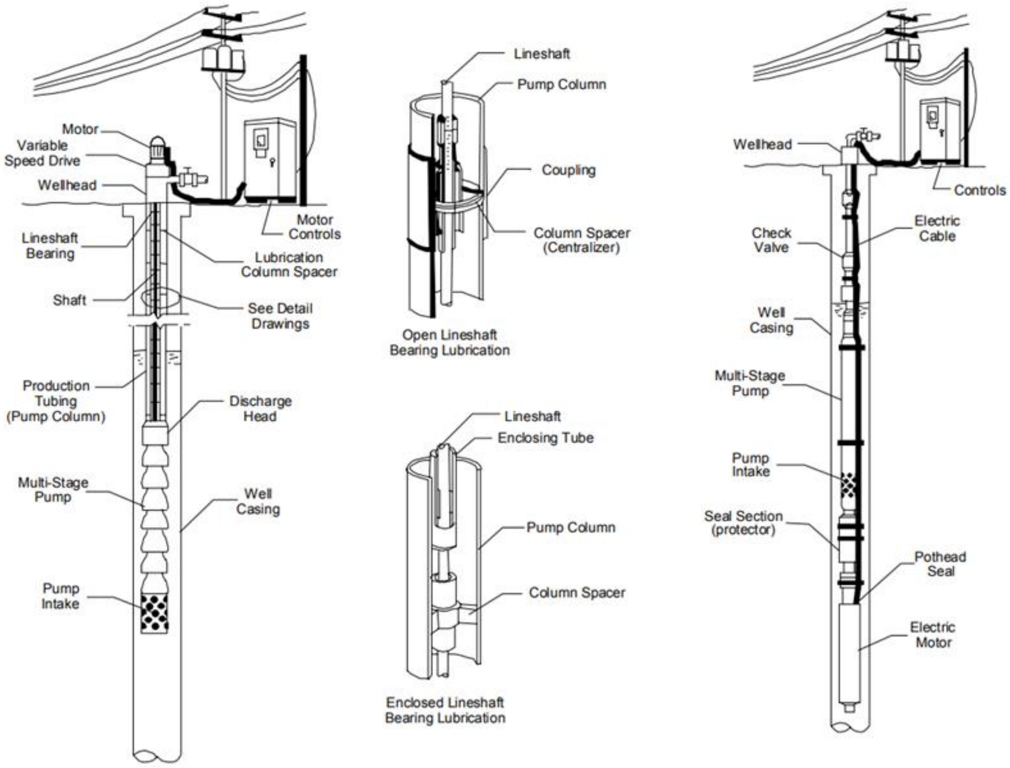


Figure 9. (a) Lineshaft turbine pumps and (b) submergible pumps.

Collector tank: The pumped water is driven the most of the times, directly from the well to a holding tank for use later on. By storing for short time the heat that has already been generated can aid to buffer heating system due to the slow heating response to the rapid temperature/weather changes. In this way, the possibility to stop the continuing heating process due to any unpredictable failure of the well pump operation, is avoided. Tank less water heaters result in lower energy use and lower maintenance costs over conventional water heaters. The required capacity of the tank is calculated according to the heating system design and the greenhouse infrastructure.

*A*fter heating the greenhouses, the geothermal water is gathered in size able cement ponds where it is chilled and hold until be in need of irrigation, usually on nearby fields. Small ponds easy to provide with plastic linings give workable and economical alternative for independent farmers (Mohamed, 2005)

Heat exchanger: The geothermal water passes from the tank in the greenhouse heating systems through a heat exchanger. In most geothermal applications, the establishment of a heat exchanger is necessary to distinct actual heating equipment from the geothermal fluid.

With this system, two fluids can exchange heat, since one mean is moving over the outside of the tubes and the second one through the tubes. Basically, the vital principle of a heat exchanger is that it transfers the heat without transferring the fluid that carries the heat. In addition to temperature regulation, protection from scaling is further achieved. Generally the exchanger system is set in the middle of two circulating loops, but is more workable in closed loop systems. The output temperature is always regulated according to inter average water temperature of the heating loop (Boyd, 2008).

In practice, the heat exchanger is filled with a liquid refrigerant at low temperature from one entrance and with geothermal warm water from the other. In this way, as the cold liquid is flowing through the exchanger unit, extra heat from the drilled liquid is absorbed, as a result a lower temperature of drilled water is directed to the greenhouse heating system and then to discharged well. Additionally, the warm compressed gas resulted from the evaporation process occurred is transferring through tubing to a compressor, so its temperature and pressure to be increased, probably to an average value more than 80 °C and 245 pounds per square inch (psi) respectively. These levels are quite common for the most of the models. To decrease these levels in order to diffuse the warm gasses within the greenhouse, a condenser and expansion device is also applied. Finally, the fluids re-enter in the heat exchanger system and the proses is repeated.

The amount of the gained heat is depending on the type of heat exchanger that eventually will be performed. There are, typically, three exchanger types in the market: plate construction, plate, shell-and tube, and the downhole ones.

Shell and tube exchanger style enables a flexible design that allows a wide range of applications in different pressure and temperature levels. A shell and tube exchanger consists of a number of tubes mounted inside a cylindrical shell (Figure 10). The fluids can be single or two phase and can flow in a parallel or a cross/counter flow arrangement. 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.

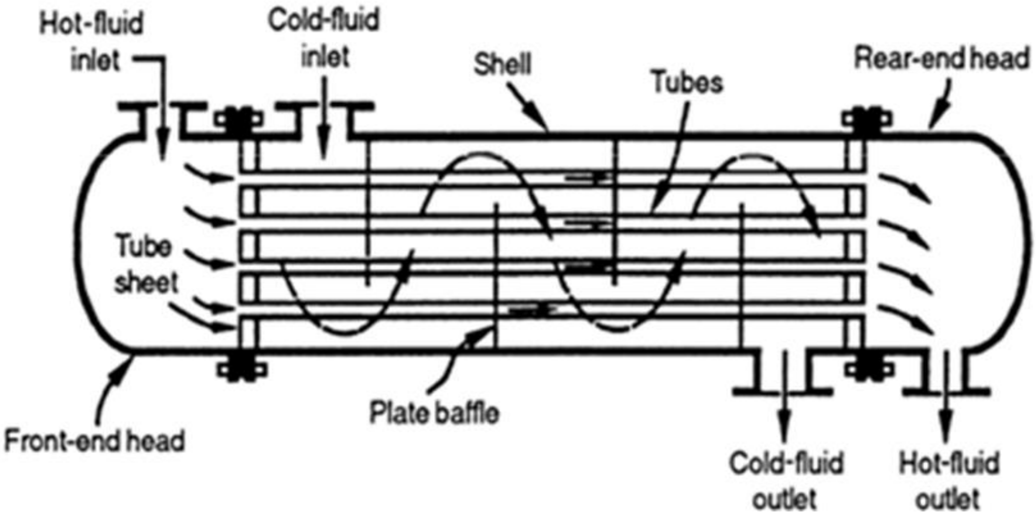


Figure 10. Shell-and-tube exchanger with one shell pass and one tube pass

The plate heat exchanger is the most widely available configuration in geothermal systems in the up-to-date designs. The specific system enables a series of thin metals plates with large surface area constructed by corrosion-resistant materials (Figure 11). The units are efficient and compact with rates of heat transfer three to ten times than those of tube and shell exchangers. For instance, if the temperature of the geothermal fluid is about 100°C, then a stainless steel plate main heat exchanger introduces a temperature loss of approximately 20%.Due to the simple construction of plate heat exchanger, such units can be developed in small sizes, economically.

The downhole heat exchanger was used extensively in Oregon, Turkey and New Zealand, by providing heating from a single geothermal well. Practically, this type of heat exchangers (Figure 12) integrates a vertical loop of pipes or tubes placed within the geothermal well through which a pure secondary water is pumped and circulated by natural convection. In this way, difficulties occurred in process of geothermal fluids disposal are minimized.

The maximum outlet capacity achieved at the moment, is less than 3 GJ/hr or 0.8 MWt. In order to gain maximum capacity, however, the drilling depth should be deeper than 150 m and the well should have an open annulus between the wellbore and casing, with perforations near the top and bottom of the submerged heat exchanger. The resulted heat output of the system is a function above all, on the bore diameter, casing diameter, pipe network length, tube diameter, number of loops in the well, flow rate and temperature of the geothermal fluid.

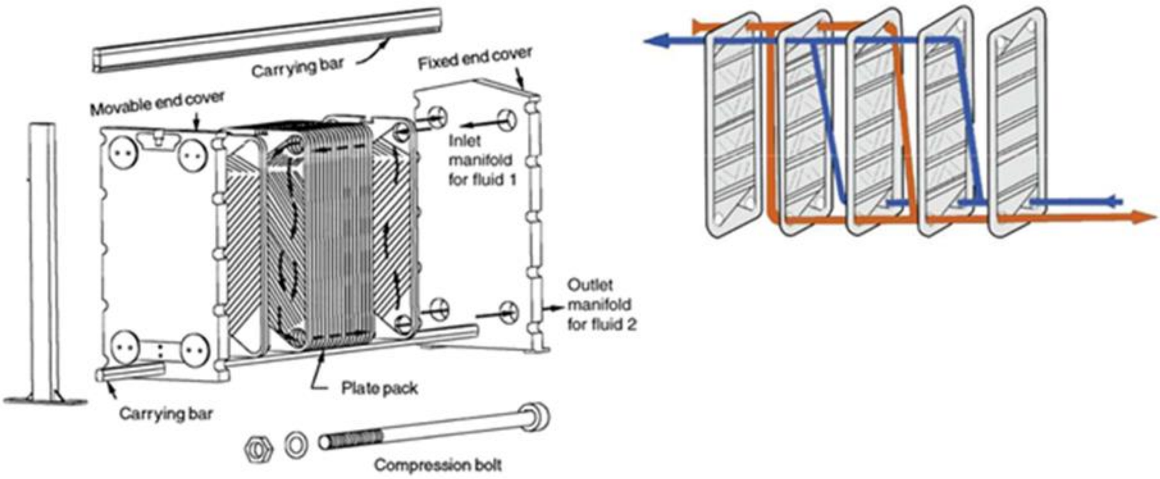


Figure 11.(a) Gasket plate and frame heat exchanger construction, (b) flows in plate heat exchanger.

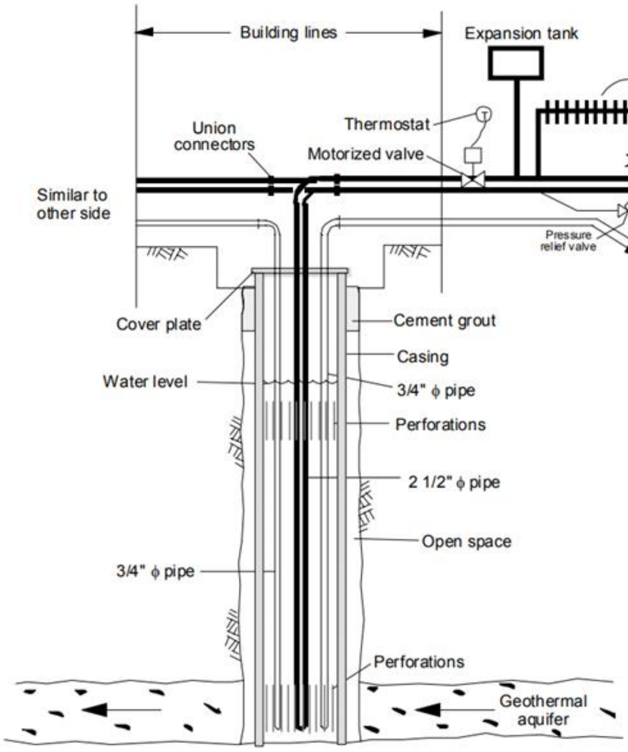


Figure12.Downwhole heat exchanger.

Geothermal heat equipment

Now that the heating demands and given water temperature has been designed, different heating systems can be assessed considering their ability to meet these requirements. Regularly, several different geothermal heating systems, such as finned pipe, standard unit heaters, low-temperature unit heaters, fan coil units, soil heating, and bare tube, are the most common methods may be applied to greenhouses. However, in geothermal greenhouses, certain types of heating methods yield better results with low-temperature fluid than others. The most common-used heating systems able to be applied in geothermal greenhouses, are those used with coercive heat convection by recuperators under the greenhouse roof (fan coil unit), and those systems placed on the surface (soil heating system; ripped tube system). Floor heating system in combination with recuperators may be, also, another option (Van Nguyen et al., 2015).Some of the natural heating circulation with heating pipe and forced air circulation systems are presented in Figure 13.

The choice of heating system type is dictated by the combination of the maximum geothermal energy availability and the actual crop needs. Often the choice of heating system is influenced by the establishing and operating costs needed.

Fan-coil heating unit: A typically fan-coil heater belongs to water-air heat pump category and consists of a finned coil and a centrifugal blower in a single cabinet. That type is mostly used when the water temperature exceeds 60°C. In the fan-coil system, the coil includes a series of rows consisting of thick fins in a close spacing to enable enough warm surface area able to heat the air is passing through (Figure 14).

In this way, a well-designed fan-coil system can heat or cool more than double the outlet air temperature from its ambient degree. For instance, during winter with low air temperature and the fluids inlet with 50-60 °C water temperature, then the temperature within the greenhouse is maintained at 20 °C. Regularly, the total heat supplied (q, Btu/h) is calculated according to the flow rate (Q, gpm) and the temperature drop (ΔT, °F):

$$q = 500 \times Q \times \Delta T \qquad (1)$$

Thereafter, if the heat that is lost from the greenhouse is known, then the final space area that can be heated is calculated.

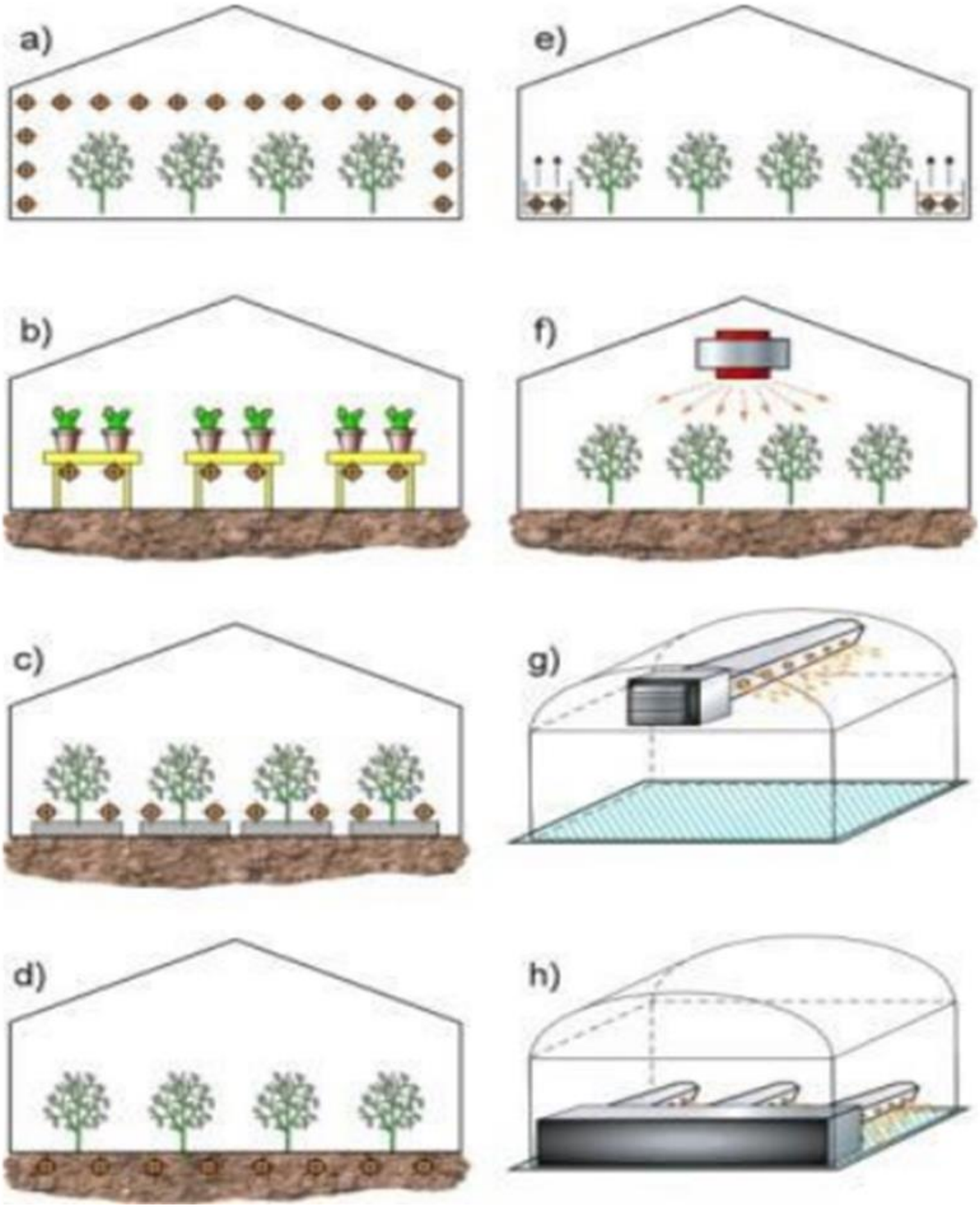


Figure 13. Systems for greenhouse heating. Natural heating circulation with heating pipe: (a) aerial heating, (b) bench heating, (c) low level air heating, (d) soil heating. Forced air circulation: (e) lateral position, (f) aerial fan, (g) ducts located in the to

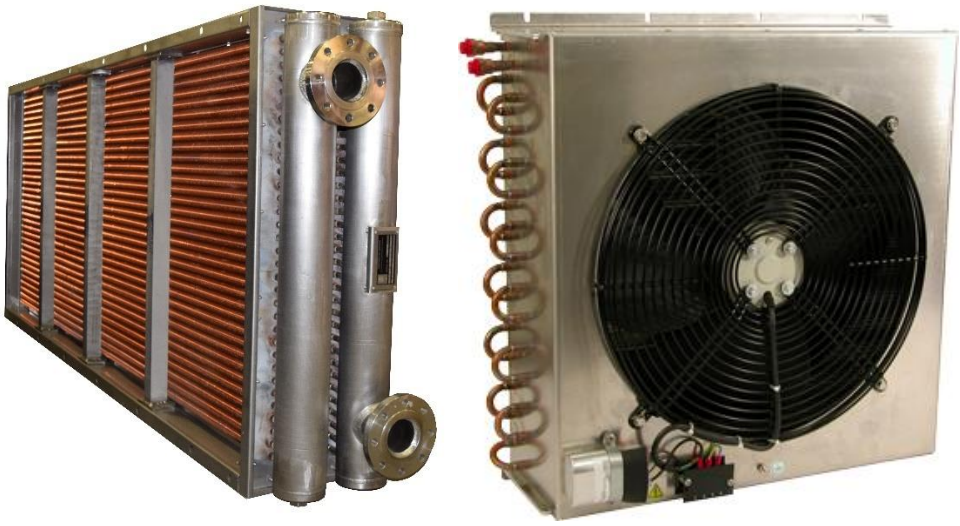
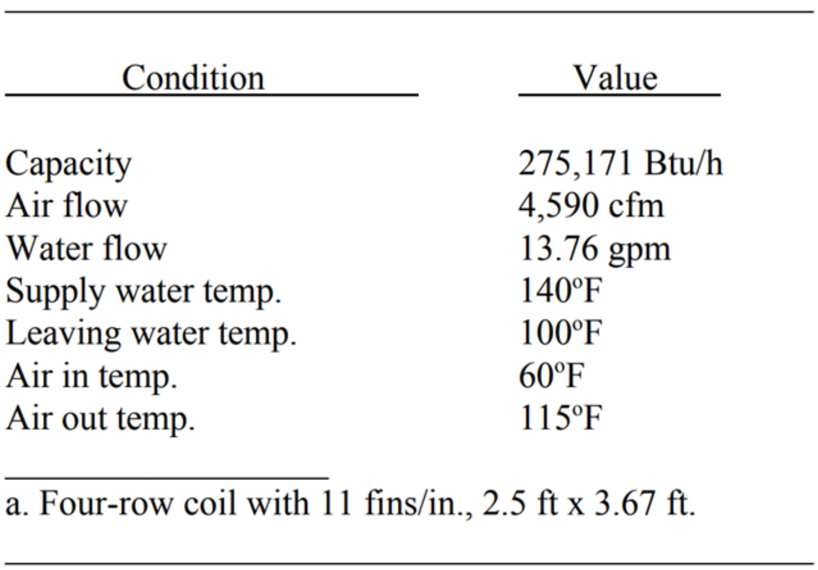


Figure 14. Fan-coil heat exchanger with finned coil and centrifungal blower.

Table 1. Fan Coil Examplea (4-row). Source by Rafferty & Boyd (2008)



Condition	Value
Capacity	275,171 Btu/h
Air flow	4,590 cfm
Water flow	13.76 gpm
Supply water temp.	140ºF
Leaving water temp.	100ºF
Air in temp.	60ºF
Air out temp.	115ºF

a. Four-row coil with 11 fins/in., 2.5 ft x 3.67 ft.

The fan-coil system is the most cost effective method for extracting large quantities of heat from very-low-temperature heating mediums, since it requires less than half the cost of using only heavy-duty steel pipes. The finally, however, energy needed for its operation is depending on the unit size. The larger the row of coils, the larger fan motor is required to force the air through the added coil resistance and more horsepower is required (<0.5 hp).

Surface heating unit: Most surface heating systems applied in geothermal greenhouse style were basically designed for standard hot water use. A typically surface heating system is used when the water temperature is generally based upon 90 °C or higher. In this system, warm water is circulated through tubes or pipes that are placed located on the floor (Figure 15) or at certain heigh :under or on top of the soil between plants or overhead of the plants, on benches, or suspended from the roof (Panagiotou, 1996). Eventually, through this process, warm air is blown and heat the indoor greenhouse space.

Figure 15. Surface heating system in u-bond design.

Figure 15.

A surface heating system is more preferable, at least in recent innovative greenhouses, since it does not obstruct floor space or cause shadows. There are three calculation steps for determining the designing procedure: 1. calculation of the greenhouse total heat load, 2. calculation of the required surface temperature and, 3. calculation of the required size and spacing of the tubes. Recognising the need to maintain the balance among the elementary process of mass and heat transfer involving the plants, the indoor air, the cladding surfaces and the climatic variables, an appropriate amount of energy must be provided or removed to maintain the desired temperature set points. Besides the displayed thermal loads, the amount of energy used to feed heat pumps, chillers, water and air pumps, equipment for heat distribution, fans, motors for roof windows and irrigation pumps are considered. The whole process is analytically described in Rafferty and Boyd (2008) and Cabrera et al. (2017) research.

By way of example, assuming a 12m x 36mgreenhouse,with a total heat loss of 495,980 Btu/h, then according to the calculations, the value for heat loss (q/A) is equal to 109.4 Btu/h ft^{2}and the required surface temperature 40 ^{o}C. This high temperature, however, affects the growing rate of the plants. Taking into consideration that is not possible to grow plant under so high surface temperature, a portion of the capacity is advised to be supplied with this system, while the rest to be covered by a secondary one. If the system for instance, is used only 60% of its capacity (720 Btu/h m^2), then the surface temperature will decrease at30 ^{o}C. A secondary system could be fan-coil system in order to meet peaking demands. In Mediterranean region, usually 55% of the maximum thermal needs are covered by the surface pipe system and the rest 45% by air fan-coils systems. This surface heating system, therefore is applicable in greenhouses with plants which can stand higher temperatures at the level where the plant grows, such as tomatoes and peppers.

The spacing, size and the number of the tubes supplying the heat is dependent upon the available water temperature and the heating requirements; parameters that they define velocity rate. Common sizes are 1/2 in. or 3/4 in.

Transmission and distribution pipeline network

After adequate sizing of the system, the pressure drop of the pipe network and the material and the quality of the tubes has to be defined. In the past, tube materials were generally copper or steel. However, corrosion and expansion problems force the manufacturers to turn in non-metallic materials, such as polyethylene (PVC), polypropylene (PP) and polybutylene. Non-metallic material in roll formation are easy to install, are resistant to H_2S-induced corrosion and are able to keep quite high temperature (up to 80 °C).

For transmission of geothermal fluids, PVC is by far the most widespread material, since it’s a low cost material easy to found. For water temperature of 50 °C, PVC has a share of 93% with respect to the pipe length, while the rest materials include PE (2%), PP (1%) and carbon steel or iron (3%) (Andritso et al., 2007).

As already mentioned, the length of the pipeline is a function of the loop style. In case of horizontal loops pipes are located in trenches in lengths up to 400 ft, while multiple loops are needed to cover the heat in greenhouse. In vertical loops, small diameter holes from 35 to 200 m deep are buried.

The tube used to transfer geothermal water from the collector tank in the greenhouse heating system and then to the reinjection tank, is consisted by 10 cm black poly-butylene pipe with simple thermostats connected to pumps to push water.

For transferring heat through surface heating system polybutylene is the most common used material. The pipe system may be placed in different high levels within the greenhouse, according to the farming needs. Preferable is recommended to fit the tubes parallel in u-bond design, by placing the pipes in 65-85 cm distance from the floor and at 1–2 m space interval. In this way, the pipeline system run closed to the growing plants. Higher or lower interval distance of the tubes may affect the ability of heating efficiency and in turn, the heating area potential. Usually, plastic pipes of 30–40 kcal/(h m) capacity are recommended. For fluids less than 50°C, however, bigger pipe diameter (25 mm) is required, since the heating efficiency is decreased about 8%.

2.3 Estimated installation cost&completion time-frame

The last decade, geothermal greenhouses gain popularity, since their operation is based on renewable energy by providing low environmental impact. This type of system can gain up to 70% in heating costs and for that reason more and more geothermal greenhouses are established. Before undertaking such work, however, the estimated installation cost and the completion time-frame must be defined. Particularly, the overall price is composed by the cost needed for drilling and underground loop, the geothermal energy production equipment and the energy distribution system.

The drilling and underground loop price is actually changed with the soil type, the access to the drilling site, the stability of the drilling rig site, and how deep the hole must be dug. All these criteria are functions linked with the total greenhouse heat demands that varied according to the size of the greenhouse (Btu required for the area to heat or cool) and its insulation properties: the geothermal heat pump, the supply/return manifold, and the pump module. The heavy-duty steel pipes for instance, cost more without improving the heating system performance, while the fan-coils cost four times more than plastic pipes of similar efficiency. Additionally, northern climates have higher costs due to the need for extra equipment such as thermal curtains among others.

Briefly, the geothermal system is around 1.5 times more expensive than a conventional heating system. The process of drilling a well is a factor among other that make the system more expensive. Additionally, the rising price is a fact because more plumbing involved to the greenhouse installation. Through this process, however, the yearly operation costs are considerably decreased by saving more heat energy. Campuzano-Páez(2014) present a financial method to calculate all cash flows required in a geothermal project.

*In practice, a*n average cost of one acre of geothermal greenhouse, including the greenhouse and operating equipment, is approximately 135,000 €/acre$624,000, excluding economies of scale. Of the total, construction costs alone are 100,000-140,000/acre. The total greenhouse costs (includes greenhouse and operating equipment) ranged from €100 - 140/m^2 of greenhouse, while the construction costs alone were in the €70–80/m^2. Land costs are a significant portion of the total capital investment (Boyd, 2008).The average cost of drilling a non-pressurised well to a depth of 80 m is estimated to be around €20,000 (Thain et al., 2006).

The annual operating cost of a geothermal system, on the other hand, is a function of the greenhouse space need to be covered, the total hours of running the system and above all, the cost of the electricity performed that period. This relationship is expressed by an equation presented below:

$$\$_{space} = h \times \frac{Q_{\max}}{COP} \times \$_{unit} \tag{2}$$

Where:
$space = cost of space heating
h = number of hours operated per year
COP = coefficient of performance
Qmax = maximum heat load (kW)
$unit = unit cost of electricity

The annual cost of running heat pump ($heat pump) for hot water is calculated by another equation that enable parameters concerning the unit cost of electricity ($unit), geothermal energy supplied (Egeothermal, kWh/day), the number of days (d), the maximum heat load (Qmax, kW) and the electric power input for pump (Pelectric, kW):

$$\$_{heatpump} = \frac{E_{geothermal} \times P_{electric} \times \$_{unit} \times d}{Q_{\max}} \qquad (3)$$

Details about calculating the geothermal energy supplied in the greenhouse is presented in the next section (see Equation 6).

The geothermal greenhouses are building regularly in three phases. In Phase I, the technical and business plans are completed in order to receive the license of the authorities. Additionally, the funding, the vital partnerships, the insurance and the land availability and ownership have been already clarified until the end of that phase. PhaseII involves construction of the project, while PhaseIII involves initiating operations and management of the project including building the sustaining income crucial to the system long-term viability. The time-frame completion of a geothermal greenhouse is depending, however, first and foremost on the license process. If that process takes too long, project financing can, among others, be jeopardized. Practically, less than 2-years long, a geothermal greenhouse of 100acre will be in operation.

3. Works Required for the installation of the Geothermal Greenhouse

A concrete knowledge of this energy demand, is the start point to design and thereafter to build a sustainable geothermal energy system in greenhouse cultivation (Cabrera et al., 2017). However it is essential, before deal with the geothermal system installation, to carefully calculate the payback expected after few years, due to the energy-saving measures applied, such as installing energy curtains, insulating sidewalls and the foundation perimeter or making good use of growing space and installing electronic environmental controls. These measures reduce the size of the geothermal heating system needed to heat the greenhouse, since the total heat loss is significant decreased.

Afterwards, with this knowledge, the size, the interconnections and distribution lines of the system and the way in which the system interact with the greenhouse environment are able to be assessed. Additionally, all the operating costs based on overall energy demands are able to be estimated. Particular attention must be also focus in the corresponding calculations of the energy storage ability of the system under different meteorological conditions.

However, before considering to build a geothermal unit to cover greenhouse need, there are some items that need to be thought about, such as the location, type and size of the greenhouse. Additionally, crops to be grown, the growing period, the growing media and system, the type of heating / cooling system, the marketing system and the type of the greenhouse are among others, few of the items you need to think about before you can get together a plan.

In general, to establish a geothermal greenhouse, technical and business plan is required by experts and greenhouse managers. Figure 16and 17show the different stages of the study and the whole simulation of the steps needed to be followed in designing a geothermal greenhouse, which will be explained in detail below. These steps are involved in ongoing process in which some of them will managed on different phases and some shall be carried out simultaneously.

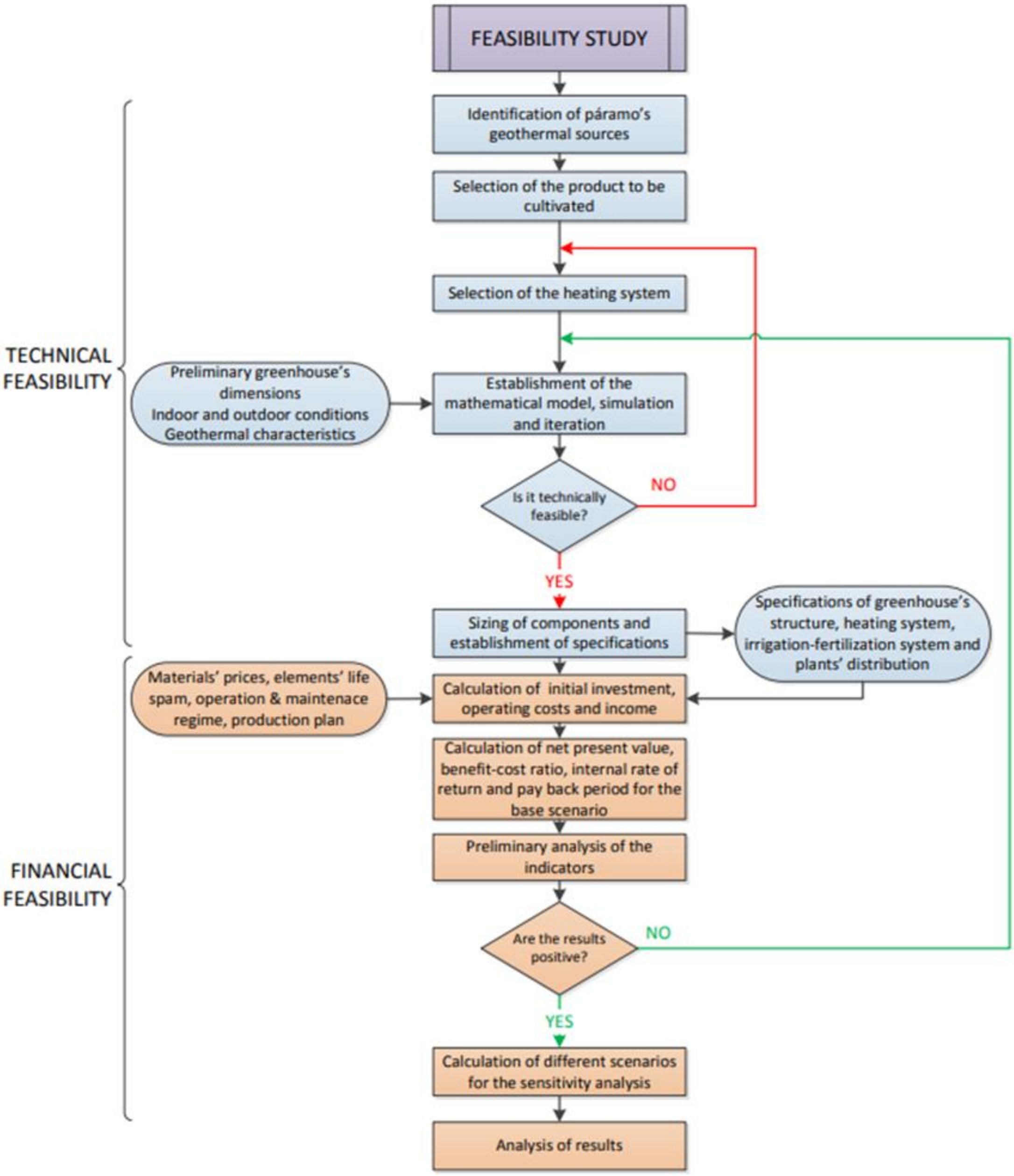


Figure 16. Feasibility study stage of a geothermal greenhouse. Source by Campuzano-Páez (2014).

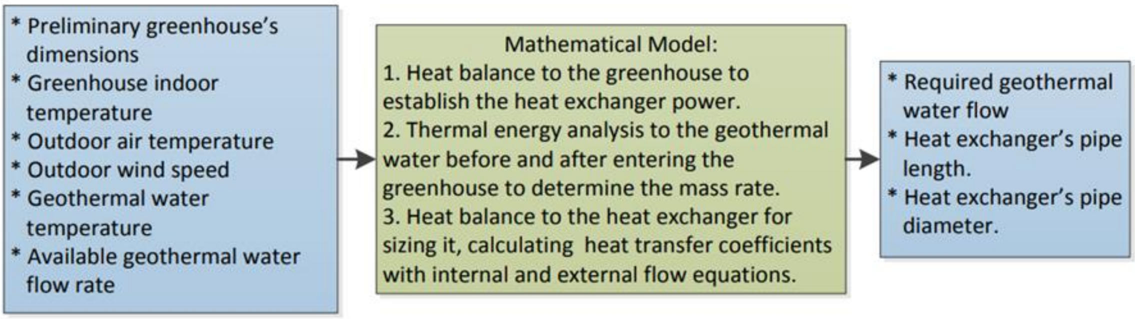


Figure 17. Simulation of the steps needed to be followed in designing a geothermal greenhouse. Source by Campuzano-Páez (2014)

Technical feasibility plan

One of the steps is to develop a technical plan in which all the details about the technical point of view of geothermal greenhouse construction including equipment and materials are designed. Additionally, a technical plan seeks to determine the possibility to provide an easy to install system with the existing technology in the desired region taking into account food security and market conservation.

The technical specifications of the geothermal greenhouse designed system that can be implemented in the future are provided step by step below.

Step1: Greenhouse energy requirements

The first step in designing a geothermal greenhouse is to determine the heating requirements which primarily on of the total heat load and losses. As already mentioned, the heat loss for the greenhouse structure is a function of the heat transmission losses through the walls and roof, and of the ventilation losses caused by heating of cold air to replace warmed air vented from the greenhouse. In Figure 18 the accurate thermal load calculation that must consider, according to the approximation of the actual behavior to steady-state conditions and a lumped parameter representation are presented.

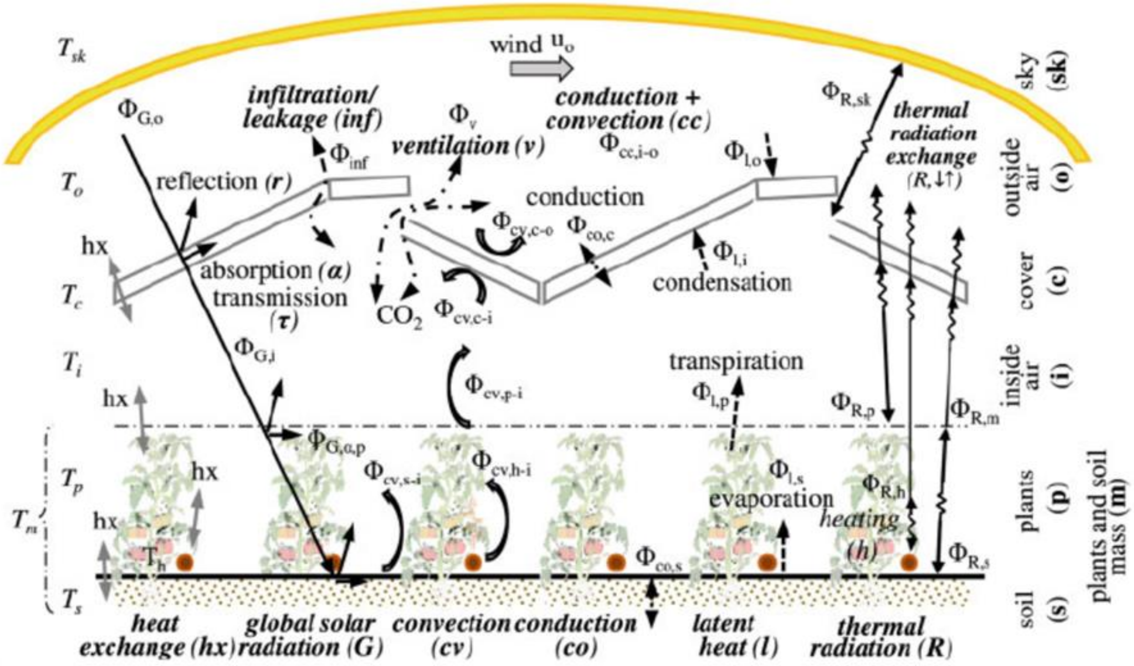


Figure 18. Performance of thermal loads of a greenhouse.

To achieve heat loss estimation, the total surface area exposed to outside air temperature is initially calculated along with the heat transmission loss. A single polyethylene- greenhouse for instance, with dimensions of approximately 7 m x 90 m with and 2.5 m and 1.5 m sides and curved- roof high respectively, perform 8,9 m^{3}internal volume and 3,5 m^{2}totalsurface area exposed to outside the air temperature. Afterwards, the heat transmission loss through the covering material is a function of heat loss due to transmission (Q_1, kW), the surface area exposed to outside air (A, m^2), maximum temperature difference (T_{diff}, °C) and heat loss due to material for given conditions (Q_{mat}, kJ/m^2 /°C):

$$Q_1 = \frac{A \times T_{diff} \times Q_{mat}}{3600} \qquad (4)$$

Then, since transmission heat loss is calculated, the heat loss through ventilation (Q_2, kW) is estimated according to internal volume of greenhouse (V, m^3), maximum temperature difference (T_{diff}, °C) and air heat transfer coefficient (U_{air}, kJ/h/m^2/°C):

$$Q_2 = \frac{V \times T_{diff} \times U_{air}}{3600} \qquad (5)$$

The sum between the transmission and ventilation heat loss define the total heat load required (Q_{max}, kW) to maintain growing space at the desired temperature.

Step 2: Source of geothermal energy-Drilling and well construction

Each project concerning greenhouse constructions includes a series of processes in order to drill a new geothermal well. Initially, particular attention must be focus on designing the proper dimensions of the well, like the depth and the hole's diameter, and sometimes to the number of the new wells are required to drill in order to cover greenhouse needs. Regularly, the length of each casing well is roughly 1/3 of the depth

of the hole to be drilled; 300 m of drilling well for instance, requires about 100 m available surface area. Additionally, the materials which will be used in the construction procedure, also have a key role, since their choice will define the effectiveness of the system. The exact determination of the above parameters are function of the desired fluids temperature and flow rate needed. The main consideration, however, is the depth, the thickness and the transmissivity or permeability of the aquifer. So, before undertaking any well design, the geothermal and geological mapping is required, while geophysical and geochemical surveying such as sampling and analysis of natural outflows will facilitate the implementation process.

After adequate sizing of the system, the drilling operation starts. There are several versions of rotary drilling rigs but in all cases, the fundamental principle is the same. The well is opened rapidly, once the temperature of the water becomes high enough to cause the water to boil spontaneously and cause enough steam "air-lift" for the well to flow. It is usually enough to open a 2" or3" valve fully to release the air to induce the well to flow. In a stage further, the capacity of the well-pump adjusted in the head of the drilling hole is calculated. Commonly, a well-pump of approximately 485 hp is capable of pulling out the geothermal fluids. The geothermal fluid at 42 ton/h can meet the heat needs of a surface area of 10,000 m^2 for high-quality cultivation.

Afterward, there is usually not much to do to keep the well properly maintained (Thorhallsson, 2003).For better understanding the production well behavior, however, and its long term monitoring of the physical and chemical changes, usually a monitoring system is set up. The main parameters that are continuously measured are among others the wellhead pressure (WHP, bar-g), temperature (WHT, °C) and the total flow rate (Q, kg/s). The downhole temperature and pressure surveys are examined 1- 2 times per year, either with the well shut in or while flowing. Occasionally, tests about casing damages or corrosion are run, while chemical samples are taken at the wellhead 1-2 times per year through a small sample separator of the steam and water phases.

Usually, a resource consent that allows to the owners to drill underground water, must be approved by the local regional council for the use of geothermal resources. In this way, it is ensured that all the activities are carried out according to the standard conditions.

In Greece, licenses for exploration, exploitation and management of a field (or part of it) are provided by the Decentralized Administrations (for low temperature fields) or directly from the Ministry of Environment and Energy (for high temperature fields).The geothermal exploration and exploitation in Greece are defined by Geothermal Law 3175/2003 ("Exploitation of geothermal potential, district heating and other provisions") and the relative Ministerial Decrees.

__Step3: Geothermal energy and flow rate calculation according to greenhouse requirements and energy source__

The geothermal energy (Egeothermal ,kWh/day), eventually is drilling to supply the greenhouse is depending on the size of the greenhouse itself and its volume of water required (V, L), the enthalpy for high temperature (H_{T1}, kJ/kg) and the enthalpy for low temperature (H_{T2}, kJ/kg):

$$E_{geothermal} = \frac{V \times (H_{T1} - H_{T2})}{3600} \tag{6}$$

With this knowledge, the flow rates of geothermal fluid ($F_{geothermal}$, kg/sec) in a greenhouse heating circuit with a95% heat transfer efficiency is calculated, see equation xx:

$$F_{geothermal} = \frac{Q_{\max}}{0.95 \times (H_{80} - H_{45})} \tag{7}$$

Where H_{80} is the enthalpy at 80°C (334.8 kJ/kg) and $H_{45}$the enthalpy at 45°C (188.3 kJ/kg), assuming that the geothermal fluid temperature is about 80°C, and a geothermal fluid exit temperature about 45°C. In case of two-phase, a secondary fluid is provided to heat the energy to the greenhouse. In the secondary geothermal fluid, the flow rate is usually estimated with lower enthalpy, see equation xx:

$$F_{secondary} = \frac{Q_{max}}{(H_{75} - H_{40})} \tag{8}$$

The pressure exerted by a column of fluid (Thorhallsson, 2003) is:

p (bar)=9.81 * density (g/cm3)*length of column (m)/100

Step 4: Type and length of loop system requirements

In order to calculate the loop size and the length of piping (l_{pipe}, m), the Q_{max}, the heat transfer coefficient of pipe (U_{pipe}, kW/m^2 /°C) and the natural log mean temperature difference (LMTD, °C) are considered, see Equation xx. The LMTD parameter is calculated according to the greatest heating water temperature (T_{GHWT}, °C),least heating water temperature (T_{LHWT}, °C) and the growing temperature (T_{grow}, °C).

$$l_{pipe} = \frac{Q_{max}}{U_{pipe} \times LMTD} \tag{9}$$

$$LMTD = \frac{(GTTD - LTTD)}{Ln\frac{GTTD}{LTTD}} \tag{10}$$

However, not only in choosing and designing loop type but also in the construction of the greenhouse in general, the land availability is of high importance consideration. To gain access to lands either through lease or direct ownership is a big step forward to the geothermal greenhouse construction process. Ownership of geothermal resources, in any case should be clarified by law. By defining through the legislation who is accountable in the establishment and operation procedure, will avoid a possible confutation occurring in surface and subsurface owners, as well as deceleration for project corporations that can influence their ability to gain new investors.

It is necessary, however, the land which is under recommendation, to provide some specifications, such as secure water right in order to permit the construction of productive wells with sufficient fluid disposal. Additionally, in regulation process, is required contact local and/or county agencies to ensure compliance with local land use laws including building permits and zoning restrictions.

Step 5: Heating equipment

In some cases, the loop type and the pipe network itself are not able to reach the optimum heat quantity needed under a specific set of conditions, and heat exchanger system is required. To quantify the heat exchange capacity and its required surface area (A, m^2), regardless the style, the heat load in (Q, kJ/h) and heat transfer coefficient (U, $kJ/h/m^2/°C$) are taken into consideration. Additionally, the log mean temperature difference (LMTD, °C) and the LMTD correction factor (0.85 to 1.0) for most geothermal applications are adjusted, see equation xx. However in this case, the LMTD parameter is calculated by the difference between the entering and leaving temperatures of the two fluids, as shown in the equation xx.

$$A = \frac{Q}{U \times LMTD \times C_f} \quad (11)$$

$$LMTD = \frac{\Delta_{Ta} - \Delta_{Tb}}{Ln\left(\Delta_{Ta} - \Delta_{Tb}\right)} \quad (12)$$

Where:
Δ_{Ta} = Temperature of inlet geothermal fluid – Temperature of outlet process fluid
Δ_{Tb} = Temperature of outlet geothermal fluid − Temperature of inlet process fluid.

In a stage further, the greenhouse heating system is selected by defining first the type of crop being grown. Tomatoes and peppers require heat to be supplied around the plant canopy, thus the heating pipe should be above the ground. In contrast, root crops like calla lilies require heated ground and in this case, the heating pipes should be buried in the ground. To heat a greenhouse, temperatures of geothermal water should be between 60°C and 80°C. The quantity of hot water required will depend upon the optimum growing temperature for the selected crop, size of the greenhouse, and the lowest outside temperature expected in the area (Emeish, 1999).

Business plan

A financial feasibility study assesses a base case financial plan about the materials investment and services required to build and install the geothermal greenhouse designed in the technical step.

Operation and maintenance costs include seeds, fertilizers, pesticides, water and electricity bills, salaries, the reposition of materials that have ended their life span and all the materials needed for production. Income is determined with an estimated production yield based on the assumption that geothermal heating allows for optimum plant growth. The project's financial feasibility is usually evaluated according to general rules suggested in the literature analysing the indicators for different scenarios.

In this effort, government investment therefore playsa crucial role in opening up and preparing geothermal projects. If these initiativesare successful, other entities step in with funds for subsequent phases (Ngugi,2012). The scope of the public sector, on the other hand, in geothermal energy progress is to promulgate the required policy coordination and legislation and provide fiscal incentives to attract investors. Governments assign the geothermal resources according to the general demands and coordinate sponsor finance. Additionally, among others the government smooth the way for geothermal resources exploration and contribute in research promotion. Besides, governments can expand guaranteed concessionary funding to financiers to raise investments in geothermal energy progress.

Occasionally, according to the country, the regional authorities are first and foremost responsible for the integrated management of natural and physical resources and the regulation of food protection and biosecurity within each region. Otherwise, the public sector finance the progress of the procedure (according to Clean Energy Council, 2011), by providing loan guarantees for pilot projects, so that unsuccessful projects do not have to repay loans in full. Last but not least, the region bodies play a key role in motivating private insurance companies to undertake the risks of developing geothermal resources and commercial banks to invest in geothermal development projects at earlier stages of their implementation (Van Nguyen et al., 2015)

4. Replicability procedures

There is no significant geographical limit to outcome geothermal energy for covering heating and cooling demands, since the ground surface temperature is used without any geographical restriction. However, even in direct use geothermal systems that work by taking the advantage of the higher temperatures performed in greater depth, ground is not the limit but the investment and functional cost demanded to drill to this depth and the accessibility in innovative technologies needed for producing geothermal heat.

Aspects that affect the drilling procedure, therefore, among others, is the geology, hydrology and land availability. Ground synthesis(rock or soil) and its properties act on heat transfer rates and therefore need to be taken into consideration for designing geothermal systems, while the quality of the ground and surface water define the style and the effectiveness of the ground loop. The size and layout of the land, landscaping, location of sprinkler systems, etc., determine the design of the geothermal system as well. Additionally, ignoring the high cost required in any geothermal project, the most significant aspect limiting the integration of geothermal technology in greenhouses is the competition for land-use between the need of intense cultivation and the energy systems themselves. In this sense, although geothermal energy is promising for greenhouse application, it is only possible at sites with suitable geothermal resources that can be developed (Adaro et al., 1999; Bakos et al., 1999).

An access to the spatial distribution data, therefore, of the area in which geothermal technology intended to be transferred will aid the experts to clarify the feasibility of the system in the specific area. The use of specialized software for maps (such as ArcGIS) may supply more accurate spatial information. Otherwise, maps in JPEG format could aid to determine in more details the interested territory. Orientation to the geothermal maps, if such maps are available, facilitates even more the process, since it is provided on where to explore to reduce the risk and ensure a higher likelihood of drilling success.

In support of transferring geoscience data, the subsurface temperature, fluid and permeability of the new region should be defined, while the need for an additional heating or cooling function for the pump can be assessed. By studying how much heating or cooling is demanded in that particular geographical location using heating and cooling “degree day” data will adjust the system in the current greenhouse needs.

Overall, during the process of transferring technology from one region to another, it should be carefully considered if the system design properties meet the specifications defined by the responsible ministry authority of the area concerned. An effective, efficient, fair and common system for regulating exploration of geothermal in

Mediterranean regions is a critical firststep to encouraging geothermal energy progress. One approach for transporting geothermal energy technologies to another countries easily is to create a single window based on specific guidelines about system adjustments in technical inputs, financial and reporting requirements, so that the investors does not have to apply to separate authorities for different permits. Likewise, a plain language version should be developed that outlines for stakeholders the regulations for geothermal energy exploration and development, and opportunities for public consultation (Holroyd &Dagg, 2011).

5. Pros & cons compared to Conventional Greenhouses

5.1 Advantages

Geothermal energy has many advantages, especially when it's applied in greenhouse cultivations:

1. Geothermal system perform minimal impact to the environment, since the demanded energy is produced without burning fossil fuels. So practically, the system operates by producing only minor emissions (like hydrogen sulfide, carbon dioxide, methane and ammonia), while more than 80% energy savings is occurred.

2. Generally, once the capital cost of installing the well and piping has been covered, the operating costs of a geothermal plant are lower than for other energy sources and maintenance can usually be done by the user. For operations in rural areas, the cost of installing geothermal may be similar to, or even cheaper than, setting up fuel storage facilities or constructing power or gas lines from the nearest retail source.

3. The energy capacity of the system is stable and predictable over all year long, even under inconstant external circumstances.

4. High efficiency of geothermal systems is occurred, because it is supplied with 25% to 50% less electricity compare to the conventional systems.

5. The duration of the geothermal heat pump lifetime is relatively high, since only few movable compartments are not buried in the ground. Regularly, a geothermal heat pump last for at least 20 years.

5.2 Disadvantages

However, each system perform a series of drawbacks as well:

1. The basic disadvantage of the system is the up-front high capital cost is needed to establish a geothermal greenhouse. Although such investment is sounds profit, the need for drilling and installing quite a complex technology makes the price climb quite high. Overall, it is worth-wile to invest in large scale geothermal greenhouses, payback.

2. Another disadvantage is the possibilities of depletion of the geothermal well that performed in a time after drilling, without afterwards allowing to harvest more

geothermal energy in future. This phenomenon is avoided only if the well is drilling close to a magma, but therefore is not still possible, since a new developing technology is required. However, it is worth to invest at that direction, since the geothermal wells in that area may be active for many many years.

3. A drawback of applying geothermal energy in greenhouse operation is, additionally, the extended land required for drilling and exploitation. Generally, the geothermal unit delivers the maximum capacity, as less is the distance between the greenhouse and installed point of the drilling wells. That makes geothermal systems hard to be applied in already established greenhouses, unless a vertical ground source heat pump is used.

5. Geothermal project requires experts and trained operators to monitor the whole system, while proper education and training of the growers is required.

5.3 Comparative analysis

Table 2. Comparative analysis

Category	Geothermal	Conventional
Energy Consumption		2,500-3,000 kWh/20acre/year
Installation/construction cost	100-140,000/acre	20-50,000/acre
Fuel cost	80% less	
Functional cost	5-8% less	
Production Capacity		
Water consumption		
etc.		

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