INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy

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Division of Earth Sciences

HEATING GREENHOUSES WITH GEOTHERMAL ENERGY

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1 INTRODUCTION

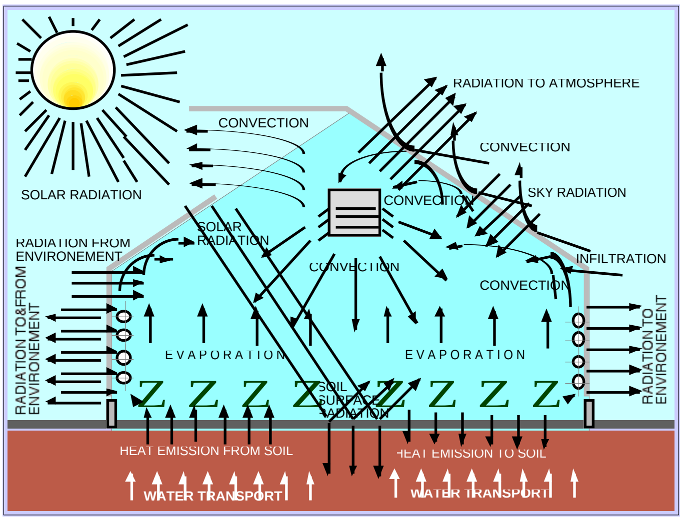
Geothermal energy has been used most extensively in agriculture in greenhouse heating. Many European and other countries (Table1*)* are experimenting (Popovski and Popovska Vasilevska, 1998) but also regularly using geothermal energy for commercial out-of-season production of vegetables1 flowers and fruits.

Although not in order of importance the reasons for choosing geothermal energy in this sector are:

1. Good correlation between the sites of greenhouse production areas and low enthalpy geo-thermal reservoirs.
2. The fact that greenhouses are one of the largest low-enthalpy energy consumers in agriculture.
3. Geothermal energy requires relatively simple heating installations, but advanced computerized installations can later be added for total conditioning of the inside climate in the greenhouses.
4. Economic competitiveness of geothermal energy for greenhouse heating in many situations.
5. Strategic importance of energy sources that are locally available for food production.

Table 1. Geothermally heated greenhouses in the world (Popovski,1998)

Country	*Total area (ha)*
U.S.A.	183.12
Hungary	130.38
China	115.92
Rep.Macedonia	62.46
China (Taiwan)	60
Italy	50.5
Russia	34
France	24.3
Spain	20
Iceland	18
Greece	17.95
Bulgaria	17.6
Slovakia	17.36
Georgia	16.5
Romania	13
Japan	12
Yugoslavia	10.13
New Zealand	10
Turkey	7.3
Slovenia	6
Israel	3
Bosnia/Herzegovina	2
Algeria	0.72
Germany	0.3
Croatia	0.25
Portugal	0.22
Belgium	0.05
Poland	0.05
Total	833.11



As with other uses of geothermal energy, it is not possible to make a general statement that greenhouse heating is the optimal form of application. Each situation must be evaluated separately, and local factors play a decisive role in any decision making (Popovski, 1988b).

2 ENERGY ASPECTS OF PROTECTED CROP CULTIVATION

2.1 Why protected crop cultivation?

Each plant can be considered a chemical factory. Sunlight converts the CQ_2 from the air and the 1120 from the air and soil into plant material such as sugars. The production techno-logy involved in this conversion is called photo-synthesis. Photosynthesis is a reversible process: the free energy of the surrounding environment is captured and stored in the form of plant material, which may he transformed back into $C0_2$ and 1120 by the process of plant respiration.

The energy stored in the form of plant material is used by the plant as 'building material' for its growth. By creating optimum growth conditions we can accelerate such life processes of the plant.

In order to complete a full life cycle, each type of plant needs a specific quantity of energy (i.e. heat). The duration of its development, the quantity and the quality of the crop are governed by the quality and density of the energy supplied to the plant, which are in their turn correlated to the intensity of light available. The ideal natural conditions for supplying the energy required for plant development are available during only a part of the climatic year. These conditions will also be different for different plants, depending on their origin and specific needs. The objective of protected crop cultivation is therefore to guarantee these optimum growth conditions, independently of climatic conditions outside the greenhouse, so as to increase the quantity and improve the quality of the crop. The main problem is thus to identify the factors influencing plant development and the technique, and technologies necessary to maintain optimum growth conditions, within the framework of the prevailing social and economic situation.

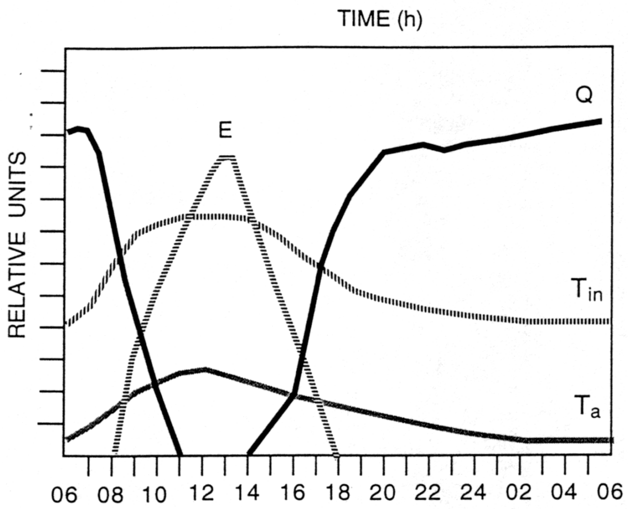


Fig.1. Heat requirement fluctuations in a greenhouse; average conditions in January in a greenhouse in Gevgelia, Republic of Macedonia (from Popovski, 1984). E = solar radiation energy flux (Wh/m^2); T_a = outside air temperature (°C); T_{in} = optimal inside air temperature (°C); Q = greenhouse heat requirements (W)

2.2 Greenhouse climate

A greenhouse is a space bounded by transparent partitions, in which we can maintain a desired 'climate' that is different from the climate outside the greenhouse. There are four physical phenomena that play a major role in creating these differences in climate:

1 Solar radiation, in particular the short waves, penetrates the glass or plastic film covering the greenhouse with practically no loss of energy. On reaching the soil surface, the plant canopy, and the heating and other installations, this radiation

changes to long wave. As long waves are unable to penetrate the walls of the greenhouse as easily as short waves, the energy is trapped within the enclosed space.

2. The air within the greenhouse is stagnant.

3. The concentration of plant mass in a protected space is much higher than outside, so that mass transfer is different.

4. The presence of heating and other types of installations changes some of the energy factors of greenhouse climate.

All the above phenomena involve physical parameters that control the plant growth process We will now discuss these parameters:

2.2.1 Light

This is the most important parameter in plant growth All the other parameters depend directly on light intensity It should be stressed at this point that only radiation with wavelengths between 400 and 700 nm influence the intensity of plant life processes.

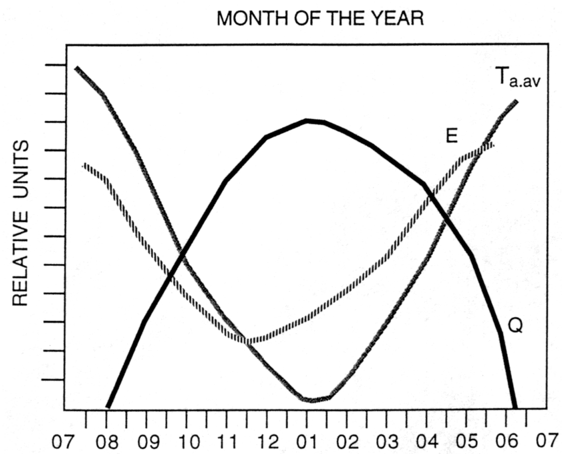


Fig.2. Heat requirement fluctuations in a greenhouse over a typical year in Gevgelia, Republic of Macedonia (from Popovski, 1984). E = solar radiation energy flux (Wh/m^2); $T_{a.av}$ = monthly average outside air temperature (°C); Q = greenhouse heat requirements (W)

2.2.2 Temperature

The transfer of energy from the environment to the plant is governed by plant temperature. This transfer of energy is influenced mostly by the surrounding air temperature but also by the temperature of the soil and of other elements of the environment (greenhouse construction, installations, etc.).

Optimum development of plant life processes depends directly on the level of plant temperature, which depends on the intensity of light avail-able, i.e. the higher the intensity of light, the higher the plant temperature.

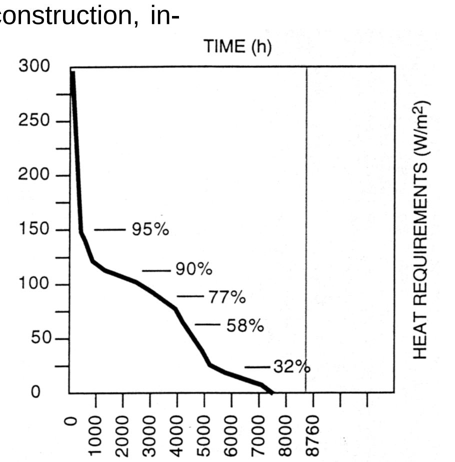


Fig.3. Percentual coverage of annual heat demand for greenhouse heating by alternative energy sources relative to Naaldwijk, Netherlands (from van den Braak and Knies, 1985)

2.2.3 CO2 concentration

The CO_2 in the atmosphere surrounding the plant is used to form the plant 'building materials, such as sugars. Its transformation is governed by light intensity and plant temperature. The higher the intensity of the light and the temperature, the higher must be the concentration of CO_2 in the air.

2.2.4 Air movement

Air movement in a greenhouse influences the transfer of heat between the plant and the air, and the exchange of water between them. Different plant species require different types of air movement for optimum growth.

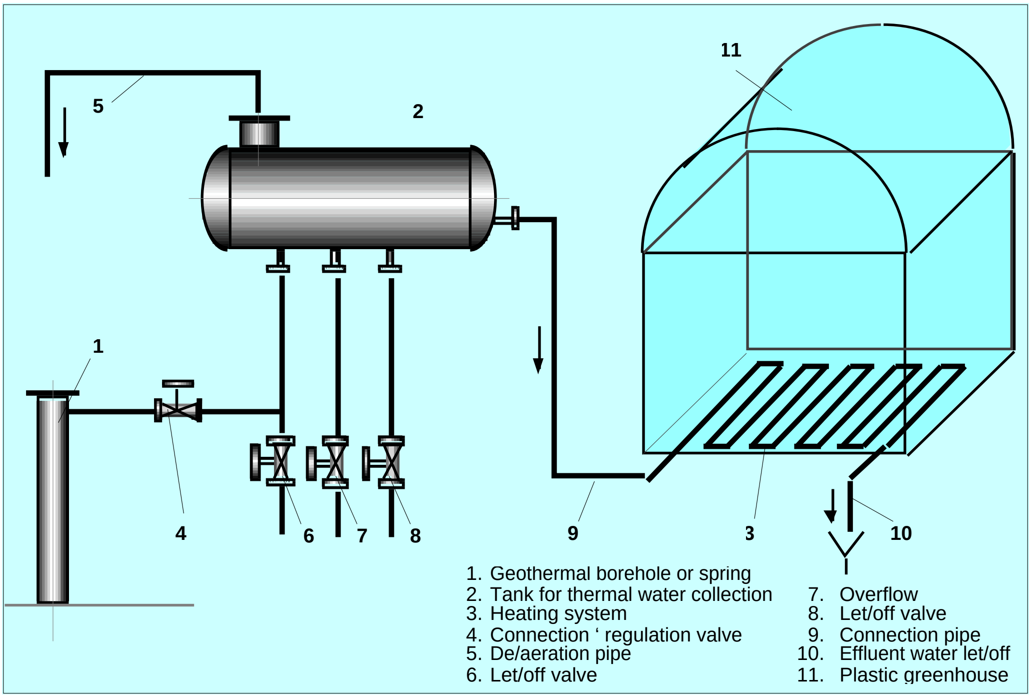


Fig.4. Simple direct connection to the geothermal spring or well

2.2.5 Water transport

Water is also an important element in the production of plant 'building' materials. The plant takes in water from the surrounding air and from the soil around its root system. Optimum conditions of air and soil humidity will, however, depend on the type of plant and its stage of development.

2.2.6 Heating installation(s)

The heating system affects air and soil temperature, and also influences the type and velocity of inside air movement It therefore plays an active role in the plant energy balance.

2.2.7 Cooling installation(s)

Cooling installations are also an active element in creating a greenhouse climate as they influence air temperature and humidity There are other elements that also affect greenhouse climate such as the type of construction of the green-house the materials used for the transparent walls the type of crop and its stage of development

The optimum greenhouse climate i.e. the cli-mate that will permit optimum plant growth de-pending on the available light intensity and qua-lity is the result of a compromise between the op-timal values of each of the above parameters or elements These values are interdependent and at times may be contradictory (Popovski, 1991).

3 CHARACTERISTICS OF HEAT CONSUMPTION

A greenhouse is a construction aimed at creating a protected space for plant cultivation in a controlled environment, even during climatically unfavorable periods The importance of light in the life processes of the plants entails the use of transparent materials such as glass, plastic films, and plates, fibreglass, etc., which also exploit solar energy to raise the inside temperature conditions. However, this is not enough to maintain optimal growing conditions during periods when so-lar radiation is not strong enough and during the night (Figure 1). An additional source of heat is required that can be regulated. The amount of extra heat required depends on the local climate, plant requirements and the type of greenhouse construction. Over a 12-month period, it mainly depends on changes in the outside air tempera-ture and in the intensity of solar radiation (Figure 2).

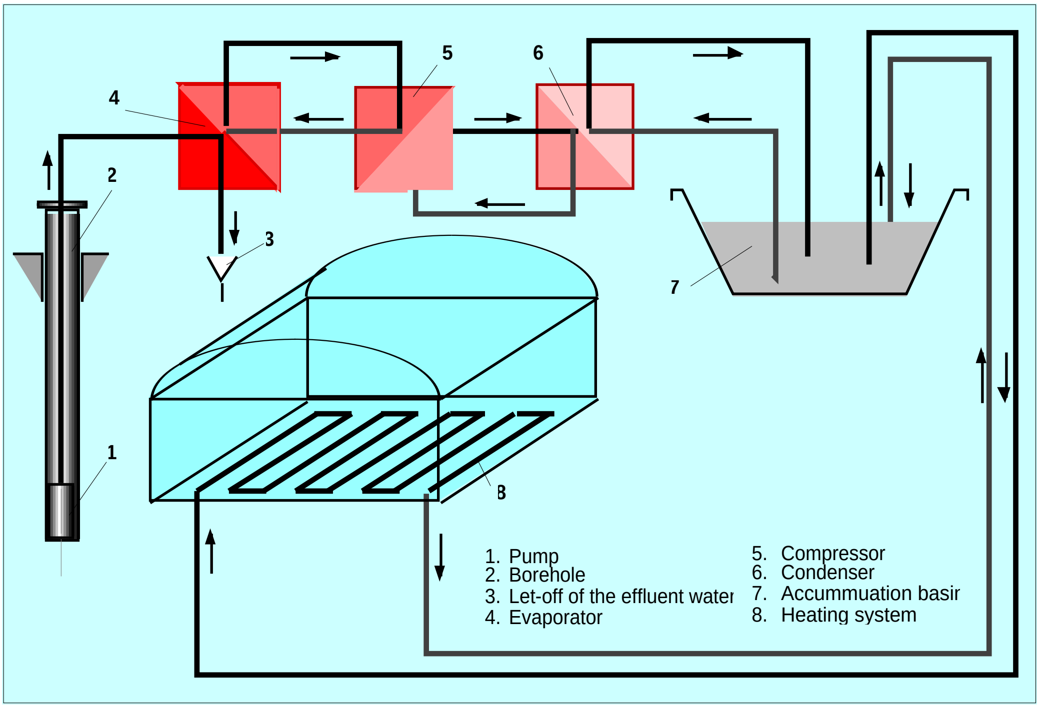


Fig.5. Heat pump installation with simple connection to the well (Agence pour les Économies d'Énergie, 1982)

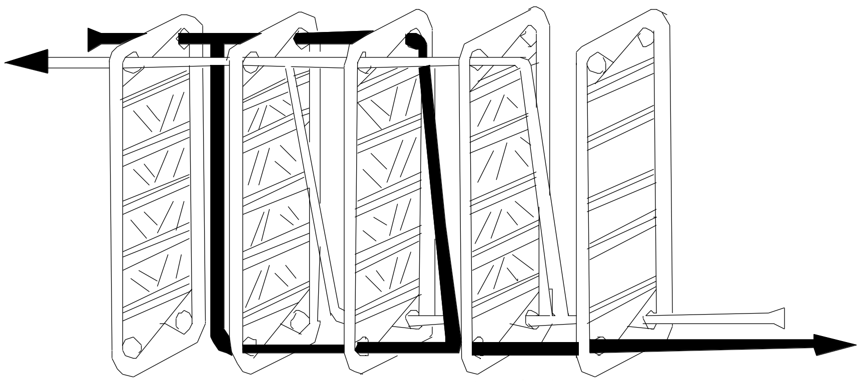


Fig.6. Plate heat exchanger

In Figure 3, which shows the heat requirements of a greenhouse in the Netherlands, we can note that peak demands are of very short duration. Even in the conditions found in northwest Europe, only 50% of the maximum heat capacity is necessary to cover 95% of the total annual heat demand. Similarly. 40% of the maximum heat capacity can cover 90% of the annual heat demand, 25% covers 77%, etc.

We can therefore conclude that heat consumption varies on a daily and yearly basis, with rather short periods of maximum heat demand, It is not justified to invest in expensive installations to cover the total heat requirements of greenhouses. Peak load should be avoided by selective production or met by heat sources that require low investments (Popovski, 1988c).

4 TECHNICAL SOLUTIONS FOR GEOTHERMAL GREENHOUSE HEATING

4.1. Factors influencing the choice of technological solution

The technological solution adopted for the greenhouses depends on:

1. The type of greenhouse production, i.e. the plants require a controlled climate throughout the year or only during some months of the cold season.
2. The role of the heating installation, i.e. to improve or to totally control the inside temperature conditions.
3. The type of well, i.e. artesian or producing by means of electrically driven pumps.
4. Chemical characteristics of the geothermal fluids.
5. Lirnitations dictated by eventual other uses of the geothermal water.

4.2 Hot water transmission systems

The type of system adopted for transmitting the geothermal water from its source to the utilization plant depends on the type of well (artesian or non-artesian) the chemical characteristics of the water and investment and operation costs.

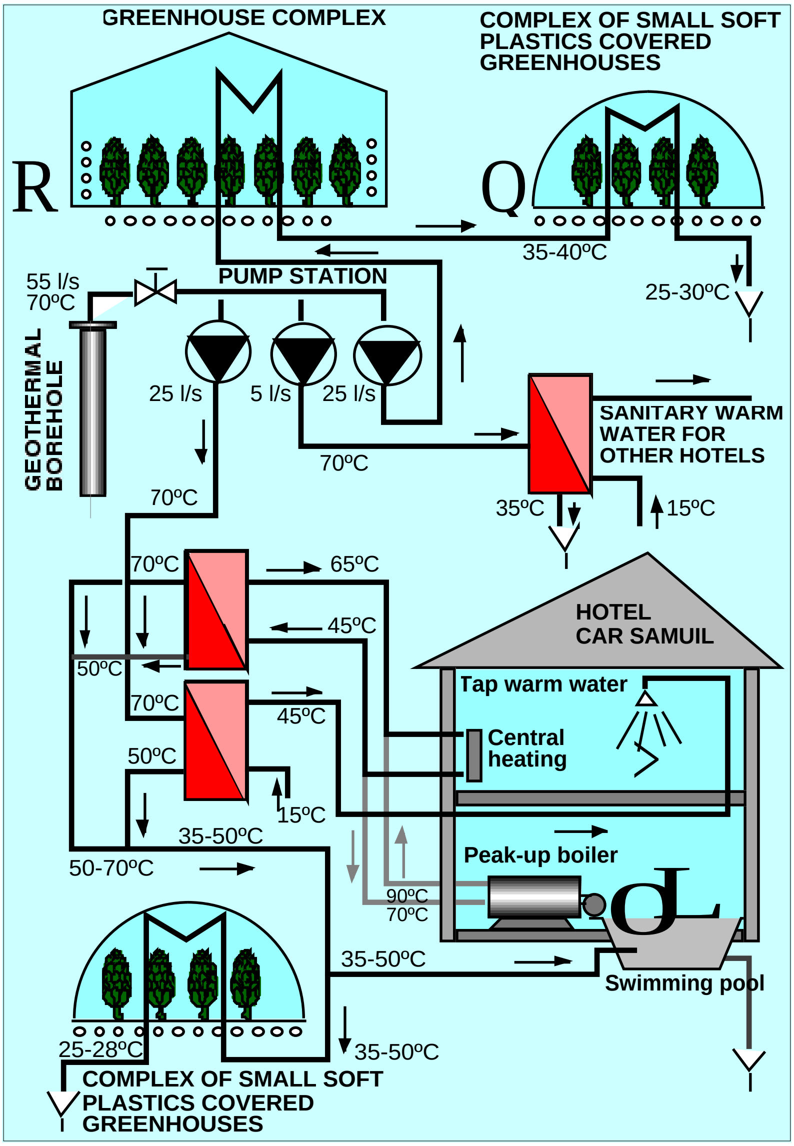


Fig.7. Simplified flow diagram of the Bansko integrated geothermal system (Republic of Macedonia), consisting of greenhouse heating and different heat users of a hotel-spa complex

4.2.1 Direct connections

Low-temperature water with a low mineral content permits us to adopt simple technical solu-tions (Figure 4). The water is collected in an open deaeration tank installed above ground level so that it can *flow* by gravity through the transmission pipeline and the heating installation. The heat is regulated by means of one or more hand valves.

This type of solution is very popular in Mediterranean countries, where simple plastic covered greenhouses are used for an earlier spring crop. It is also a viable option when the water is highly corrosive, provided that only plastic materials are used for the transmission pipes, the heat exchangers and other construction parts that come into contact with the water.

4.2.2 ***Indirect connections***

If the mineral content of the water is very low and the plants under cultivation permit higher in-vestments, a simple transmission from the well can be connected to a more sophisticated heat-ing system (Figure 5), which includes a heat pump (4, 5 and 6 in the Figure). The transmission system is therefore connected indirectly to the heating system. Environmental constraints and waters with high mineral content entail more complicated water transmission systems, including deaeration equipment, regulators of $C0_2$ content and pH, corrosion preventers.

The problems arising with indirect connec-tions (primary and secondary circuits) are mainly tied to the type of heat exchanger used. Plate he-at exchangers have proved to be the best soluti-on for geothermal waters with a high salt content (Figure.6*).* There are several advantages with this model. Their large heat exchanging surfaces are contained within a small space. Different temperature regimes can be combined in one single heat exchanger system. Cross-fluid flows between the plate sections provide high heat-transfer coefficients, and the shape of the plates is such that they can be readily assembled and dismantled. The latter is particularly important where high mineral content of geothermal fluids is concerned, as the equipment has to be dismantled and cleaned frequently to remove scaling deposits.

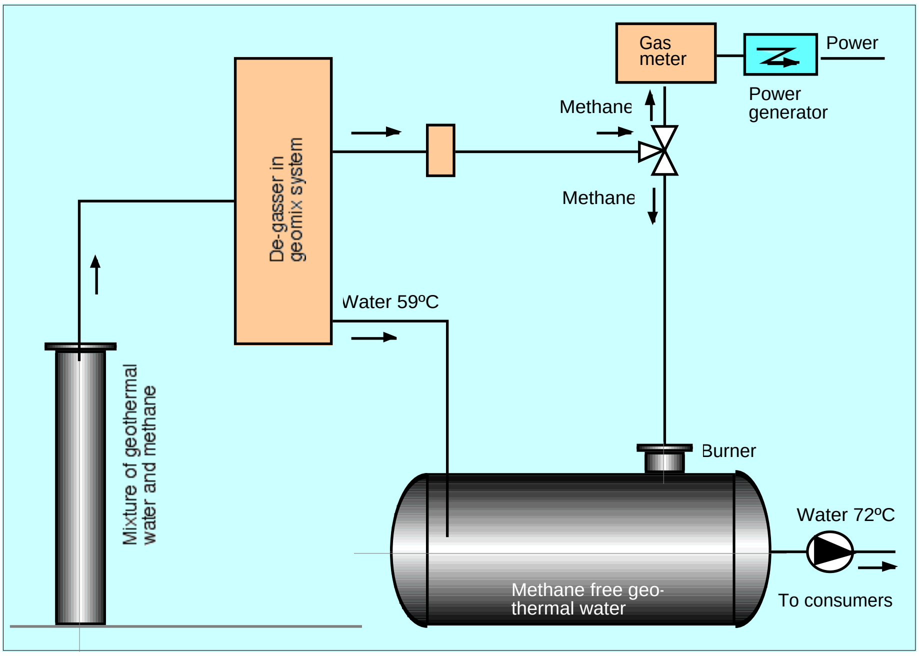


Fig.8. Technically improved geothermal installation in Srbobran (Yugoslavia), with extraction of the CH_4 from the geothermal water for electricity generation and direct heat use for peak demand in the greenhouse

4.3 Combined uses

One of the major disadvantages of using geothermal energy in greenhouses is the rather high investment costs for the well, and the transmission and regulation systems, which may be used for part of the year only (Figure 3) Consequently, the price of the heat used will be high. This problem can be overcome by finding other potential users of the heat Ideally, the annual and daily heat requirements of these potential users should be different, i.e. when one user needs maximum heat the other should need a mini-mum. For example, the price of heat in Bansko (Macedonia) decreased from 6.25 US cents/kWh for greenhouse heating only to 2.-9 US cents/ kWh for the integrated system shown in Figure 7.

In particular situations, it may be more convenient to add cheap auxiliary heating equipment to the system in order to meet peak heat loads of short duration (Figure 8).

5 GEOTHERMAL GREENHOUSE HEATING INSTALLATIONS

5.1 Classification

' Heating installation is the term commonly us-ed for the heat exchanger providing supplementary heat in green-houses. The temperature of the heating medium, i.e. the geothermal water, and the particular requirements of the plants in the greenhouse dictate its design, location, material and means of regulation, etc. The level of sophistication depends on the technological level of production, green-house construction. climate. technical and economical factors.

There are two extreme technological solutions, encompassing a wide spectrum of intermediate schemes. The two extrem-es are described below:

1. Simple heating installation made of plastic materials that connects the heat source directiy with the greenhouse, and manual regulation of the heat supply. The aim of this type of installation is only to improve inside temperature conditions all year round, in mild winter climatic con-ditions or during early spring and late au-tumn in more severe climates (Campiotti er *al., 1985).* It is in use in cheap plastic house constructions that are not tech-nologically suitable for intensive produc-tion. Usually there is no provision for water treatment. Pumping of the water is not always economically justified, but depends on the plants grown, production levels and marketing conditions.
2. Sophisticated heating installations for total alr-conditioning, with automatic regu-lation of the heat supply. The factors influencing heat requirements are indoor and outdoor conditions, plant growth and production schedules. These installations are economically justified in expensive glasshouse or rigid plastic constructions, equipped with technology for intensive production. If the chemical characteristics of the thermal water are unfavourable, the well can be indirectly connected to the greenhouse installations.

These two technological solutions use different types of heat exchanger, depending on heat requirement, chemical characteristics of the geothermal water, greenhouse construction and economic factors.

Aerial heat exchangers can he classified according to the type of heat transfer and location of the heating elements (von Zabeltitz, 1986) (Figure 5.9). From the technical viewpoint this approach is incomplete, since it does not in-clude some typical low temperature installations that are not limited to heating the air only. Nowa-days, the combinations that are most commonly used are those developed between 1986 and 1988 by Bailey, von Elsner and Popovski, becau-se these combinations have been accommo-dated to the growers, particular needs and are therefore much more practical and easy to under-stand. They are as follows:

I Heating systems with heat exchangers within the soil or cultivation base.

2 Heating systems with the exchangers laid on the ground surface or on benches.

3 Aerial pipe heating systems.

4. Fan-assisted convector air heating systems.

5 Non-standard heating systems.

6 Combined heating systems.

5.2 Soil heating installations

The objective of soil heating installations is to heat the plant root system (Figure *5.10).* ey can cover only a part of the total heat demand, and can be used without other heating systems only in very mild climatic conditions. They are eco-nomically feasible only for cultures that require precise temperature regulation of the root system, or in combination with other types of heating installation for temperature control of the greenhouse environment.

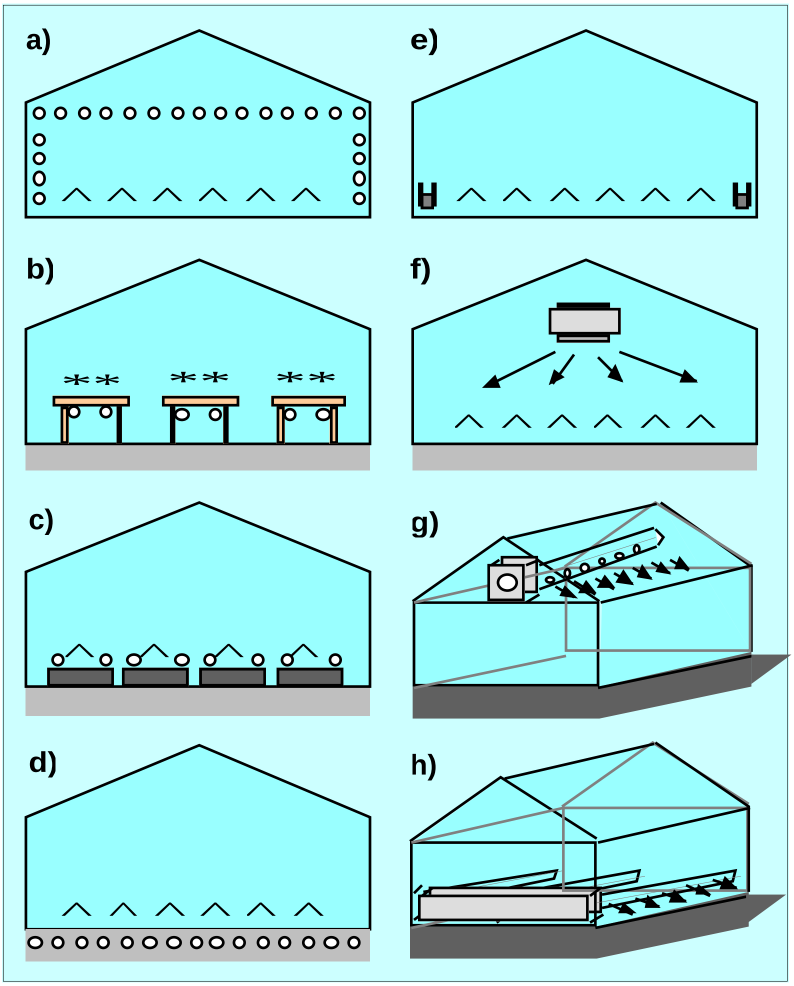


Fig.9. Classification of low-temperature heating systems (von Zabeltitz, 1986). Heating installations with natural air movement (natural convection): (a) aerial pipe heating; (b) bench heating; (c) low-position heating pipes for aerial heating. (d) Soil heating. Heating installations with forced-air movement (forced convection): (e) lateral position; (f) aerial fan; (g) high-position ducts; (h) low-position ducts.

5.3. Soil-air heating installations

These installations consist of a system of heating elements positioned on the ground surface (Fig.11). With this layout the upper layer of the soil and the air are heated, which is very convenient for many cultures. There are different types of heating elements commercially available for this purpose:

I Thin metallic pipes, smooth and corrugated thin plastic pipes, as for soil heating.

2. Transparent plastic sleeves (tubes of large diameter).

3. Polytube plates of soft and rigid plastic.

4. Plastic plates.

Proper positioning of the heating elements (Figure 11) permits an optimum transfer of heat to the plants and minimum heat loss to the environment. It is an excellent solution for covering total heat demand in milder climates or the base demand in moderate and rigid climates.

5.4 Aerial pipe heating installations and convectors

This group of heating installations consists of metallic pipes, finned metallic pipes or convectors positioned above the ground surface (Figure 12) The advantage with these installations is that they permit a rapid and precise regulation of temperature, and can he used on their own even in moderate and rigid climates The drawback is that the heat-transfer coefficient for low-temperature heating fluids is very low which means that the heating surfaces must be very large and may thus reduce light diffusion in the greenhouse and jeopardize working conditions.

The vertical temperature profiles are rather uneven for the pipe heating elements but not for the convectors However, convectors are un-suitable for low-temperature thermal waters.

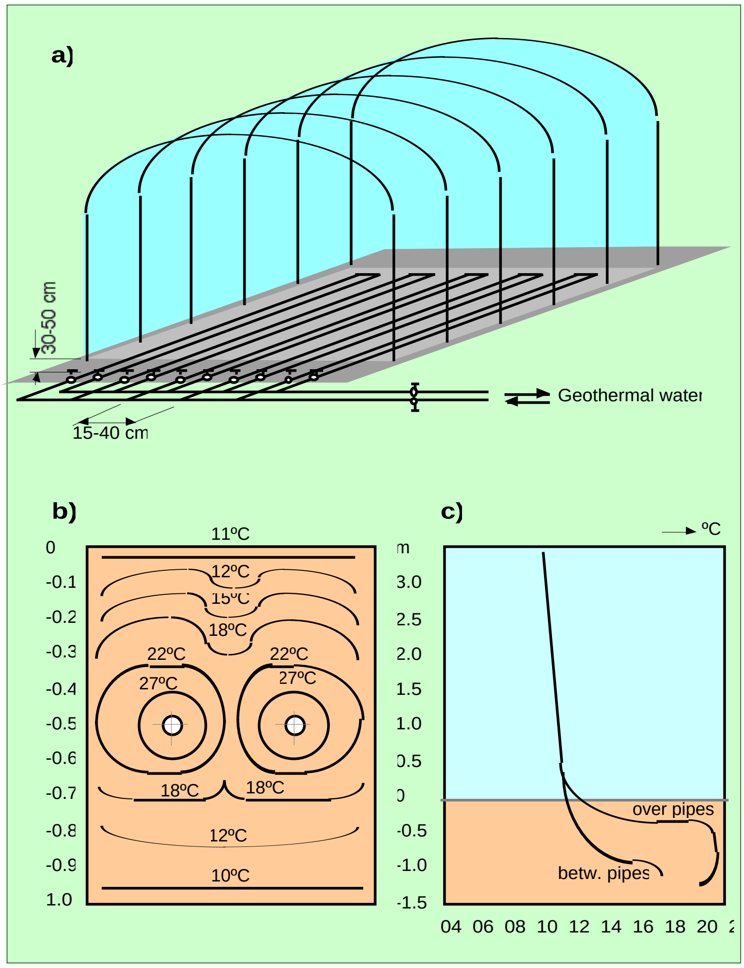


Fig.10. Installation for heating the soil in greenhouses: a) position of heating pipes; b) temperature profile of the heated soil; c) vertical temperature profile in the greenhouse

5.5 Fan-assisted convectors

Significant improvements to the heat-transfer coefficient can be achieved by introducing fanassistance even for rather low-temperature heating fluid. Compact fan-assisted air heating units can be used as the heating element blowing warm air directly into the protected environment; alternatively, these can be combined with one or more soft-plastic air distribution tubes positioned over or between the plant rows (Figure 13) A good technical solution is also that of positioning the fan-assisted convectors longitudinally

The quality of heating achieved depends very much on the technical solution adopted Vertical temperature profiles are fairly uniform when the air distribution pipes are positioned in the middle of the plants, but very uneven when located over them This type of installation is very popular in the Mediterranean countries and the United States as it is simple, cheap, suitable for automatic regulation by means of cheap equipment and guarantees a fast response to outside temperature changes

5.6 Other types of heating installation

Some ingenious heating installations have been designed for particular local conditions For example, an air-water beat exchanger has been developed in Greece (Figure 14) to overcome the scaling problems caused by the geothermal water The pipe carrying the water is positioned inside the air distribution tube The latter is made of cheap polyethylene material, which can he replaced after one or two productive seasons.

Evaporative heating units are also adopted in some cases

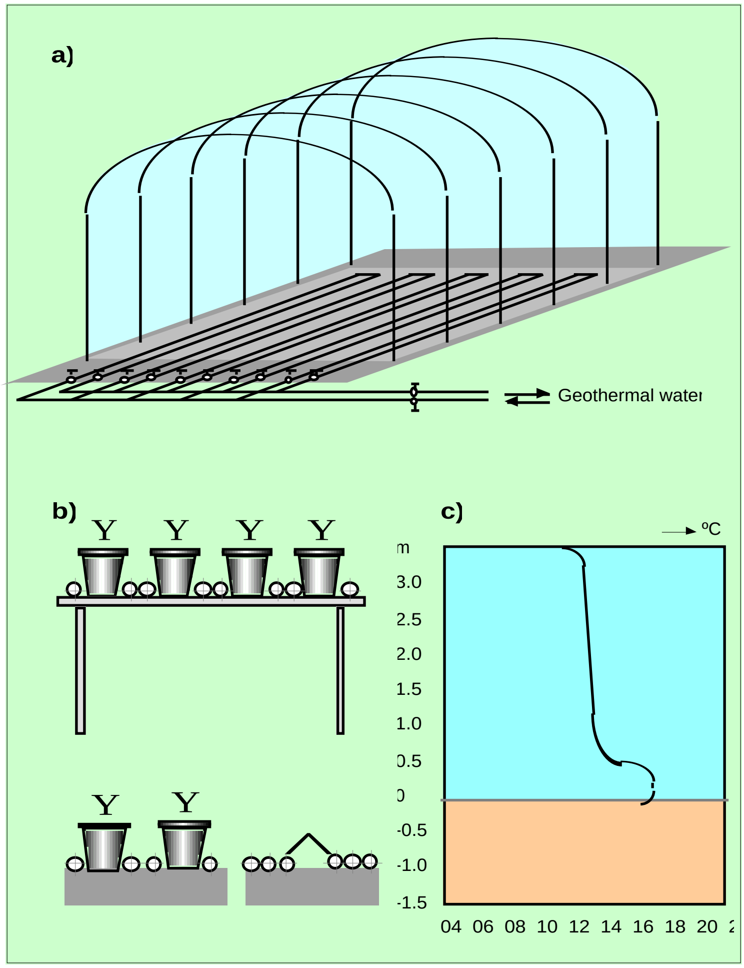


Fig.11. Installation for heating the air and soil in greenhouses (heating pipes placed on the soil surface); a) position of heating pipes; b) different solutions for allocation of heating pipes (cultivation on benches, in pots on soil surface and in soil); c) vertical temperature profile in greenhouse

6. FACTORS INFLUENCING THE CHOICE OF HEATING INSTALLATION

One of the most difficult design problems in a geothermal greenhouse project is the choice of a technically, technologically and commercially feasible heating installation Each case must be judged on its own merits, taking into due consideration all the influencing factors in order to reach the optimal solution.

6.1 Temperature profiles in the greenhouse

The primary objective of the greenhouse heating installation is to maintain the temperature of the environment at values near to optimal However, none of the installations what we have just described will guarantee a totally uniform vertical (Figure 15*)* or horizontal (Figure 16) temperature profile inside the greenhouse For a reference air temperature 1.0 m above ground level, the difference at ground level and below the greenhouse roof could be as high as *56* ºC (Figure 17) It is obvious that such differences can he of crucial importance for the choice of heating installation.

6.2. Economic aspects

The commercial feasibility of geothermal greenhouse heating depends on a number of factors, such as capital investment costs, operating costs, cost of energy with respect to the value of the product, and market available for the product If we leave out all the factors that are common to any energy source, it is obvious that the crucial factor for estimating the comercial feasibility and competitiveness of geothermal energy is the price of the heat *used*

The final price of heat depends on factors such as capital investment required, credit conditions, maintenance and utilization costs, insurance and taxes, labor costs, fuel prices, plant efficiency and utilization coefficient Depending on the type of energy utilized and local conditions, characteristic curves can be plotted (Figure 18) to show the dependence of the used heat price on the annual heat load factor (hours of utilization of the installed heat capacity) (Popovski, 1988a).

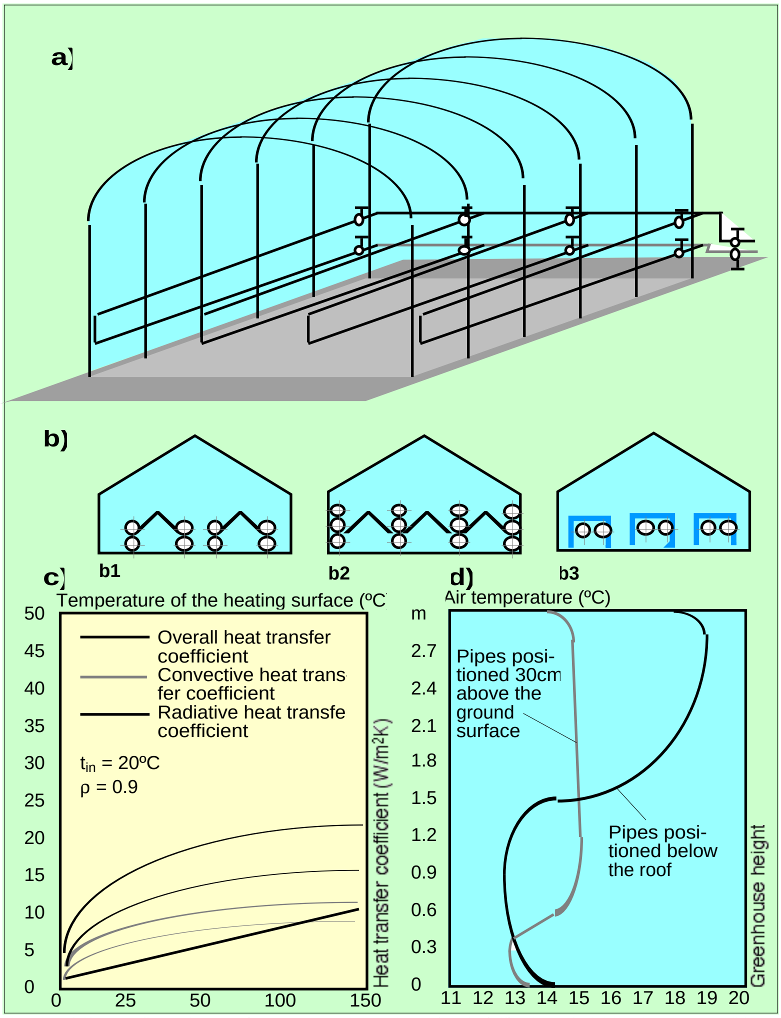


Fig.12. Aerial heating installations made of smooth or finned steel pipes; a) and b) position of aerial pipe heat exchangers for low-temperature heating fluids: b.1) along the plant rows; b.2) in the plant canopy; b.3) below the benches; c) heat transfer coefficient for the greenhouse interior based on pipe diameter and temperature of the heating fluid; d) vertical air temperature profile in a greenhouse heated by aerial pipe heating installations.

These curves will differ from case to case, but generally they show that geothermal energy is not economical for short utilization periods Real benefits can be attained if the available thermal power is used over long periods of the year, i.e. it is very convenient for covering base heat demands It is more economical to meet peak demands with some other energy that does not require high capital investments.

As an example, Figure 58 reports an analysis of economic data for geothermal greenhouses located in Macedonia (Popovski, 1988b) The greenhouses cover 3 ha, with 6 MW, of installed capacity; the geothermal well produces 50 Us and the temperature regime for the heating installations is 70/40 ºC The price of heavy oil is 200 *US$It,* of 12 000 J/kg coal it is 75 US$ and of electricity US$0065/kWh Credit conditions are: 8 years repayment, 2 years grace period, 10% rate of interest The analysis was made by determining the price of the used kWh of thermal energy for different loads during the year, for each of the listed fuels and geothermal energy.

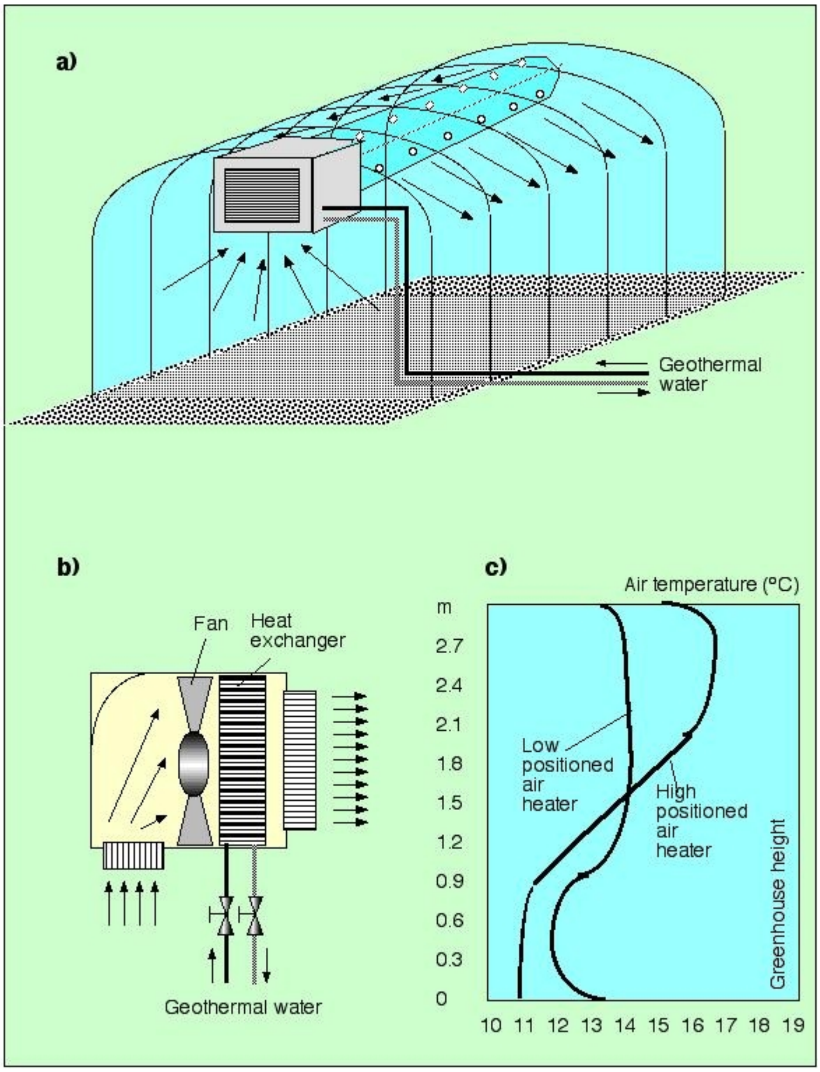


Fig.13. a) Position of the 'fan-jet' heating system in a greenhouse; b) layout of a fan-assisted convector unit; c) vertical temperature profiles in a greenhouse heated with fan convector units at different heights

The optimal ratio of the different energy sources covering total heat consumption can be defined by additional analysis that again accounts for local factors. In the case described above, if total heat consumption is met by geothermal energy, the price of the used heat would be about USs 0.07/kWh. If 50% of the thermal capacity is designed to be supplied by geothermal energy and *50%* by a heavy oil boiler plant, then the price would drop to about US$ 0.04/kWh, which is more economical than using a single form of energy. Ideally the project should envisage a combination of different heat users, with different utilization factors.

For instance, if 6 MW of the total capacity is utilized for greenhouse heating, 6 MW for space heating and sanitary warm water, and 6 MW for crop drying (from July to October), all connected to the same well mentioned above and to a heavy oil boiler plant of 6 MW, it would be possible to attain a utilization factor of 59% for the well (heat load L=0.59) The price per kWh would then drop to only US$ 0023/kwh, which is far more competitive than other energy sources.

6.3. Operating problems

Operating problems are mainly related to the nature of the geothermal resources The problems begin at the spring or wellhead If it is a natural artesian spring then few difficulties will be encountered, but if it is a borehole where pumping is necessary, two important problems may arise: overexploitation could exhaust the reservoir and sand could damage the pumps To avoid first problem, the reservoir characteristics must be thoroughly investigated before starting commercial use, to define the optimal resource management The problem of sand can be solved only by filtering the water before it reaches the pumps and by avoiding abrupt start-up of the pumps.

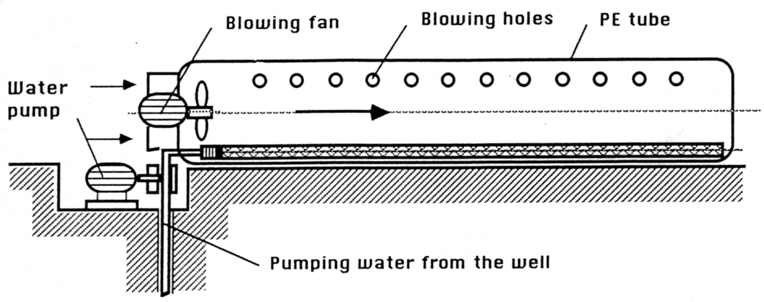


Fig.14. Water/air heat exchanger in air distribution tube (Grafiadellis, 1986)

Another problem is corrosion, mainly caused by O_2, CO_2, and Cl in the geothermal water Three solutions are now being adopted: non-corrosive materials, modification of the chemical composition by de-aeration and separation or neutralization of aggressive chemical components, and indirect connection of the heating installations to the well. A good compromise between technical requirements and economic results has still to be reached Simple solutions will lead to frequent maintenance, whereas sophisticated solutions are too expensive and rarely economically justified.

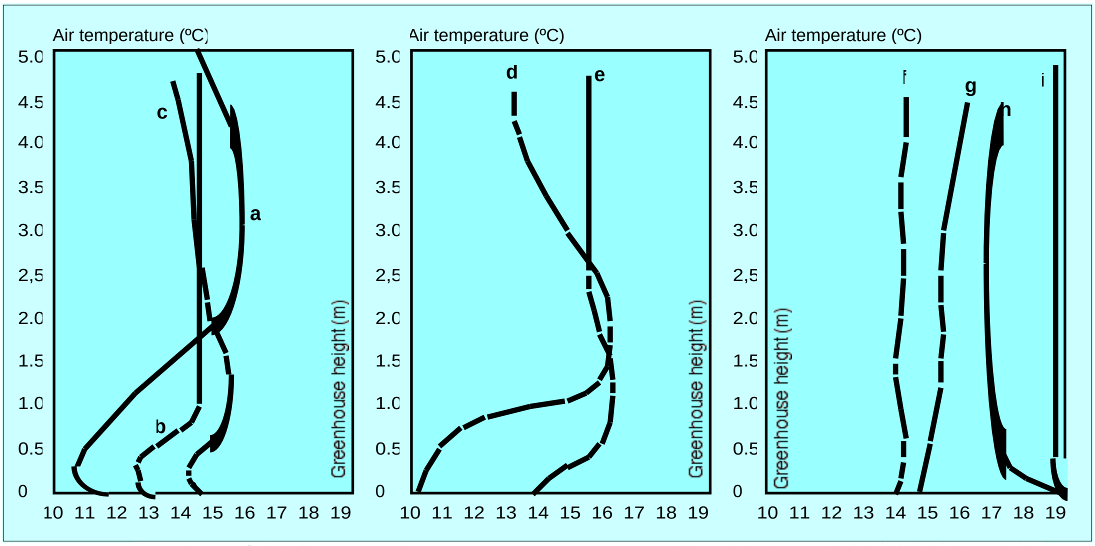


Fig.15. Vertical temperature profiles in a greenhouse, depending on the type and location of the heating installation: a) high aerial pipes; b) high pipes; c) low pipes; d) high-positioned air-heaters; e) 'fan-jet' system 2 m above the crop; f) high-speed air heating; g) convectors; h) 'fan-jet' between the plants; i) 'fan-jet' below the benches (von Zabeltitz, 1986)

A similar problem occurs with scaling Several methods for combatting scaling have been developed, such as chemical inhibitors and treating the water with a magnetic field and ultrasonic waves Again each situation must be assessed separately.

The problems with regard to the heat exchanger stem from the physical properties of the materials used and regulation of the supply The soft-plastic exchangers are liable to puncture, for example Apart from impairing the supply of heat, this can also cause damage to the surrounding plants

There is still no real solution to these problems, except in the short term

Heat-regulation problems are mainly related to the voluminous heat exchanger installations and their large inertia For the moment the best solution seems to be that of avoiding situations where precise regulation is required (simple installations only, aimed at improving the inside temperature characteristics) and using a combination of types of installation, some of which are easy to control.

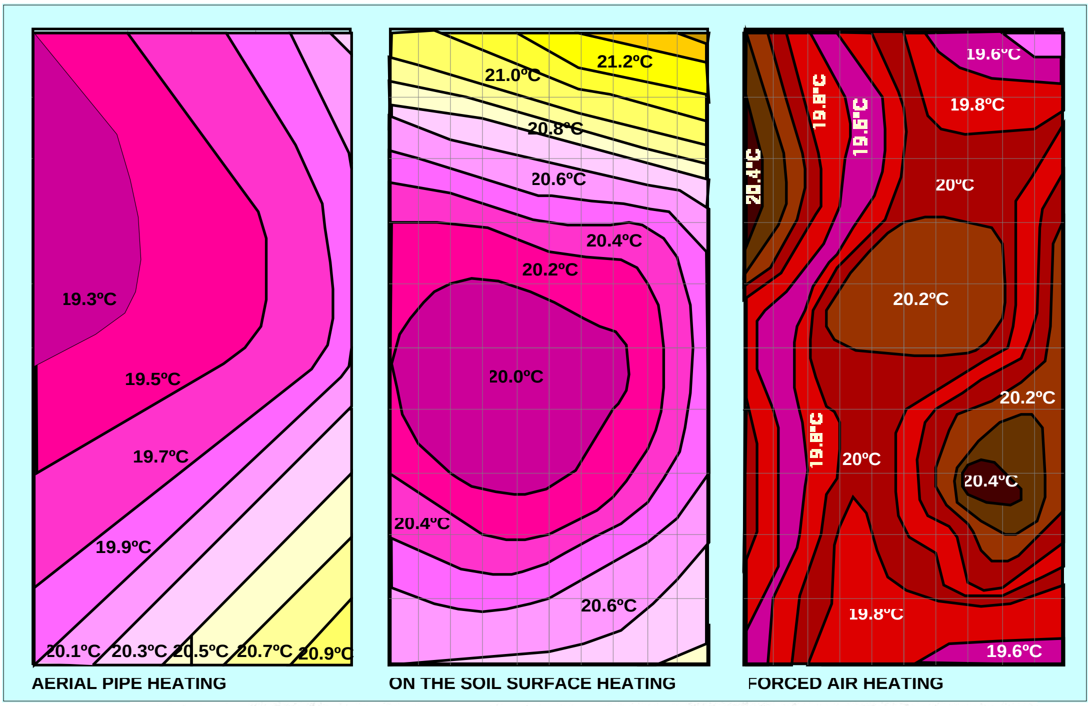


Fig.16. Horizontal temperature distribution (°C) in a greenhouse heated by different types of heating

6.4 Environmental aspects

Although considered a 'clean' form of energy for a long time, geothermal energy is in fact not so, At least two negative effects on the environment can be identified: thermal and chemical pollution, which are particularly important when large flows of thermal water are involved, as in the case of greenhouse heating.

Thermal pollution is the result of poor technical design of the geothermal heating installations, irregular modifications to the design in order to lower investment costs, and irregular use during routine operations. As a consequence, only the upper part of the available temperature interval is used, so that the waste water is discharged at high temperatures, representing a possible risk to the surrounding environment.

Chemical pollution is a result of the chemical composition of the thermal waters, which often contain aggressive and toxic elements; chemical disequilibrium will also cause scaling. Both phenomena have negative effects on the environment.

Any measures adopted to protect the environment will have a direct influence on the economy of geothermal energy use and positive results can only be achieved through state legislation. Regulations must be enforced, prescribing the maximum temperature of the thermal effluents and maximum concentrations of harmful chemical constituents.

One way of tackling thermal pollution is to use low-temperature heating installations or a combination of installations that guarantees use of the entire temperature interval available.

The only real solution to chemical pollution is to reinject the used water, but unfortunately this is also the most expensive one. Only a few countries have regulations for environmental protection during geothermal exploitation. In the others, and particularly in developing countries, this problem has been more or less neglected. This is unfortunate, as the negative consequences sooner or later will become evident.

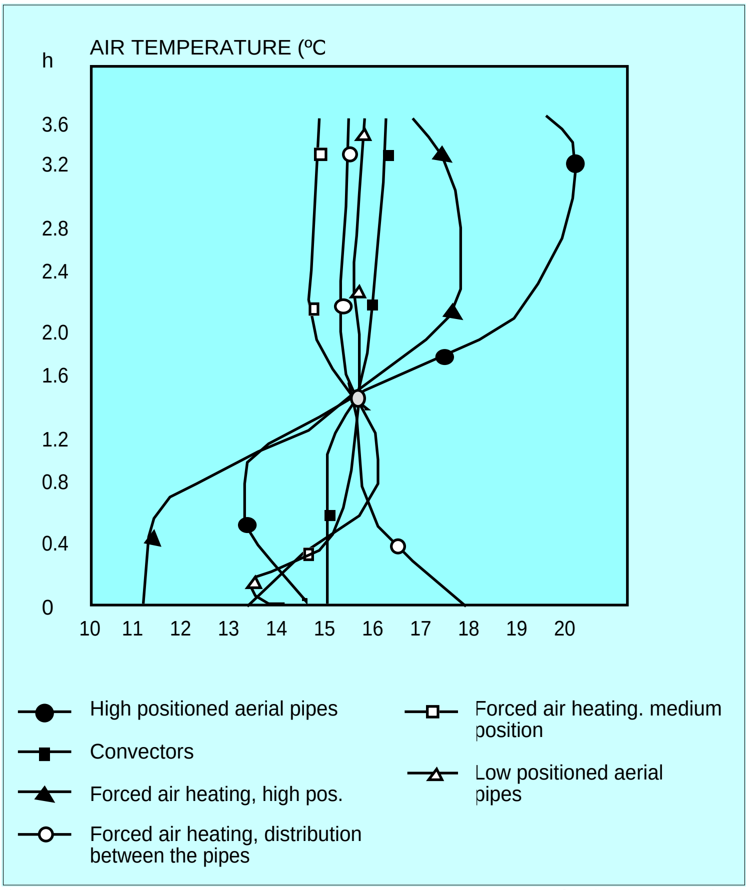


Fig.17. Vertical air temperatures in a greenhouse, heated by different types of heating installations

6.5 Adaptation of technological solutions to local conditions

Changeable market conditions and requirements have a negative influence on the choice of geothermal energy for greenhouse heating. Geo-thermal energy requires higher capital investments compared to other types of energy, and therefore entails longer pay-back periods. Considering that each production necessitates a specific type of heating installation, very expensive additional investments are needed if we change the type of crop. It is for this reason that geo-thermal energy has been used so far for 'guaranteed sale cultures, such as tomatoes, cucumbers, and carnations, and for simple, cheap greenhouse constructions. Nowadays, with such a large number of installations commercially available, this is not a major limitation, but it is still not possible to make drastic changes; i.e. good results can only be achieved with the same heating installation if we keep to similar cultures.

Low-position heating installations that provide natural air movement in the greenhouse offer, in principle, better vertical temperature profiles and lower heat consumption (lower air temperatures below the cold surfaces of the roof). Ilowever, this characteristic of these installations is also one of their limitations, as they do not protect the plants from cold radiation from out-side, which is very important in colder regions and for some high-growing plants. Their use is thus limited to milder climates, when they are the only heating installation in use. An auxiliary installation has to be used in colder climates to cover peak heating demands and protect from cold radiation

Another important factor is shading of the plant by the elements of the heating installation Ideally there should be as little shading as possible of incoming solar radiation For low growing plants medium and high positioned heating elements should be avoided; high growing plants on the other hand should receive heat directly on the plant canopy from high positioned elements.

Greenhouse construction can limit our choice of heating installation Heavy heating elements cannot be hung from cheap lightweight plastic constructions and similarly for expensive highly sophisticated equipment

Local climate can influence our choice in one or another direction For example although the optimal installation for the greenhouse and for the plants may be natural movement of heated air we may have to resort to forced air movement because of local strong winds so as to reduce their negative effects on horizontal temperature distribution

A ready supply of materials is important when choosing the type of installation Spare parts materials and equipment must be easy to procure to ensure the smooth running of operations The extremely small thermal inertia of the greenhouse construction will not permit long breaks for maintenance

Local traditions should also not be neglected It must be remembered that few greenhouse operators have had a technical education~ and they are incapable of appreciating immediately all the advantages of a new type of heating installation **It** is better to avoid drastic change and adopt a step-by-step approach of gradual small improvements, even though better technical solutions may actually be available.

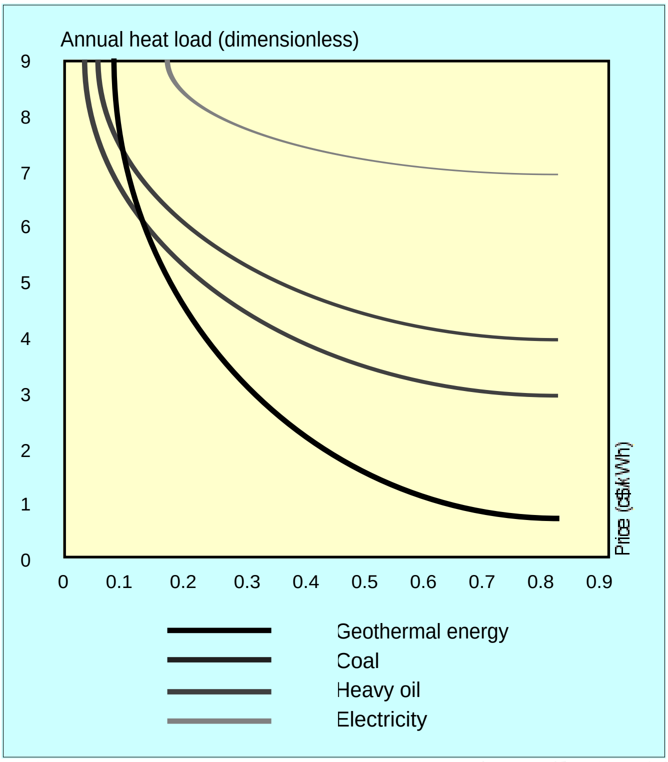


Fig.18. Heat cost of geothermal energy, heavy oil, coal and electricity, as a function of annual load factor. Annual load factor L = (Q/P) 8 760 x 3 600, where Q is the heat consumption during the year (Joules) and P is the heat capacity of the geothermal well (Watt). Example of greenhouse heating in Bansko, Macedonia (from Popovski and Popova, 1987)

FINAL CONSIDERATIONS

As we have already said, the choice of heating installation for a geothermal greenhouse. is a complicated process because of the interdependence of various scientific and technical factors It is impossible to define any precise methodology for approaching this problem, except for the iterative method of identifying the influencing factors and gradually eliminating those that are least important in the case in question However, it is of paramount importance in all cases to carry out a careful and thorough study of the characteristics of the geothermal resource before proceeding with this type of application, so as to avoid expensive mistakes later Local conditions will dictate the type and extent of the investigations that will be necessary, but in general the recommended approach is as shown in Figure 19.

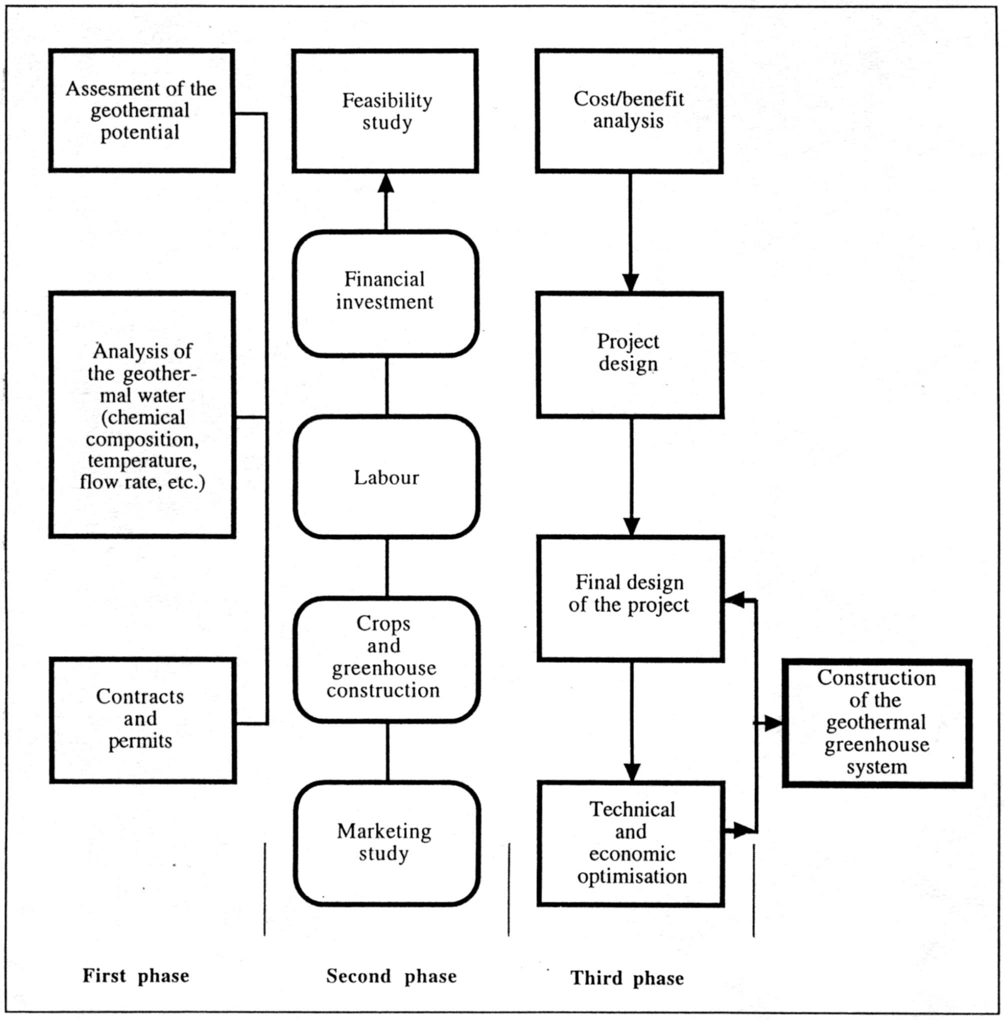


Fig.19. Block diagram of the development of a geothermal greenhouse heating project

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