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AGRICULTURAL ASPECTS OF GEOTHERMAL HEATING IN GREENHOUSES

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INTRODUCTION

In Europe, after the energy crisis in the late seventies, many new "energy saving technologies" have been introduced in agricultural production systems. The contribution of geothermal energy could be significant if there were to be complete exploitation of the available sources since large amounts of high and low grade heat – stored in water – have been found in most of the European countries.

Iceland was the first country to use hot water for heating greenhouses. This dates back to 1920. By the end of 1970 some 120000 m^2 of glasshouses were heated by hot water in Iceland and 22000 m^2 in Yugoslavia. Other countries followed the positive methods already used. Nowadays, the distribution of the geothermal energy used by category is approximately 37% for space heating, 22% for bathing and swimming pool heating, 14% for geothermal heat pumps, 12% for greenhouse heating, 7% for aquaculture pond and raceway heating, 6% for industrial applications, less than 1% each for agricultural drying, snow melding, air conditioning and other uses,(Lund and Freeston,2000).

The capacity and energy utilization during the years 1995 and 2000 for comparison reasons are given in table 1 and figures 1 and 2.

Table 1. Categories of utilization of geothermal energy world – wide (Lund and Freeston, 2000).

	Capacity MWt		Utilization TJ / yr	
Category	2000	1995	2000	1995
Geothermal	6,849	1,854	23,214	14,617
Heat Pumps	4,954	2,579	59,696	38,230
Space Heating				
Greenhouse	1,371	1,085	19,035	15,742
Heating				
Aquaculture pond	525	1,097	10,757	13,493
Heating	69	67	954	1,124
Agricultural Drying	494	544	10,536	10,120
Industrial Uses				
Bathing and Swimming	1,796	1,085	35,892	15,742
Cooling and Snow				
Melting	108	115	968	1,124
Others	43	238	957	2,249
TOTAL	16,209	8,664	162,009	112,441

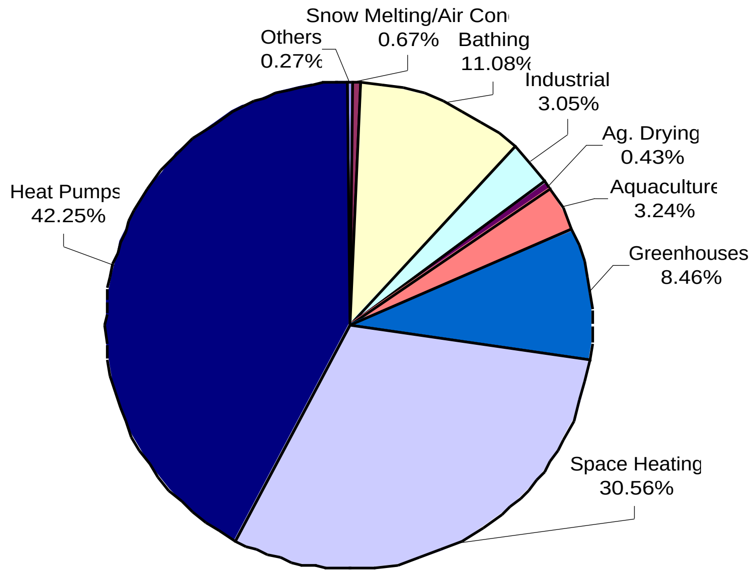


Figure 1. Categories of capacity in % for 2000 (Lund and Freeston, 2000).

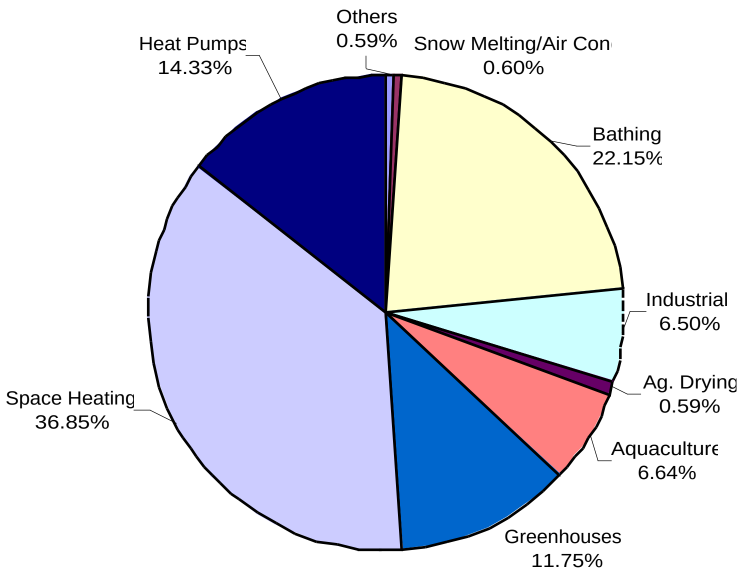


Figure 2. Categories of energy use in % for 2000 (Lund and Freeston, 2000).

The geothermal energy application for heating greenhouses is of importance in reducing the cost for the out of season crop production. Under a controlled environment for out of season crop production, heat is one of the most important factors considerably affecting the crop yield. Heat is usually provided by the use of conventional fuels, when solar energy is not sufficient to cover the needs of plants cultivated in greenhouses. The amount of this additional energy ranges in high levels and this proportionally affects the cost of the products. For this reason several trials and investigations have been made to reduce the cost of heating the greenhouses by means of alternative energy sources such as wasted heat from power plants, solar energy, biomass and Geothermal energy. Many of these sources are already used by growers, while others are still under investigation. Among those alternative energy sources, which need further investigation, geothermy is of particular importance for countries with a considerable geothermal energy potential. The reason for more investigation is the nature of geothermal fluids, since several problems have been en-countered in large scale application up to date. The geothermal fluids contain salts, acids and gases, causing corrosion, salt deposition and blockages. Also, each geothermal reservoir is refeeded by fluid in rate which is depended on hydrogeological and weather condition of their field. Therefore, a good management of the hydraulic and energy potential of the geo-thermal fields is prerequisite. For this reason, investigation related to the increasing of hydraulic and energy efficiency of the geothermal systems used for greenhouse heating is necessary in order to increase the energy use factor (Popovski,1998).

GEOTHERMAL HEATING GREENHOUSES IN GREECE

It is well known that Greece disposes a considerable geothermal potential allocated in many areas. The possibilities for the use of geothermal energy of low enthalpy in agriculture, at the present level of technology knowledge, are very wide. Nevertheless, the use of it in greenhouse production is the most developed sector.

The commercial introduction of geothermal energy into practice of the greenhouse production is particularly important for the areas of Northern Greece, where it could secure a great benefit. The reason is that the production of protected crops during the winter is possible only when heating is used due to the unfavorable climate conditions. But heating by conventional methods is of high cost and does not enable profitable production in comparison with this corresponding to Southern Greece.

Moreover there are many factors which favor the expansion of geothermal greenhouses in Northern Greece.

Some of them are:

a. The geothermal fields are es-timated as fairly rich.
b. The fields are located in flat cultivable areas.
c. The main sector of population activity in these areas is the agriculture.
d. The local market could absorb the produced products.
e. Exportation of the products to Europe could be realized at favorable conditions, taking into consideration the geographical position of these areas.

Cultivation in greenhouses is one of the most dynamic branches of agriculture in Greece. But the most noticeable fact is that the development of them up to date took place in areas where the climate is favorable. In example Crete is the biggest greenhouse center with 49% of the total area whereas in Peloponese there is 21% of the total area.

In Northern Greece the greenhouses are limited. The reasons is that the production of protected crops during the winter is possible only when heating is used due to the unfavorable climatic conditions. But heating by convetional methods is of high cost and does not enable profitable production in comparison with this corresponding to Southern Greece. Therefore the commercial introduction of geothermal energy into practice of the greenhouse production in the areas of Northern Greece is considered very important since it could secure a great benefit.

In tables 2 and 3 the disposition of geothermally heated greenhouses in Greece at the periods 1988-89 and 1998-99, for comparison reasons, are given.

Table 2. Disposition of geothermally heated greenhouses in Greece at the period 1988-89. (C. Nikita – Martzopoulou, 1989).

Location	Model	Covered area 10^3 m^2	Temper. of geoth. water ºC	Status
Eleochoria	P	1.26	34	OE
Nea Kessani	G	2	70	O
	P	4		
Therma of Nigrita	G	21	50	O
	G	13		C
	P	4		O
	G	4		C
Nigrita	G	4	50	PL
Langadas	P	25	41	O
	G	4		PL
Nea Apollonia	P	10	50	O
Sidirokastro	G	4.5	50	C
Milos	P	0.33	43	O
	P	0.40		O
	G	10		C
Lesvos	P	4	85	O
	G	1		O
	G	4		PL
	G	4		PL
Nisyros	P	0.33	40-60	PL

G - Glass covering   P - Plastic covering   O - Operating
C - Under construction   PL - Planned   E - Experimental

Table 3. Geothermal greenhouses in Greece at the period 1998 –99 (Coroneos, et al, 1999).

Location	Area	Temperature	Flow	Cultivation	Method of Heating	% Coverage of needs
Therma Nigritas	32 (G) (22 oper.)	58/38	70	Gardening	Plate-type	>90
	4 (G) 1 (P)	41/28	50	Chrysanthemum	Fined Tubes	<95
	5 (P)	37/25	25			100
	22 (P)	45/30	70	Gardening Gardening, Strawberries,	Plastic Bags Plastic	50
	30 (S)	37/20	60	Asparagus Asparagus	Bags PP	100
					PP	
Sidirokastro	10 (G)	48/35 68/35 43/33	35 28 30	Plants in flowerpots	PP PP + fan heater	100
	8(G),4(P)	37/26	50	Floriculture (gerbera)	PP PP	<50
Lagadas	4, 15 (G)	36/15	20	Gardening	PP	100
	14 (G) 6 (P)	37/25	30	Floriculture (roses)	PP	25

	3 (P)	35/22	20	Gardening	Plastic bags	100
Nimfopetra Thes.	18 (S)	45/20	40	Asparagus	PP	100
Nea Apollonia Thes.	4 (P)	46/32	25	Gardening	Plastic bags	100
	9 (G)	45/30	40	Flowerpot+roses	PP	100
	19 (P)	46/28	35	Gardening	Plastic bags	100
Elaiohoria Chalkidikis	2 (P)	30/20	20	Gardening	Plastic bags	100
N. Erasmio Xanthis	67 (S)	60/30	60	Asparagus	PP	
Polihnitos Lesvou	30 (P)	80/35	60	Gardening	Fan Heaters+PP	100
Geras Lesvou	4 (P)	38/25	20(?)	Gardening	?	100
Milos	5,5 (P)	46/24	15	Gardening	PP	100

GREENHOUSE HEAT REQUIREMENTS

The heat losses of a greenhouse and consequently its heat requirement is given by the following expressions:

During the night:

$$Q = A_c U(\theta_i - \theta_o) \qquad (1)$$

Where
Q = rate of heat flow, W
A_C = surface area of the greenhouse covering, m^2
U = overall heat consumption coefficient, W/m^2 ^{o}C
θ_i = desired inside air temperature, ^{o}C
θ_o = outside air temperature, ^{o}C

The heat requirement per square meter of greenhouse area is:

$$q = \frac{Ac}{Ag} U(\theta_i - \theta_o) \qquad (2)$$

Where
q = rate of heat flow, W/m^2
Ag = floor area of the greenhouse, m^2

For the application of equations (1) and (2) the determination of the overall heat consumption coefficient (U- value) is required since Ac and Ag of the greenhouses are easily determined. Empirical determination of the U-value of the most used covering materials gives an orientation for the following values:

Glass U = 5.5 W/m^2
Single foil U = 6 – 7.8 W/m^2
Double foil U = 4.2 – 5.5 W/m^2

During the day :

$$q_H = \frac{A_c}{A_g} U(\theta_i - \theta_o) - q_{GL} Dn \qquad (3)$$

Where
q_H = rate of heat flow of the heating system, W/m^2
q_{GL} = intensity of solar radiation, W/m^2
D = penetration of solar radiation in the greenhouse, dimensionless.
n = proportion of solar radiation entering the greenhouse which is used to increase the internal temperature.

The penetration of solar radiation in the greenhouse depends on the wave-length of solar radiation, the transmissivity of covering material, the geometrical shape of greenhouse and also its structural elements. Mean value of D varies from 0.5 – 0.7 for single foil and 0.4 – 0.6 for double.

The coefficient n depends on the soil characteristics, the plants mass, the structural elements and the equipment of the greenhouse. Mean value of n varies from 0.5 - 0.7.

The needing geothermal water quantity to feed the heating installation is in relation to the greenhouse heat requirements and can be calculated by the following expression:

$$Q = c(t_1 - t_2)v \qquad (4)$$

Where

Q = heat load requirement, W

c = coefficient of the water heat exchange, J/Kg ^oC

t_1 = inlet water temperature, ^oC

t_2 = outlet water temperature, ^oC

v = geothermal water flow rate, Kg/s

GEOTHERMAL HEATING OF GREENHOUSES

The geothermal energy is classified in three categories. The criterion of this classification is the "temperature":

20^o - 80^o C low enthalpy

essentially for heating

80^o - 150^o C medium enthalpy

heatitng plus electricity production

> 150^o C high enthalpy

electricity production by dry or wet steam

Geothermal resources at low temperature are mainly used for heating greenhouses. The energy substitution provided by a geothermal heating option at 40^{o}C is around 25 – 30% (only in some cases is up to 50%) while, 60^{o}C to 80^{o}C water can economically provide up to 80^{o}C of the total energy needs (Carella, 1992; Dimitrov et al,1997).

Although, many large growers and private factories have already been regarding these energy resource as an attractive and economical solution for space heating of commercial greenhouses, very few commercial geothermally – heated greenhouses are in operation in the Mediterranean regions, actually less than 400 ha (Campiotti et all, 1999).

Different types of heat exchangers between the well and the distribution system have been used so far. The greenhouse heating installations are different and can be classified as follows:

a. Soil heating
b. On the ground heating
c. Air heating with natural convection
d. Air heating with forced convection
e. Combinations

Greece can be classified as a country with considerable geothermal potential. By research work in this country as well as in other countries new means and methods for the engagement, conversion and exploitation of the energy from thermal fluids were investigated intensively (Nikita – Martzopoulou, Gabriilidis, 1988).

Some representative results of experimental work are presented below.

Research work has been carried out in N.Greece (Eleochoria of Chalkidiki) to investigate greenhouse heating systems suitable for exploiting geothermal energy. Six greenhouses 25 x 8.5 m were constructed, five being used for testing different heating systems, while the sixth was used as a control plot for comparison measurements and it was heated by conventional fuels. The geothermal water is of low enthalpy (33.5 ^oC) and the flow rate varies from 140 – 740 m^3/h within a year.

In this paper the influence of three geothermal heating systems, as a part of this large research project, on the growth and the field of tomato crop is presented.

Greenhouse A. The greenhouse was of arch type with a double polyethylene wall and the geothermal water was sprayed in the space of 0.3 m between the outer and inner plastic covers.

Greenhouse B. The greenhouse was of arch type covered by a single polyethylene film. The heating system was based on forced convection of heat supplied by the geothermal water. Two heating installations were designed successively. In the first installation the warm water flows through polypropylene (PP – C) 12 m pipes of some type as those used for floor heating. The pipes were housed in tubes of 16 cm dia and 22 m long. Eight rows of such tubes were suspended on the ceiling of the greenhouse and the air stream produced by an air pump flowed through a plenum along them so as to transmit heat from the warm pipes. The warm air was distributed within the greenhouse through perforated polyethylene sleeves suspended also on the ceiling along the greenhouse.

This installation were used for the first two years and was proved disadvantageous for the crop examined, because it produced a large shading area. For this reason the installation was replaced by a water – to – air heat exchanger.

Both installations were designed by the research team of the project and constructed in lab. of Agric. Engineering of the University of Thessaloniki.

Greenhouse C. The greenhouse was exactly the same with the previous one. The heating system was consisted by black corrugated (spiral type) polypropylene pipes of 28 mm outer dia, with very fine wall thickness. Four pipes were originally placed on the soil, near and along each crop row. In the last year an additional pair of pipes was placed to increase the heat. The geothermal water flowed through the pipes and the heat was transmitted by free convection and radiation to the environment and plants as well as by conductance to the soil near the roots of the plants.

Greenhouse D. The greenhouse was exactly the same with the aforementioned one and of single PE cover. The heating system initially was a conventional one (oil air heater) and was used as a control plot. In the last year the system was replaced by a similar to that of the greenhouse C, with four black corrugated polypropylene pipes placed on the soil along each crop row and a pair of pipes suspended on the ceiling above each row.

The crop used for the evaluation of the effectiveness of the heating systems was tomato crop.

The results shown are referred to the years 1987 – 89. (Tab.4, Fig. 3-7).

The results derived after three successive years showed that the energy saving with the systems used was ranged between 55.5 W/m^2 and 110.5 W/m^2 . The yield was ranged between 10.6 kg/m^2 and 14.5 kg/m^2 for the first eight inflorescent. A comparison between the systems showed that the system A is significantly superior to the other systems with reference to the plant growth while systems C and D gave a significant better yield.

The results of the experiment generally showed that geothermal energy, even of very low enthalpy such as this of the field examined, can be used for efficient greenhouse heating.

Very recently during the years 2000 – 01 some similar experiments were carried out in Nea Apollonia of Thessaloniki to examine the efficiency of three geothermal heating systems in glasshouses with flower production. The geothermal water is of low enthalpy (40^{o}C).

The glasshouses and the heating systems used are described below:

<u>Glasshouse A</u>: It is a multispan glasshouse of a total area of 3000 m^2 with plant pots of flower production. The pots are placed on the ground which is covered by a 5 cm layer of sandgravel (Fig. 8).

The heating system is made of black corrugated polypropylene tubes, _28. The tubes are placed under the layer of sandgravel.

<u>Glasshouse B</u>: It is a multispan glasshouse of a total area of 2500 m^2, with roses cultivation.

The heating system is made of black corrugated polypropylene tubes _28 placed on the ground in a slightly elevated level (Fig. 9).

<u>Glasshouse C</u>: It is also a multispan glasshouse of a total area of 2000 m^2 . In this glasshouse there are plant pots of flower production placed either on the ground or on benches. The ground is covered by a 5 cm layer of gravels. The benches are covered by polysteryne plates of 10 cm width and of 3cm thickness.

The heating system is also made of black corrugated polypropylene tube _28. A part of them are placed under the sandgravel layer while the remainder on the benches between the polysteryne plates (Fig. 10).

Table 4. Geothermal energy and tomato yield produced. (Martzopoulos, 1991).

	1987		1988		1989	
Greenhouse System	Energy W/m^2	Yield Kg/m^2	Energy W/ m^2	Yield Kg/m^2	Energy W/m^2	Yield Kg/m^2
A	67.7	10.6	67.8	12.3	67.8	11.7
B	55.5	10.7	79.5	13.0	97.3	13.1
C	71.1	11.5	17.2	13.3	106.7	14.4
D	139.7	11.6	139.8	13.9	110.5	14.2

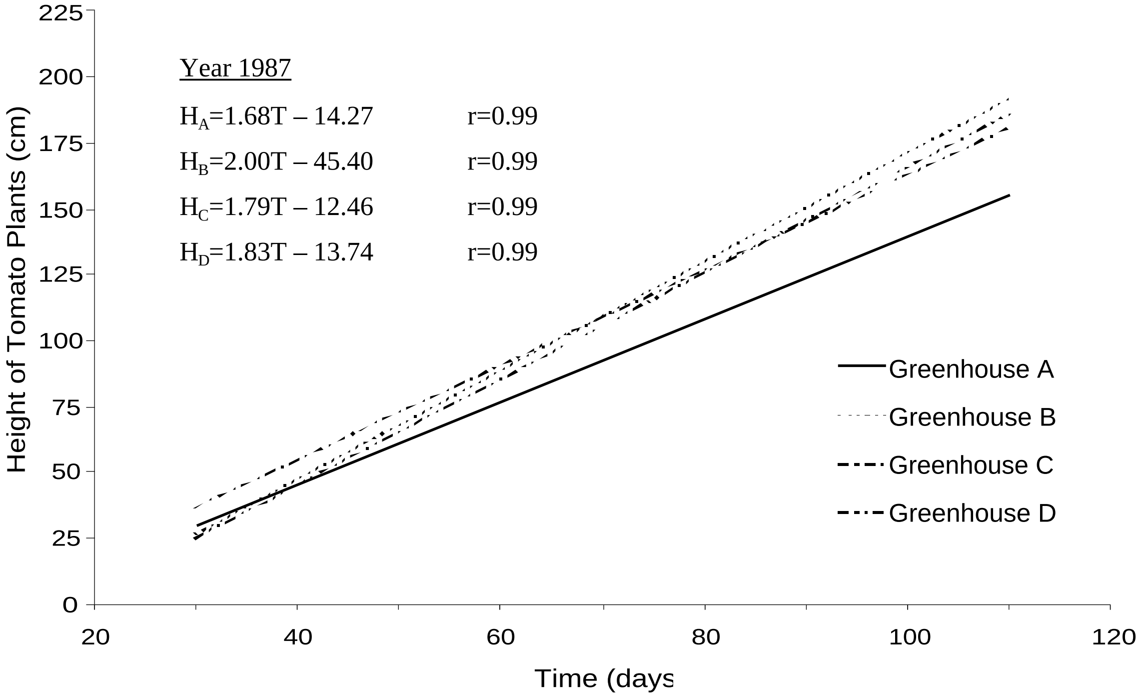


Figure 3. The growth rate of tomato plants in 1987 (Martzopoulos,1991).

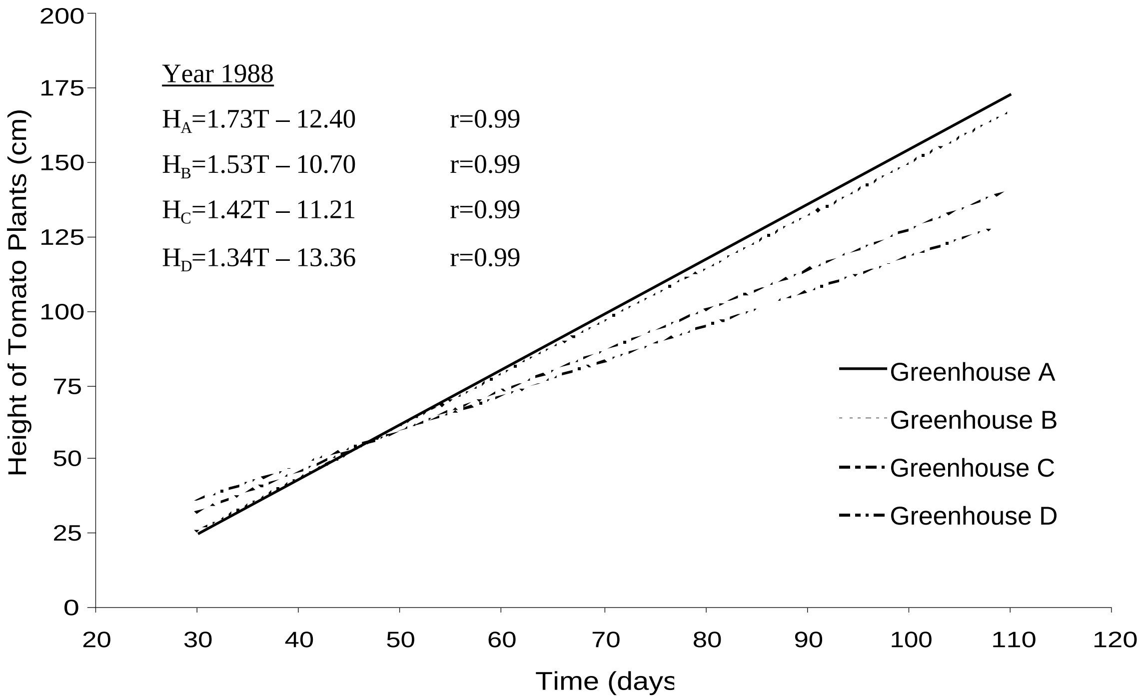


Figure 4. The growth rate of tomato plants in 1988.

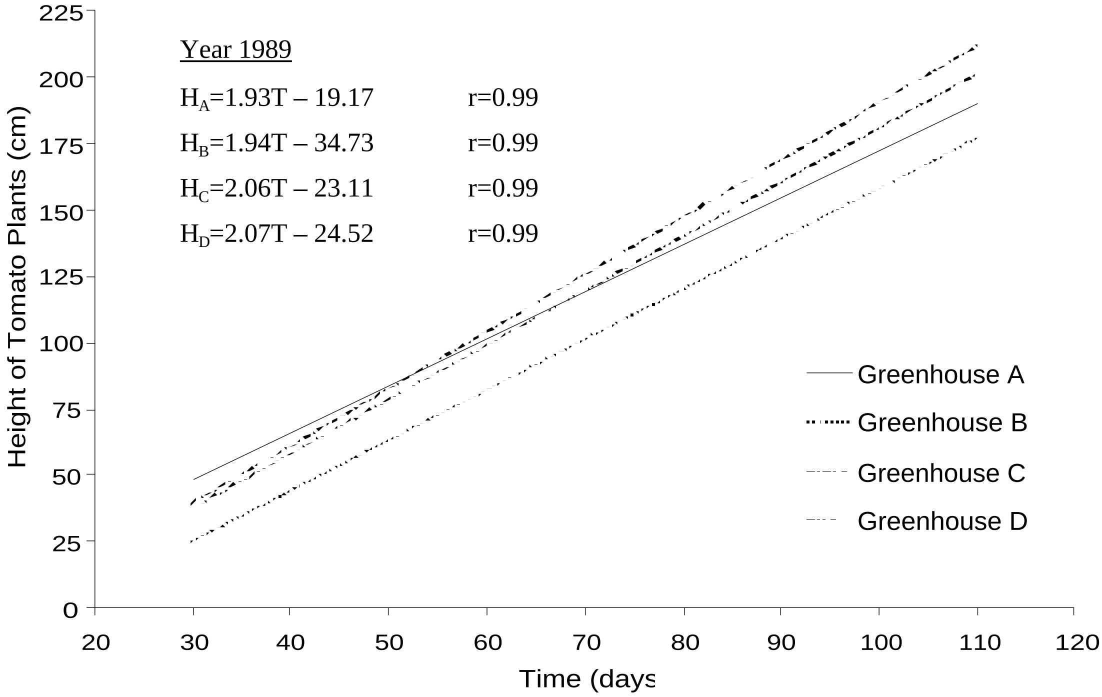


Figure 5. The growth rate of tomato plants in 1989.

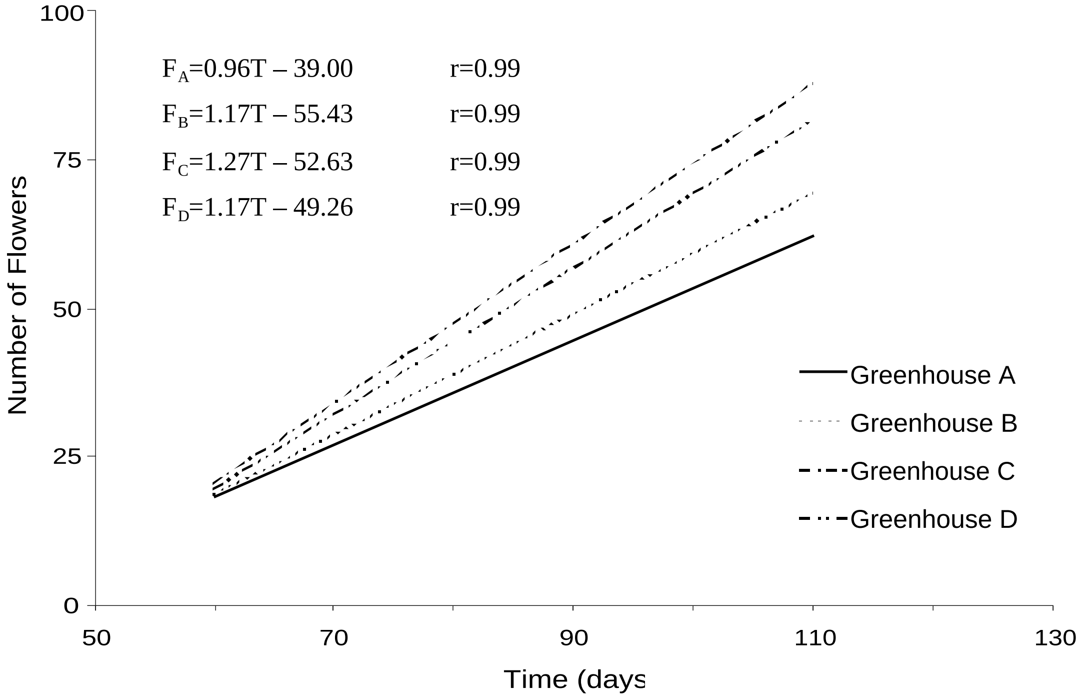


Figure 6. The total number of flower production of tomato plants vs. time in 1989 (7 – 8 inforescents).

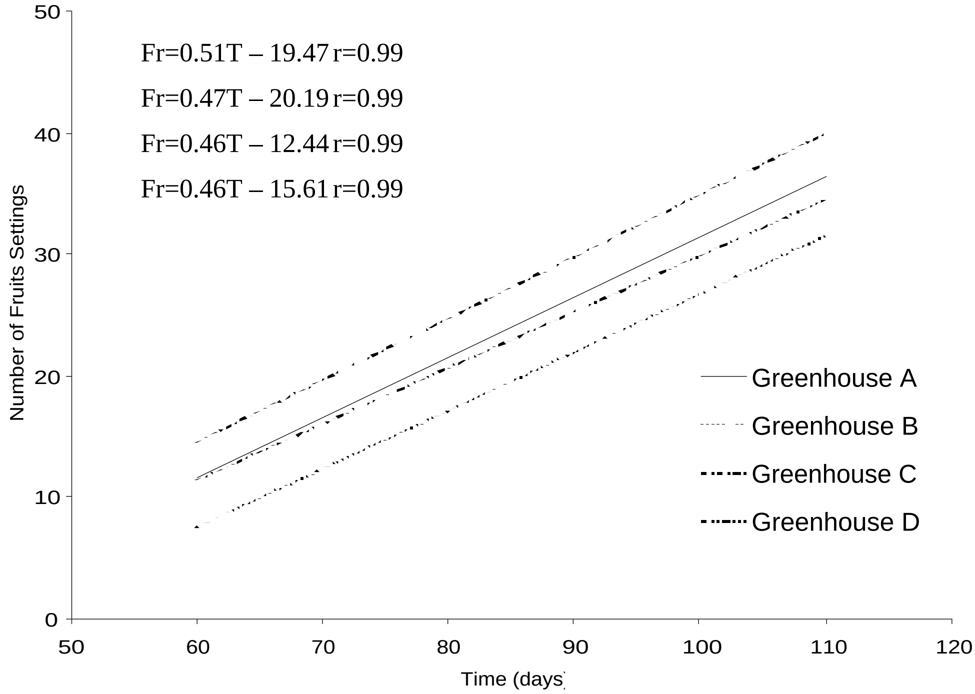


Figure 7. The rate of fruit settings of tomatos in 1989.

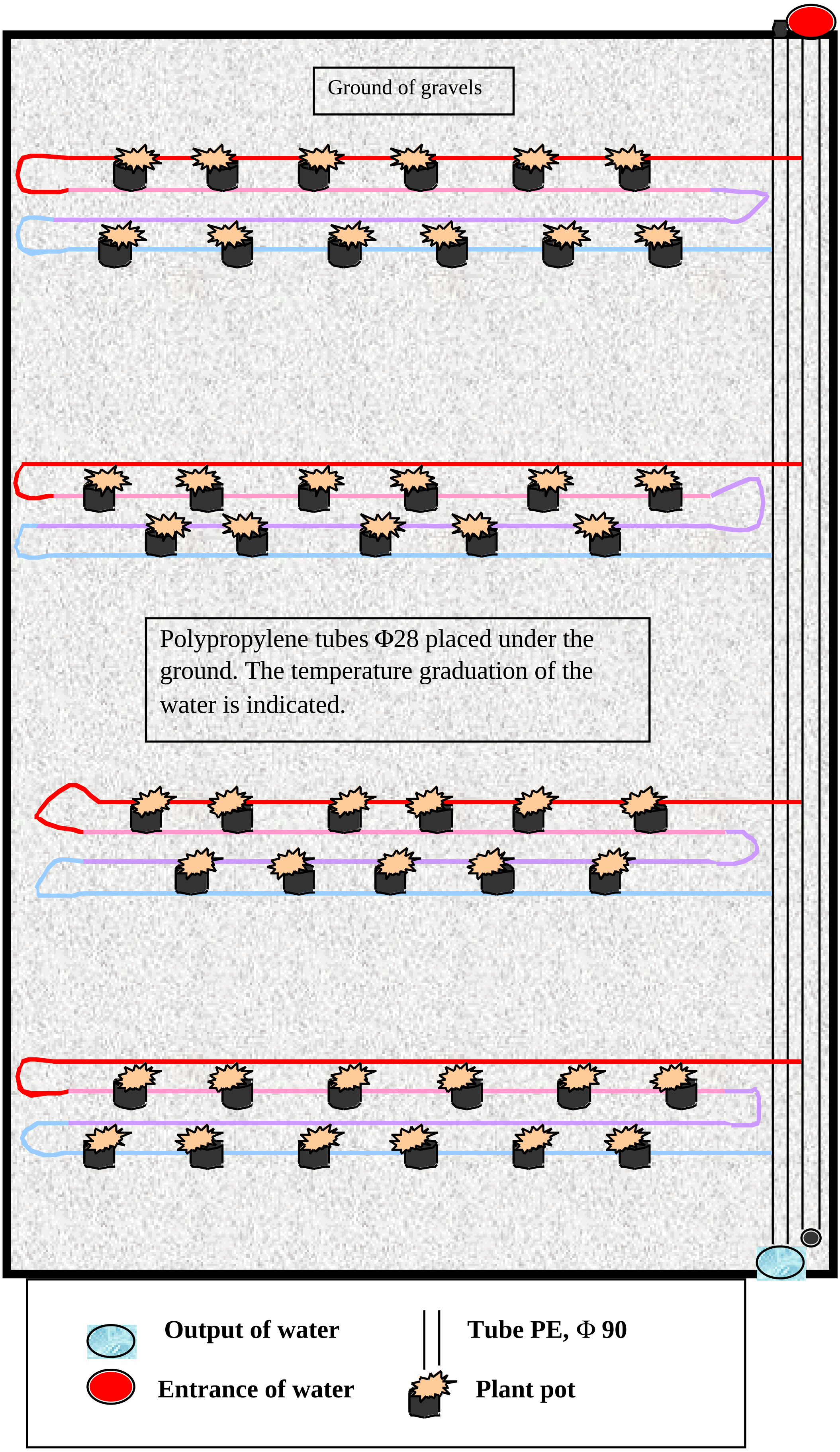


Figure 8. Plan of the glasshouse with pots of flower production (Martzopoulos, et al, 2001).

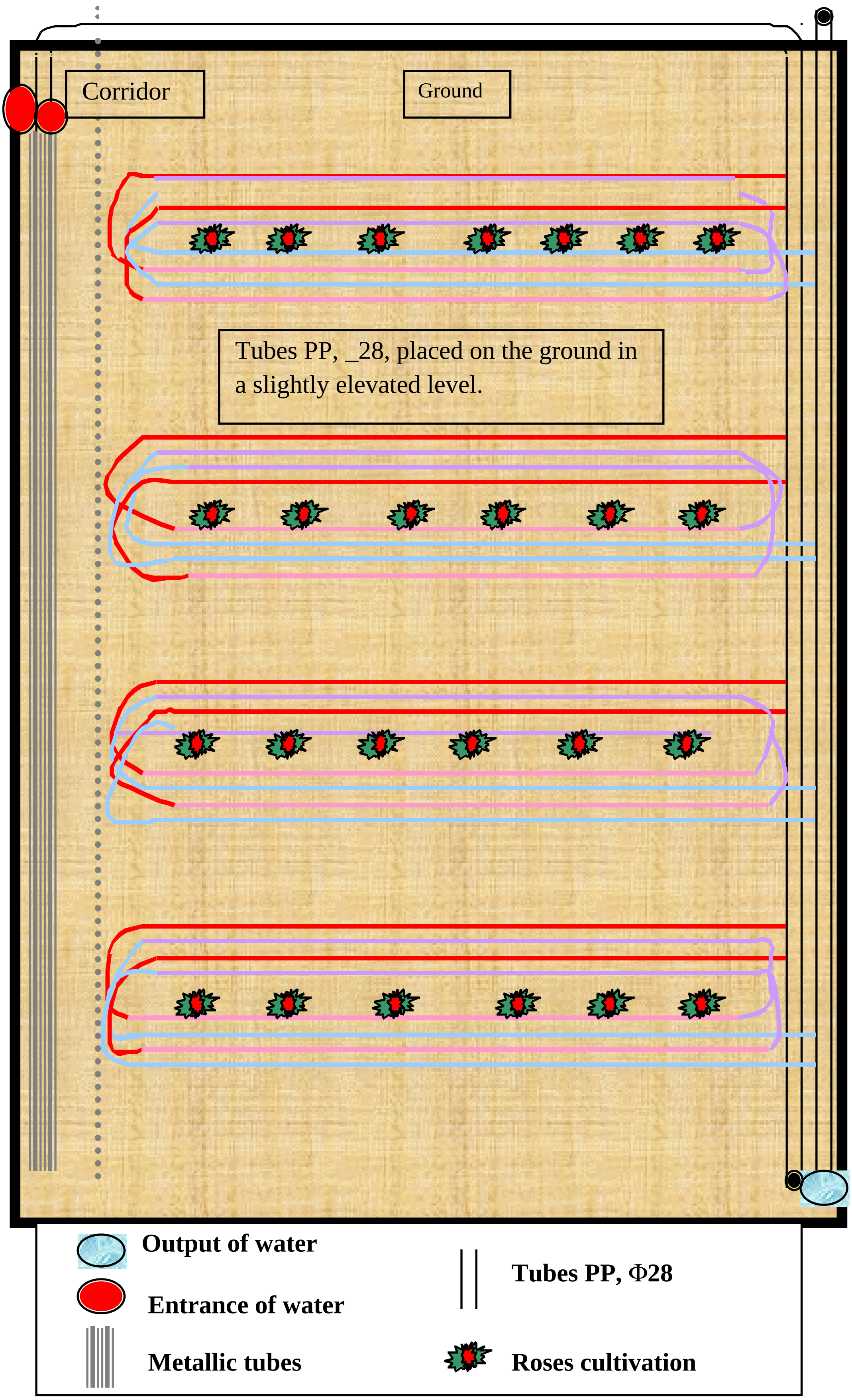
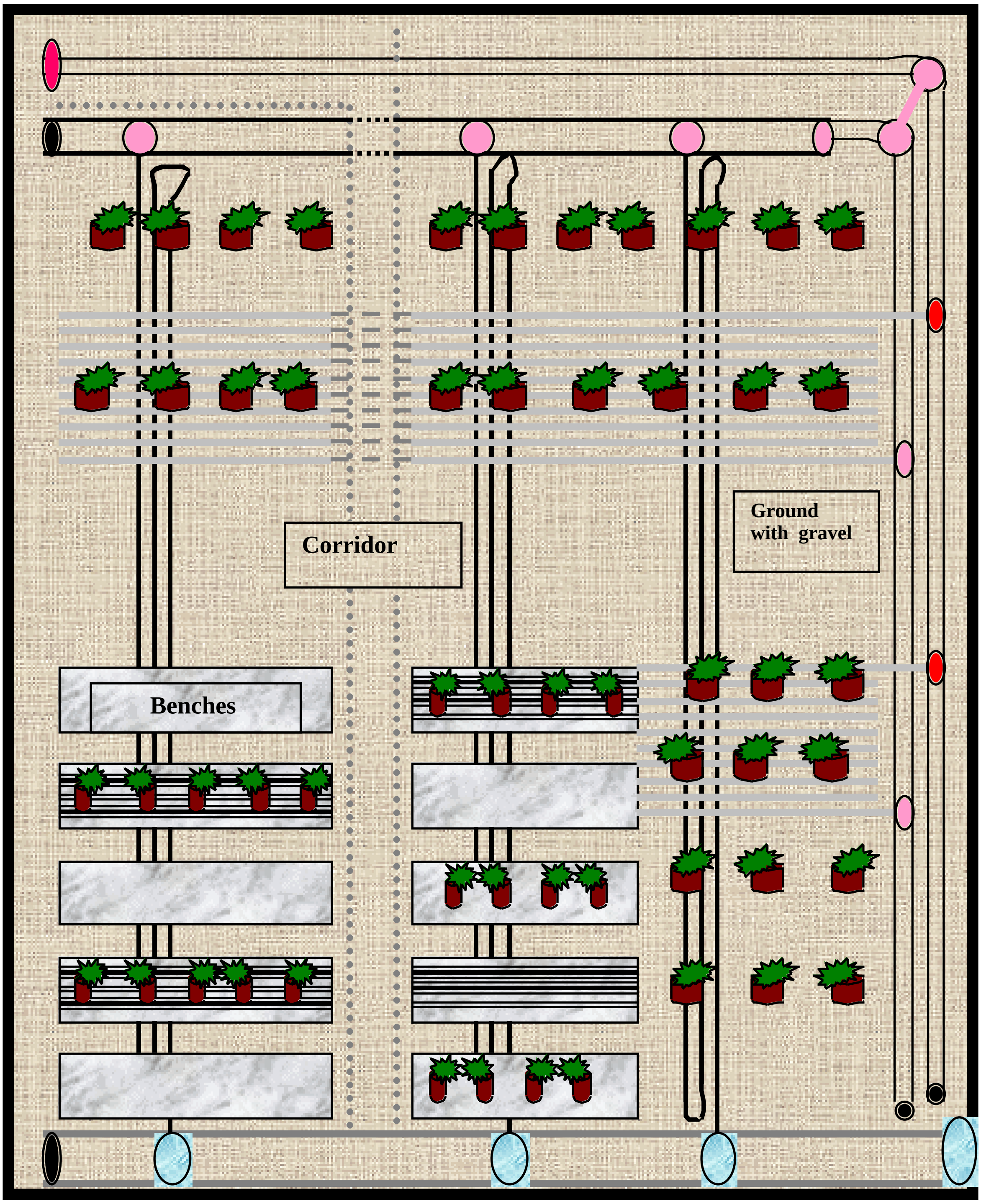


Figure 9. Plan of the glasshouse with roses cultivation.



Entrance of water of 1^{rst} circulation
Movement of water of 2nd circulation
Output of water
Pots

Tubes PP, Φ28 on bences (1^{rst} circulation)
Tubes PP, Φ28 under the ground (1^{rst} circulation)
Tubes PP,Φ28 on the ground (2nd circulation)

Figure 10. Plan of the glasshouse with pots on benches.

Some results of this work are presented below:

Table 5. Variation of some important values in the glasshouse with roses (Martzopoulos, et al, 2001).

	Glasshouses with roses			
	January		February	
	min	max	min	max
Q_{gain}	290357.4	324137.4	175130.5	191162.4
Q_{loss}	135943.1	189323.9	119928.9	135943.0
_i	2.89	8.23	11.38	12.55
_–	-7.33	-0.61	3.74	5.81

Table 6. Variation of some important values in the glasshouse with pots on the ground.

	Glasshouses with pots on the ground			
	January		February	
	min	max	min	max
Q_{gain}	733781.5	848403.3	687373.2	710316.1
Q_{loss}	262046.8	327507.2	216901.7	235780.5
_i	8.23	12.93	15.23	16.38
_–	-7.33	-0.61	3.74	5.81

Table 7. Variation of some important values in the glasshouse with pots on benches.

	Glasshouses with pots on benches			
	January		February	
	min	max	min	max
Q_{gain}	332771.2	382730.9	232354.1	309973.7
Q_{loss}	178295.5	233657.9	190503.6	231244.7
_i	15.87	17.98	16.58	19.23
_–	1.17	3.31	0.29	5.81

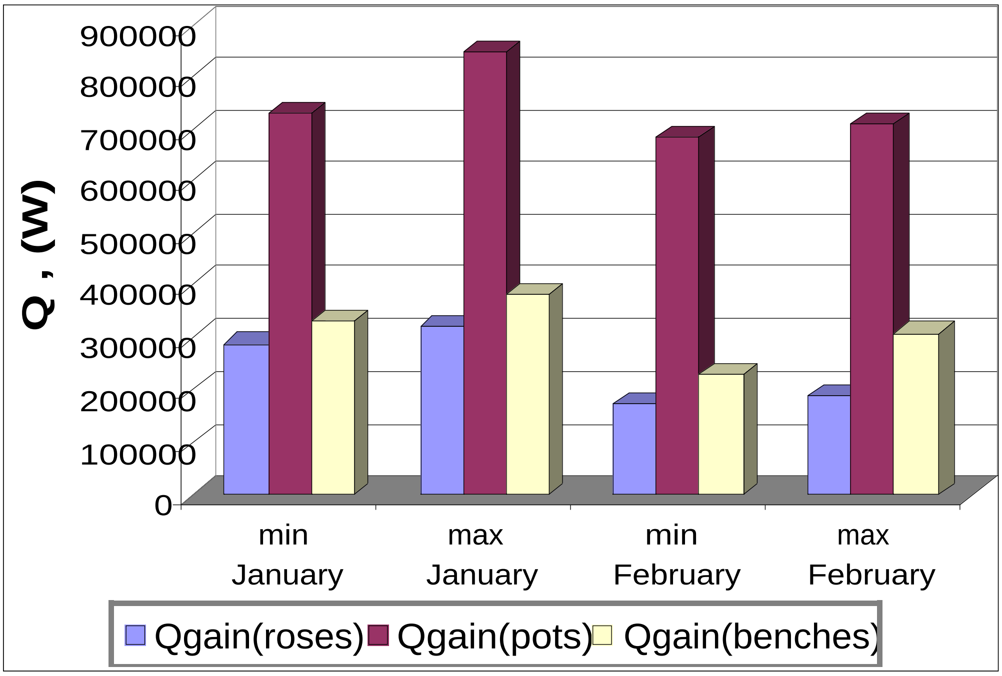


Figure 11. Limit values of the heating systems gain in the three glasshouses during January – February (Martzopoulos, et al, 2001).

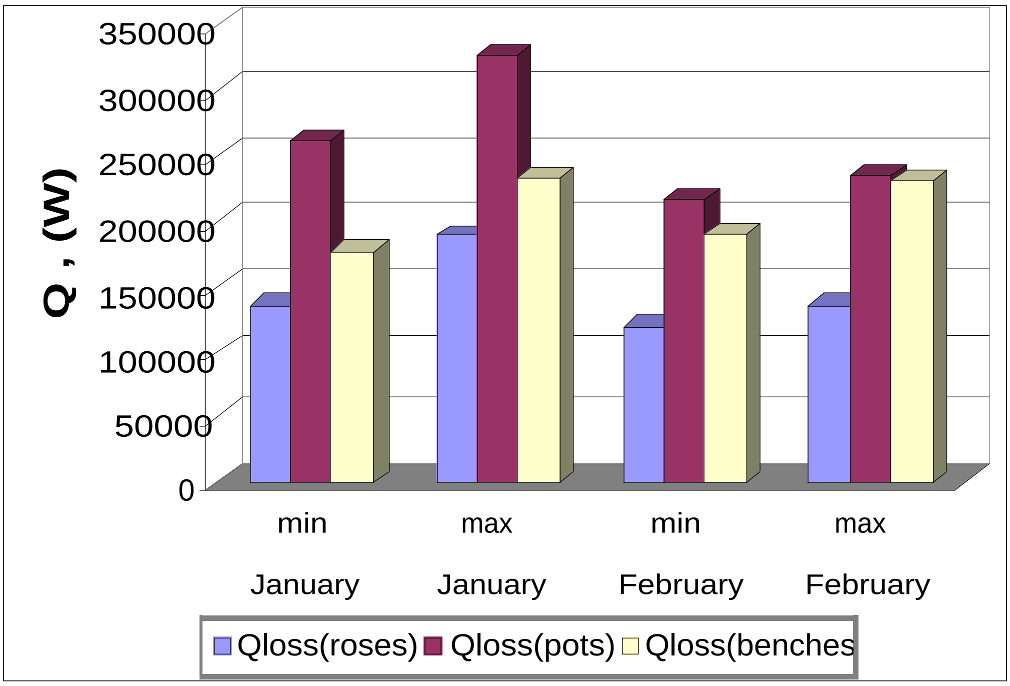


Figure 12. Limit values of heat losses in the three glasshouses during January – February.

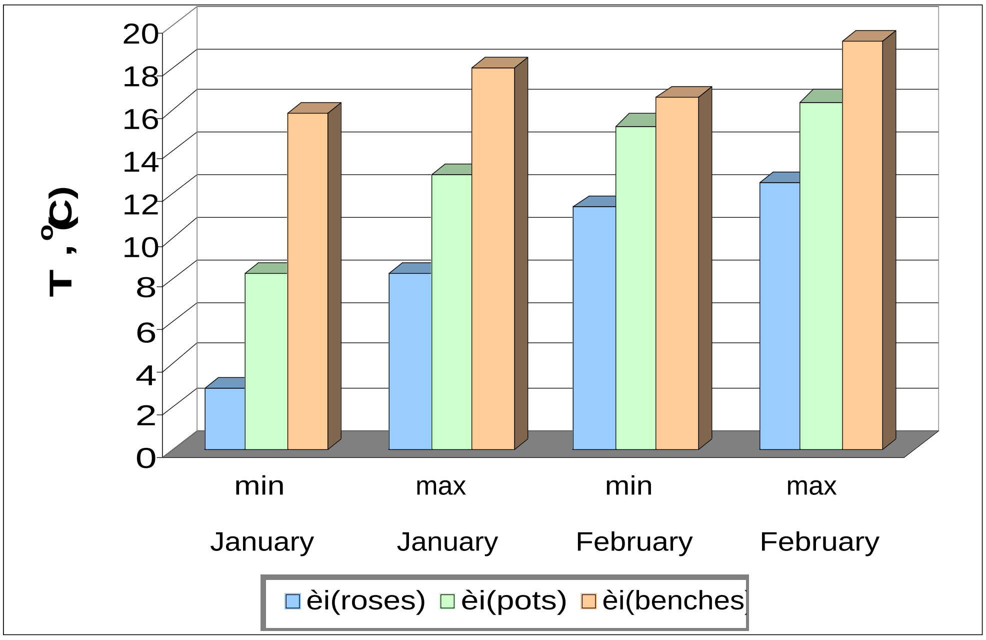


Figure 13. Limit values of air temperature in the three glasshouses during January – February (Martzopoulos, et al, 2001).

From the data presented in the above tables and figures the following relations are derived.

Q_{loss}

January	***February***
$Q_{pots} > Q_{benches} > Q_{roses}$	**$Q_{pots} > Q_{benches} > Q_{roses}$**

Q_{gain}

January	***February***
$Q_{pots} > Q_{benches} > Q_{roses}$	**$Q_{pots} > Q_{benches} > Q_{roses}$**

—i

January	***February***
—benches > —pots > —roses	**—benches > —pots > —roses**

From the above relations it is obvious that the heat gain from the heating system in the glasshouse with pots on the ground is better than the others.

CONCLUSION

The results of many experiments carried out so far with reference to the heating systems could be considered quite promising for the use of low temperature geothermal water in heating greenhouses. The estimation of the thermodynamic properties of the systems and the evaluation of their efficiency showed that the contribution of geothermal energy, in the spectrum of the alternative energy sources, is very significant from the economic and environmental point of view since the intensity and the duration of solar radiation are not sufficient to cover the functional needs of a greenhouse during the winter. Moreover the pollution caused by geothermal water is limited when a properly designed system is used.

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